Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

DETAILS
447 pages | 8.5 x 11 | PAPERBACK

CONTRIBUTORS
Deborah Matherly, Jon A. Carnegie, and Jane Mobley; Transit Cooperative Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

Visit the National Academies Press at NAP.edu and login or register to get:

- Access to free PDF downloads of thousands of scientific reports
- 10% off the price of print titles
- Email or social media notifications of new titles related to your interests
- Special offers and discounts

Distribution, posting, or copying of this PDF is strictly prohibited without written permission of the National Academies Press. (Request Permission) Unless otherwise indicated, all materials in this PDF are copyrighted by the National Academy of Sciences.

Copyright © National Academy of Sciences. All rights reserved.
ACKNOWLEDGMENT

This work was sponsored by the Federal Transit Administration (FTA) in cooperation with the Transit Development Corporation (TDC). It was conducted through the Transit Cooperative Research Program (TCRP), which is administered by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine.

COPYRIGHT INFORMATION

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

Cooperative Research Programs (CRP) grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, FAA, FHWA, FMCSA, FRA, FTA, Office of the Assistant Secretary for Research and Technology, PHMSA, or TDC endorsement of a particular product, method, or practice. It is expected that those reproducing the material in this document for educational and not-for-profit uses will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from CRP.

DISCLAIMER

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research. They are not necessarily those of the Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; or the program sponsors.

The information contained in this document was taken directly from the submission of the author(s). This material has not been edited by TRB.
The National Academies of Sciences • Engineering • Medicine

The National Academy of Sciences was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The National Academy of Engineering was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The National Academy of Medicine (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the National Academies of Sciences, Engineering, and Medicine to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at www.national-academies.org.

The Transportation Research Board is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board’s varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at www.TRB.org.
Emmanuel C.B. "Cris" Liban, Los Angeles County (CA) Metropolitan Transportation Authority, Los Angeles, CA (Chair)
Madinah Ali, Excelente, Inc., Atlanta, GA
Andrew D. Brennan, Massachusetts Bay Transportation Authority, Boston, MA
Dana C. Coyle, MTA Metro North Railroad, New York, NY
Erik S. Johanson, Southeastern Pennsylvania Transportation Authority, Philadelphia, PA
Hilda Lafebre, San Mateo County Transit District, San Carlos, CA
Steven Loehr, MTA New York City Transit, New York, NY
Vincent D. Pellegrin, Metro Transit - Minneapolis/St. Paul, Minneapolis, MN
Susan K. Reinertson, AMTRAK, Washington, DC
Linbing Wang, Virginia Tech, Blacksburg, VA
Nina Chung, FTA Liaison
Adam Schildge, FTA Liaison
Richard Weaver, APTA Liaison
Monica Starnes, TRB Liaison
Acknowledgments: The study team appreciates the contributions of time, information, and materials from APTA, the transit agency case study participants, and the National Aeronautics Space Administration (NASA).
# Table of Contents

## Appendix A. Literature Review

Reference Documents Cited in the Literature Review Synthesis Report...A-2

## Appendix B. Case Study Summaries

Hillsborough Area Regional Transit Authority (HART).......B-2
Honolulu Department of Transportation Services (DTS) B-10
Idaho Valley Regional Transit (VRT)............................B-14
Kansas City Transit Authority (KCATA).......................B-19
Los Angeles County Metropolitan Transportation Authority (LA Metro)........B-29
Maryland Transit Administration (MTA)........................B-38
Massachusetts Bay Transportation Agency (MBTA).........B-47
Metropolitan Atlanta Rapid Transit Authority (MARTA)....B-53
Nashville Metropolitan Transit Authority (MTA)...........B-63
New Jersey Transit Corporation (NJ TRANSIT).............B-68
New Orleans Regional Transit Authority (NORTA)........B-76
San Francisco Bay Area Rapid Transit (BART).............B-84
SFMTA/MUNI: San Francisco Municipal Railway...........B-92
Southeastern Pennsylvania Transportation Authority (SEPTA).........B-101
Swedish Transportation Administration (STA)...............B-113
Transport for London (TfL)....................................B-122
Utah Transit Authority (UTA)................................B-136

Explanatory Notes on Case Studies:

1. Attachments such as tools, presentations and documents that are referred to in the case studies are in the project database and not included with this document.
2. Some tools are followed by a number reference in parentheses (#). The numbers refer to the references at the bottom of the case study.
REFERENCE DOCUMENTS CITED IN THE
LITERATURE REVIEW SYNTHESIS REPORT
(Chronological Order as Cited in the Synthesis)
### Citation

### Website/Source
onlinepubs.trb.org/onlinepubs/sr/sr290.pdf

### Focus Area(s)

<table>
<thead>
<tr>
<th>Area</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy and Administrative Procedures</td>
<td></td>
</tr>
<tr>
<td>Systems Planning</td>
<td></td>
</tr>
<tr>
<td>Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction</td>
<td></td>
</tr>
<tr>
<td>Asset Management</td>
<td></td>
</tr>
<tr>
<td>Operations and Maintenance</td>
<td></td>
</tr>
<tr>
<td>Emergency Preparedness, Response, and Recovery</td>
<td></td>
</tr>
</tbody>
</table>

### Document Type
Research Report

### Intended Audience
Planners, engineers, decision makers, federal, state, private and public transportation agencies, local and state government

### Abstract
Funded by various organizations, the report intends to highlight the potential impacts of climate change on transportation, as of 2008, in the face of differing opinions on the actual occurrence of climate change. The report details the relevance climate change has on transportation, and suggests the organizational and adaptation actions agencies should be considering in advance of the changing environment.

### Populations Referenced
Planners, engineers, decision makers

### Topics Covered
- Climate change overview;
- Role of design standards;
- Emergency response;
- Transportation impacts from climate change;
- Barriers to responding to climate change; and
- Adaptation strategies.

### Type of Sponsoring Agency or Organization
TRB, NCHRP, USDOT, TCRP, USEPA, USACE

### Geographic Distribution
National

### Type of Transit Mode(s)
Marine, air, and land including rail and roadway.

### Type of Vulnerability
Heat, Sea-level rise, Precipitation, Coastal storms

### Goals and Motivations
See Abstract

### Context
N/A

### Tools
Outlines a decision framework to address climate change:
1. Assess how climate is changing in your region;
2. Inventory infrastructure to determine the vulnerability and impact climate change will have on it;
3. Analyze adaptation strategies to address potential impacts;
4. Prioritize investments;
<table>
<thead>
<tr>
<th>Potential Impacts:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- HEAT - Limits on constructions due to health and safety concerns;</td>
</tr>
<tr>
<td>o Reduction of impacts from cold-related maintenance restrictions</td>
</tr>
<tr>
<td>- HEAT – Rail-track deformities and failures;</td>
</tr>
<tr>
<td>- HEAT – Bridge expansion;</td>
</tr>
<tr>
<td>- HEAT – Bus overheating and deterioration;</td>
</tr>
<tr>
<td>- HEAT – Increased energy consumption;</td>
</tr>
<tr>
<td>- HEAT – Reduction in snow and ice removal costs and impacts (Not all regions);</td>
</tr>
<tr>
<td>o Reduction in ice jams and ice on marine vessels</td>
</tr>
<tr>
<td>o Improved mobility and safety</td>
</tr>
<tr>
<td>o Longer construction season</td>
</tr>
<tr>
<td>- SLR – Flooding of low-lying roadways and tracks;</td>
</tr>
<tr>
<td>- SLR – Evacuation impacts;</td>
</tr>
<tr>
<td>- SLR – Increased flooding of tunnels;</td>
</tr>
<tr>
<td>- SLR – Erosion impacts;</td>
</tr>
<tr>
<td>- SLR – Loss of wetland barriers to protect surge and storm damage;</td>
</tr>
<tr>
<td>- SLR – reduce bridge clearance for marine vessels;</td>
</tr>
<tr>
<td>- SLR, changes in navigable waters;</td>
</tr>
<tr>
<td>- PRECIP – Construction impacts;</td>
</tr>
<tr>
<td>- PRECIP – Operation delays;</td>
</tr>
<tr>
<td>- PRECIP – Flooding of evacuation routes;</td>
</tr>
<tr>
<td>- PRECIP – Flooding of rail lines and tunnels;</td>
</tr>
<tr>
<td>- PRECIP – Increase in wash outs and damages to rail bed infrastructure;</td>
</tr>
<tr>
<td>- PRECIP – Increase in mudslides impact roadway and rail infrastructure;</td>
</tr>
<tr>
<td>- PRECIP – Impacts to marine channel depth;</td>
</tr>
<tr>
<td>- DROUGHT – Increase wildfire threat;</td>
</tr>
<tr>
<td>- DROUGHT – Impacts on river transport routes;</td>
</tr>
<tr>
<td>- COASTAL – More frequent emergency evacuations;</td>
</tr>
<tr>
<td>- COASTAL – More debris on rail lines and travel disruptions;</td>
</tr>
<tr>
<td>- COASTAL – Infrastructure damage and failures;</td>
</tr>
<tr>
<td>- COASTAL – Bridge deck instability; and</td>
</tr>
<tr>
<td>- COASTAL – Harbor/Port damage to docks and wave damage to infrastructure.</td>
</tr>
</tbody>
</table>

Some Report Recommendations:

- Agencies should inventory infrastructure for predicting impacts;
- Incorporate climate change into long-range transportation plans, facility designs, capital improvement plans, maintenance practices, operations and emergency response plans;
- “Transportation planners and engineers should use more probabilistic investment analyses and design approaches that incorporate techniques for trading off the costs of making the infrastructure more robust against the economic costs of failure. At a more general level, these techniques could also be used to communicate these trade-offs to policy makers who make investment decisions and authorize funding.” (Page 11-12);
- Build capacity within the organization to address emergency response and evacuation plans;
- Develop and implement monitoring technologies which provide advance warning to weather and climate change;
Consider change to design standards based on risk to lessen the need for high cost and time efforts to redevelop standards. This means focusing on infrastructure with long life cycles;

The report references climate studies for the NY/NJ/CT tri-state area, Metro Boston, Seattle Alaska, and the Gulf Coast. The metro Boston and Seattle studies outline transportation impacts based on climate data available. The Gulf Coast study focuses on Katrina and Rita and the damages to transportation infrastructure that resulted.

Captivating Value

The report does not just look at potential negative impacts of climate change but the positive outcomes such as reduction in addressing cold weather and its impacts on costs, maintenance, construction and operations.

The report recognizes that many facilities perform beyond the design life. Projects such as bridges with long life cycles provide limited availability to implement adaptation strategies while others with short life cycles allow for adaptation strategies to be implemented more frequently. Therefore location of infrastructure is a critical decision. (e.g. rail ROW is very expensive to change)

Some challenges identified include:

- Differences in planning horizons; the shorter the horizon, the less likely climate change is considered important as part of that planning horizon.
- The report recognizes the difficulty in obtaining relevant information for planning and design purposes, specifically more localized climate projections.
- Resources.

Case Study Potential – California Bridge retrofitting for seismic activity may provide insight on changing design standards and implementing those changes.

The report does address design standard options and provide recommendation forward:

Option 1: build to a more robust standard, assuming a greater frequency and magnitude of extreme events, without a full understanding of future risks and presumably at greater cost. This strategy could be appropriate for major facilities in vulnerable locations (e.g., critical bridges and evacuation routes), but its high costs necessitate a highly selective approach.” (Page 154)

Option 2: “upgrade parallel routes, but this alternative depends on the availability of right-of-way and the cost of upgrading.” (Page 154)

Option 3: “build infrastructure with shorter design lives, presumably at lower cost, to be retrofitted as more knowledge about future climate conditions is gained. This alternative probably is not viable in the United States…” (Page 154)

Option 4: “hedge by building to current standards or making marginal improvements, recognizing that the infrastructure remains at risk and may require major improvements in the future. This alternative poses many of the same problems as the previous one. All four options involve important cost–risk reduction trade-offs” (Page 154)

Table 5-1 on Page 155 goes on to outline Climate Change that could “induce” design standards.
Identification of New Zealand Transit as potential case study for addressing climate change through asset management.

<table>
<thead>
<tr>
<th>Decision Question</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Relevance         | • Outlines climate impacts and strategies;  
|                   | • Identifies potential case studies;  
|                   | • Provides details on design standards. |
| Status            | N/A |
| Critical Assessment| The report provides a great basis for transportation agencies to begin the process for addressing climate change. However, some recommendations are specific to federal level entities and not entirely applicable to transit agencies. For example, multiple recommendations focus on USDOT or other entities to take the lead on. |
| Additional        | The report highlights a recommendation for sharing best practices. Although this is something |
that can be done between agencies, the report identifies sharing of cross-sector best practices and as such, it may be beneficial to look at what other sectors such as energy are doing to combat climate change.

| Essential Vocabulary | “Intergovernmental Panel on Climate Change defines these factors as follows:
- Exposure, defined as the manner and degree to which a system is exposed to significant climate variations;
- Vulnerability, defined as the potential for loss, or the degree to which a system is susceptible to or unable to cope with adverse effects of climate change;
- Resilience, which refers to the restorative or regenerative capacity of a system when faced with change; and
- Adaptation, defined as the adjustment made to a system in response to actual or expected climate change to mitigate harm or exploit beneficial opportunities.” (Page 145). |
|---|---|
| Potential Keywords | Climate Change
Design standards
Adaptation strategies
Climate impacts |
### Citation
Cambridge Systematics. 2010. “Climate Change Vulnerability and Risk Assessment of New Jersey’s Transportation Infrastructure.” North Jersey Transportation Planning Authority (NJTPA), Newark, NJ.

### Website/Source

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Case Study

### Intended Audience
FHWA (as the study is intended to provide feedback on the FHWA Model); as well as transportation agencies that own, maintain or operate transportation assets, including state and federal DOTs, local transit operators and local public works/highway departments.

### Abstract
“The primary objective of the study was to pilot FHWA’s Vulnerability and Risk Assessment Conceptual Model using New Jersey as a case study, providing feedback for the advancement of the Conceptual Model and developing a greater awareness and understanding of the potential effects of climate change on transportation infrastructure in New Jersey.” (p. 9)

“The Conceptual Risk Assessment Model was developed to assist transportation agencies in identifying infrastructure at risk for exposure to climate change stressors and determining which threats carry the most significant consequences. It employs the following summary steps:

1. Build an inventory of relevant assets and determine which are critical;
2. Gather information on potential future climate scenarios;
3. Assess the potential vulnerability and resilience of critical assets.” (p. 9)

These three steps were performed for two study areas in New Jersey:

- Coastal Study Area: Coastal New Jersey from the mouth of the Raritan River to the tip of Cape May; and
- Central Study Area: Northeast Corridor extending southward along the Delaware River from Trenton to Salem County.

### Populations Referenced
Assessing the potential vulnerability of multimodal transportation assets to projected climate stressors is the core mission of this study; therefore the affected stakeholders and population include anyone who uses the statewide transportation system, including residents, businesses (freight), commuters, transit riders, operations personnel.

### Topics Covered
The study addresses the following topics:

- Asset inventory and criticality assessment
  - Defining asset categories
  - Determining criticality
- Determining climate impacts:
  - Developing climate scenarios
  - Sea-level rise and storm surge
  - Inland flooding assessment
  - Average climate variables
  - Extreme event climate variables
- Vulnerability and risk assessment
  - Analysis of potential exposure
### Geographic Distribution

Two regional geographic areas were used as case studies within the State of New Jersey:
- **New Jersey Coastal Study Area**
- **Central New Jersey Study Area**

Both regions are considered large, with a mixture of urban and suburban land uses:
- **New Jersey Coastal Study Area**: 6 counties and portions of 3 MPOs including the cities of Toms River and Atlantic City, and majority of the state’s tourism and leisure industry with economic activity that is highly dependent on the area’s transportation network.
- **Central New Jersey Study Area**: 6 counties and portions of 3 MPOs including the cities of Camden, Trenton and New Brunswick and the majority of the state’s interstate highways and the Northeast Corridor rail line.

### Type of Transit Mode(s)

- Commuter Rail, Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus (also Airports, Ports and highways although not considered transit)

### Type of Vulnerability

- Sea-level rise, Storm surge, Extreme temperatures and temperature ranges, Extreme precipitation and average precipitation levels, Drought, and Inland flooding.

### Goals and Motivations

“FHWA’s Sustainable Transport and Climate Change Team developed a conceptual Risk Assessment Model to assist transportation planners, asset managers, and system operators identify infrastructure at the greatest risk for exposure to climate change stressors and determine which threats carry the most significant consequences.” (p. 16) The goal of the study was to test the model with two New Jersey regions as case studies, and identify ways in which the model could be improved.

### Context

- Multiple modes exist in the region; the study assessed the entire transportation system within given data limitations/sufficiency.
- Types of assets assessed for criticality include:
  - Roadways
  - Bridges
  - Tunnels
  - Passenger Rail
  - Freight Rail
  - Traffic Analysis Zones
  - Airports
  - Wetlands
  - Evacuation Routes
  - Ports
  - NJ Transit Bus Routes
  - NJ Transit Signals, Switches and Track

- Amtrak, NJ Transit and SEPTA are the transit providers; however SEPTA data was insufficient and omitted.
  - NJ Transit is a New Jersey State-owned public transportation system serving the US State of New Jersey; along with portions of New York, Orange, and Rockland counties in New York State; and Philadelphia County in Pennsylvania. It operates bus, light rail, and commuter rail services throughout the state, notably connecting to major commercial and employment centers both within the state.
and in the adjacent major cities of New York and Philadelphia. The Governor of New Jersey appoints a seven-member Board of Directors, four members from the general public and three state officials. The Governor has veto power on decisions made by the board.

- The National Railroad Passenger Corporation, doing business as Amtrak, is a publicly funded railroad service operated and managed as a for-profit corporation which began operations on May 1, 1971, to provide intercity passenger train service in the United States. Amtrak is funded by the U.S. government, with a president and board of directors.

- The Northeast Corridor provides a key interdependency for Amtrak and NJ Transit as they share the rail right-of-way.

- Limitations of this region include aging infrastructure and alignment issues in vulnerable locations with limited resources.

- While the study assesses physical vulnerability and risk, it does not address whether there were levels of resilience planning or asset management systems in place to reduce this risk for NJ Transit and Amtrak.

- It provides a summary of current research and practices for adaptation across the country and internationally, but does not discuss ongoing efforts in New Jersey. Instead it provides “a series of matrices that identifies possible climate change impacts generally applicable to New Jersey and lists potential adaptation strategies that could be taken at the various stages of the transportation decision-making process—including planning, design, and operations.” (p. 98).

### Tools

“The Conceptual Risk Assessment Model was developed to assist transportation agencies in identifying infrastructure at risk for exposure to climate change stressors and determining which threats carry the most significant consequences.” (p. 9) “The Climate Change Vulnerability and Risk Assessment of New Jersey Transportation Infrastructure project was a FHWA-funded pilot with the overarching goal of providing feedback to support the advancement of the Conceptual Model.” (p. 117)

The project work encompassed three main steps:

1. Developed an inventory of relevant assets and ranked level of criticality from low to extreme based on their roles in connecting critical destinations;

2. Gathered information on potential future climate scenarios, including the magnitude and likelihood of change due to the following six climate stressors:
   - Sea-level rise,
   - Storm surge,
   - Extreme temperatures and temperature ranges,
   - Extreme precipitation and average precipitation levels,
   - Drought,
   - Inland flooding; and

3. Assessed the potential vulnerability and resilience of transportation assets starting with the most critical assets and the most severe climate stressors the potential vulnerability and resilience of critical assets.

### Noteworthy Aspects

“Although external to the FHWA model, this study looked at adaptation strategies to help mitigate potential climate impacts to transportation infrastructure. A review of current and recent research and planning efforts at the national, state, regional, local, and international levels was performed. Based on the findings of the review, the project team developed a series of matrices that identify possible climate change impacts generally applicable to New Jersey and lists potential adaptation strategies that could be taken at various stages of the transportation decision-making process, including planning, design, and operations. This effort is a potential precursor to a state or regional climate change adaptation plan.” (p. 11)

### Captivating

The FHWA “model is arms agencies with a rich store of information for asset management
<table>
<thead>
<tr>
<th>Value</th>
<th>through vulnerability and risk assessment, but does not complete the final link in the process—adaptation. A full adaptation module should be added to the model.” (p. 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Question</td>
<td>Should changes be made to the FHWA Conceptual Model?</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Federal: FHWA</td>
</tr>
<tr>
<td>Relevance</td>
<td>This document provides a case study review of a conceptual model for assessing the vulnerability of transportation (including transit) assets, and recommends improvements to the model for advancing the state of the practice, including adding an adaptation module with recommended adaptation measures for New Jersey. Recommendations, promising practices and lessons learned? • Develop “policy responses that provide the planning and engineering communities with thresholds that reflect a public consensus, an approach which unites public risk tolerance with concrete planning and engineering solutions.” (p. 113) • A (preferably multimodal) “guidebook of vulnerability thresholds—corresponding to the types of climate outputs derived from downscaling—could be developed as a Transportation Research Board project, by AASHTO, or by the American Society of Civil Engineers.” (p. 114) • “Recreate the primary Conceptual Model tasks (e.g. Asset Inventory) as modules, especially for the assessment phase. Each module could contain guidance on matching approaches with needs, suggest key variables and sources (particularly if a federal agency can provide relevant information), and links to existing public tools. The creation of modules could also lead to better customization of the process for different analytical scales.” (p. 114) • A full-fledged adaptation module could be added to the Conceptual Model. • “The Model could more explicitly highlight opportunities, as its current primary emphasis is limited to the identification of risks. A process, perhaps a separate module, should facilitate the determination of areas of potential intersection with other transportation and non-transportation plans.” (p. 114)</td>
</tr>
<tr>
<td>Status</td>
<td>Series of FHWA Pilots completed; FHWA evaluating potential modifications to the conceptual model.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Agree with the study’s recommendation that the FHWA model should include a method for evaluating adaptation or risk reduction measures. It would be interesting to see additional case study evaluations using this model at different geographic scales, such as for an individual city, neighborhood or site. The emphasis on corridor-wide planning, while comprehensive, prevented the consideration of localized factors that affect risk, such as existing stormwater management systems or coastal protection features.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>The study did not define key terms, however it did provide a discussion of resiliency and adaptive capacity, as follows: • An asset is not necessarily highly vulnerable just because it is potentially impacted or exposed, however. If an impacted asset is relatively unaffected (physically or temporally) or can be quickly restored, the impact itself may be of minor importance. The operating agency interviewees were asked about potential immediate and short-term adaptive responses to plausible climate stressors—ranging from maintenance and monitoring to emergency construction. This integrated consideration of impacts and resiliency/adaptive capacity allowed the project team to better understand the potential vulnerability of assets and operations to specific stressor scenarios.</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Asset Management</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------</td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Hodges, T. 2011. <em>Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation.</em> Federal Transit Administration, Washington, D.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>Research Report</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Transportation practitioners, researchers, transit agencies, users of transit systems</td>
</tr>
<tr>
<td>Abstract</td>
<td>“This report provides transit professionals with information and analysis relevant to adapting U.S. public transportation assets and services to climate change impacts. Climate impacts such as heat waves and flooding will hinder transit agencies’ ability to attain a state of good repair and provide reliable and safe service. The report examines anticipated climate impacts on U.S. transit and current climate change adaptation efforts by domestic and foreign transit agencies. It further examines the availability of vulnerability assessment, risk management, and adaptation planning tools as well as their applicability to public transportation agencies.” (p. vii (abstract))</td>
</tr>
<tr>
<td></td>
<td>“The report provides examples of adaptation strategies and discusses how transit agencies might incorporate climate change adaptation into their organizational structures and existing activities such as asset management systems, planning, and emergency response.” (p. vii (abstract))</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>The report will be a valuable resource for transit agencies and be of interest to regional, state, and federal agencies that oversee, plan, or finance public transportation.</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>A premise of the report is that responsible risk management calls for reducing vulnerability and improving resilience of transit assets and services to the impacts of climate change. To support that premise the report provides:</td>
</tr>
<tr>
<td></td>
<td>• Synthesis of literature related to climate change, adaptation, and transportation having relevance to the transit industry;</td>
</tr>
<tr>
<td></td>
<td>• Review of anticipated climate change impacts on U.S. transit;</td>
</tr>
<tr>
<td></td>
<td>• Synthesis of existing vulnerability assessment, risk management, and adaptation planning tools and explains their application to transit agencies;</td>
</tr>
<tr>
<td></td>
<td>• Discussion of strategies for adapting transit assets and operations to climate change impacts;</td>
</tr>
<tr>
<td></td>
<td>• Discussion on implementation considerations and how transit agencies can incorporate adaptation strategies into organizational structures and activities; and</td>
</tr>
<tr>
<td></td>
<td>• Supporting case studies and illustrative examples.</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>Federal Transit Administration</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>National</td>
</tr>
<tr>
<td>Type of Transit</td>
<td>The goal of this report is to increase awareness of the future environmental stressors transit systems and to provide tools and strategies that might be incorporated into organizational structures and operations to improve resilience to such impacts.</td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Mode(s)</th>
<th>assets will encounter as a result of climate change and is intended for use by transit agencies of all sizes and modes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Vulnerability</td>
<td>All vulnerabilities are considered. The report provides numerous and diverse examples of the impact upon transit services due to extreme weather including: precipitation, temperature, sea-level rise and hurricanes.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>A premise of the report is that “climate change adaptation is essentially responsible risk management” (p.3) and “that adapting to climate change impacts will require interdisciplinary efforts among engineers, planners, frontline maintenance and operation staff, strategic planners, emergency response experts, and others.” (p. 3-4) This long-term effort will require not so much doing entirely different things, but doing some of the same things in a different way. These principle beliefs spurred the effort to create a report that provides a useful departure point to help place the transit industry on the track to climate resilience. (p. 4 (not a direct quote but should be cited))</td>
</tr>
<tr>
<td>Context</td>
<td>The report recognizes that for transit agencies “already challenged by maintenance backlogs on tight budgets, climate change brings additional environmental stressors that deteriorate assets and requires more maintenance and expense.” (p. 5) “The increased frequency of extreme events (such as heat waves and severe storms) will be more challenging to manage than gradual effects such as a steady rise in average temperatures.” (p. 1) Additionally, “transit agencies will face multiple climate stressors with a combined impact on transit assets and services, and these climate stressors will interact with existing factors (such as high percentage of impervious surfaces) to amplify effects.” (p. 32) “Climate impacts on transit assets will hinder agencies’ ability to achieve goals such as attaining a state of good repair and providing reliability and safety, which may then impact ridership. Therefore, climate change adaptation should not be outside the regular purview of transit management. Rather, given that adaptation strategies offer the opportunity to avoid catastrophic losses through cost-effective preventive measures, the issue falls squarely within the mainstream duties of transit agency management.” (p. 7)</td>
</tr>
<tr>
<td>Tools</td>
<td>The report did not specifically introduce any tools or metrics.</td>
</tr>
</tbody>
</table>
| Noteworthy Aspects | The report noted that the Maryland State Highway Administration has used its asset management system as a climate adaptation tool. “The agency collects climate change data in its Transportation Asset Management Program (TAMP) to better analyze priority assets. Climate-related asset data include age, elevation, materials used, design lifetime and stage of life, FEMA flood maps, current and historical performance and conditions, vegetation, soil type, average daily traffic, bridge scour criticality, and length and width of bridges.” (p. 85-86) The report provides a case study of the Transport for London as an agency also using their asset management system as an adaptation tool. The report provide four case studies of the following transit agencies:  
- New York MTA – Partnering and Assessing Impacts  
- Mobile, Alabama - Developing a Criticality Assessment  
- Los Angeles County MTA – Initiating a Vulnerably Assessment as Part of a Broader Sustainability Framework  
- Transport for London – Incorporating Adaptation into Asset Management Systems |
| Captivating Value | “... climate stressors will interact with existing factors (such as high percentage of impervious surfaces) to amplify effects.” (p. 31) |
| Decision Question | The research document was written to encourage transit agencies to understand that climate change adaptation is essentially responsible risk management and that adapting to climate change is a necessary objective. |
| Decision Maker | Transit agency leadership |
### Relevance

To assist transit agencies, the report recommends taking a risk management approach noting that risk assessment tools developed by governments and non-profits offer guidance on how to prioritize climate risks by assessing the likelihood of occurrence and the magnitude of consequence. “Taking a risk management approach mitigates risk without expensively over-engineering assets.” (p. 2)

The report further provides examples of adaptation strategies and discusses how transit agencies might incorporate climate change adaptation into their organizational structures and existing activities. For instance:

- “Following the August 2007 flood, as well as other less severe floods, New York MTA raised many of its sidewalk level ventilation grates so that water could not enter from flooded sidewalks. New York held a design competition to incorporate the vents into street furniture.” (p. 66)
- “Kansas City’s new Bus Rapid Transit (BRT) System has 30 stations with rain gardens in bump-outs designed to collect and filter stormwater runoff from roads and sidewalks (see Figure 4-6). This reduces flooding, erosion, and the entrance of pollutants in rivers and streams. The BRT system also features a pervious concrete parking lot so that stormwater can seep into the ground, and shade trees that capture rain water.” (p. 70)
- “Portland’s TriMet noted a significant increase in slow orders due to high heat over a period of three years. Recognizing the inconvenience to customers, TriMet implemented a concerted set of strategies with an ultimate goal of no slow orders. TriMet identified areas with frequent rail buckling, many of which were adjacent to curves or in direct sunlight. The Maintenance of Way division developed expansion joints and installed them by breaking the continuously welded rail in eight to nine key areas and applying the joints. The joints allow for one and a half to two inches of relief, permitting the rail to expand.” (p. 75)
- “The Washington State DOT adopted an agency-wide policy in 2010 that requires climate change analyses—both mitigation and adaptation—to be included in all WSDOT environmental impact statements performed under the State Environmental Policy Act.” (p. 94)

The report noted that “in recent years, multiple governmental entities have begun to assess climate change impacts on infrastructure and to develop potential responses using closely related vulnerability, risk, and adaptation assessment frameworks and tools. The report draws out the elements of the frameworks that are most relevant to public transportation agencies and noted that the frameworks share a general approach: develop or gather climate projections, establish how those climate changes will impact assets, determine the severity of the impacts, and develop measures to address the high-risk impacts.” (p.45) The report identified the following adaptation assessment guidebooks as being particularly relevant:

- New York Climate Adaptation Assessment Guidebook
- Federal Highway Administration Conceptual Model Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure
- University of Washington Center for Science in the Earth System (Climate Impacts Group) and King County, Washington, Planning for Climate Change: A Guidebook for Local, Regional, and State Governments
The report introduced four categories of adaptation strategies:

1. “Maintain and manage: Absorb increased maintenance and repair costs and improve real-time response to severe events. Incorporate “smart” technologies such as sensors that detect changes in pressure and temperatures in materials; these can set off alerts of approaching damage thresholds for bridges and other structures, or of rising water levels and potential flooding (97).

2. Strengthen and protect: Design new infrastructure and assets to withstand future climate conditions (larger drainage capacity, stronger structures to withstand high winds, materials suited to higher temperatures). Retrofit existing structures and facilities. Build protective features such as retaining walls, levees, and vegetative buffers.

3. Enhance redundancy: Identify system alternatives such as increased bus service in the event of rail interruption as well as a broader regional mobility perspective, considering all transport modes.

4. Retreat: Abandon transportation infrastructure located in extremely vulnerable or indefensible areas. Potentially relocate. Site new facilities in less vulnerable locations.” (p. 63)

<table>
<thead>
<tr>
<th>Status</th>
<th>Research project is complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The report accomplished its stated desire to provide a useful departure point to help place the transit industry on the right track to climate resilience. It touches on all aspects necessary to infuse climate change adaptation into a transit agency, including organizational culture, budget priorities, asset management, planning, environmental management, project development, maintenance, performance measures and emergency preparedness. It provides a general overview, but does provide numerous specific examples to clarify the narrative and case studies to support highlighted principles.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Essential Vocabulary| The report contained the following definitions and terms:

- “Mitigation: An intervention to reduce the causes of climate change by reducing greenhouse gas emissions or enhancing sinks for capturing greenhouse gas emissions.” (p. 10)
- “Adaptation: Adjustments to reduce the vulnerability of natural systems and human communities to existing or predicted climate change impacts.” (p. 10)
- “Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.” (p. 10)
- “Resilience: A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the
economy, and the environment.” (p. 10)

<table>
<thead>
<tr>
<th>Potential Keywords</th>
<th>Climate change</th>
<th>Adaptation</th>
<th>Asset management</th>
<th>State of good repair</th>
<th>Risk management</th>
</tr>
</thead>
</table>

**Citation**

**Website/Source**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Document Type**
Research Study

**Intended Audience**
NJ TRANSIT (transit agency/operator)

**Abstract**
“This research includes a survey of current reports and research on the topic; identifies and maps specific impacts to New Jersey Transit assets - commuter rail, light rail and bus; compiles national and international agency efforts underway regarding Transit strategies to protect assets; determines appropriate resilience strategies for the impacts identified; provides a summary level costs and benefits for each of the resilience strategies identified; and summarizes and highlights cost-effective strategies to maintain NJ TRANSIT current and planned future services. This report provides a regional overview and can be used to identify critical impacts on assets and take appropriate measures to reduce its vulnerability to extreme weather.” (p. 1)

**Populations Referenced**
Anyone who utilizes the NJ TRANSIT passenger rail, bus and light rail networks, including commuters, transit riders, and operations personnel.

**Topics Covered**
The research study addresses the following topics:
- “Literature review to identify potential climate impacts
- Identification of climate impacts on classes of assets
- Mapping of assets potentially at risk
- Identification of indicators to assess severity of impacts on assets for the planning horizon
- Identification of resilience strategies
- Identification of estimates of costs to implement resilience strategies on a per unit basis to assist NJ TRANSIT in the planning process” (p. 3)

**Type of Sponsoring Agency or Organization**
Public transit corporation; the report was sponsored by NJ TRANSIT

**Geographic Distribution**
- The document addresses NJ TRANSIT’s system, which covers the state of New Jersey; along with portions of New York, Orange, and Rockland counties in New York State; and Philadelphia County in Pennsylvania.
- The geographic reach of the document covers the NJ TRANSIT service area of 5,325 square miles (13,790 km²); this is the largest statewide public transit system and the third largest provider of bus, rail, and light rail transit by ridership in the United States, linking major points in New Jersey, New York, and Philadelphia.

**Type of Transit Mode(s)**
Commuter Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus.

**Type of**
- Increased temperature
### Vulnerability
- Sea-level rise and higher storm surge
- Storm intensity and frequency that involve:
  - Higher wind velocities
  - Increased rain and rainfall per event
  - Increased lightning
  - Increased snow levels per event
  - More frequent icing events
  - Increased flooding frequency and levels

### Goals and Motivations
The goal of this project is to “determine the potential vulnerability and risk, as well as projected climate impacts on NJ TRANSIT stationary assets that include rails, structures, and buildings – and to develop cost-effective resilience strategies so NJ TRANSIT can protect these assets from negative impacts in the future. NJ TRANSIT can also use this information to protect its rolling stock (trains, buses, etc.) from severe weather.” [p. 2] The assessment activities in this study provide information for NJ TRANSIT leadership to facilitate planning over the five, ten, twenty and fifty-year horizons.

### Context
- Multiple modes exist in NJ TRANSIT’s service area, including the following modes owned, operated and maintained by NJ TRANSIT: Commuter Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus.
- Types of assets evaluated include:
  - Rails (heavy and light rail)
  - Structures (bridges, tunnels, culverts and retaining walls)
  - Buildings (offices, terminals, stations and platforms, depots and cabins)
- Interdependencies exist among operators with shared assets, such as parts of the Northeast Corridor shared with Amtrak. “This study includes all rail lines where NJ TRANSIT operates service in New Jersey. NJ TRANSIT also owns assets outside of New Jersey, such as in the train yards in Suffern, New York and Morrisville, Pennsylvania near the Trenton Transit Station; and uses Amtrak’s tunnel into Pennsylvania Station and Sunnyside Yards in Queens, New York. NJ TRANSIT relies on all of these assets to provide service, although they are not all owned by the agency. This emphasizes the need for NJ TRANSIT to coordinate its efforts with other transit agencies and freight railroads, such as Amtrak, Port Authority of New York and New Jersey (PANYNJ), Metro North, and Conrail.” [p. 11]
- Interdependencies also exist with other critical facilities and systems such as the power grid. “Heat will damage electrical equipment (switches, gates, signals), increase potential for sagging and snapping of catenary lines, and increase the opportunity for widespread electric utility brownouts and outages associated with grid damage.” [p. 12]
- Limitations of this region include aging infrastructure and alignment issues in vulnerable locations with limited resources.
- NJ Transit is a New Jersey State-owned public transportation system serving the US state of New Jersey; along with portions of New York, Orange, and Rockland counties in New York State; and Philadelphia County in Pennsylvania. It operates bus, light rail, and commuter rail services throughout the state, notably connecting to major commercial and employment centers both within the state and in the adjacent major cities of New York and Philadelphia.
- The Governor of New Jersey appoints a seven-member Board of Directors, four members from the general public and three state officials. The Governor has veto power on decisions made by the board.
- While the study does not explicitly state that asset management plans are already in place nor that the system is in a state of good repair; however, it discusses certain case study examples that illustrate existing resiliency planning prior to natural disasters, such
as for Hurricane Irene when Bus Operations moved flood-prone Oradell Depot buses to Paramus Park Mall and then again to Garden State Plaza as the water rose at Paramus Park. Further, the purpose of this study is to improve resilience planning at NJ TRANSIT.

<table>
<thead>
<tr>
<th>Tools</th>
</tr>
</thead>
</table>
| • The study references NJ TRANSIT’s ongoing Scorecard initiative to track customer satisfaction and performance metrics:  
  o “Safety and Security;  
  o Customer Experience;  
  o Corporate Accountability;  
  o Financial Performance; and  
  o Employee Engagement.” (p. 15)  
• “This report reviewed and developed statistical models for the 5, 10, and 20 year planning horizons to determine results specific to NJ TRANSIT. In recent years, NJ TRANSIT has already been experiencing more extreme weather; the models indicate these increases. The variance in the models do not demonstrate a large difference within the next 20 years (NJ TRANSIT’s planning horizon); however, in 50 years there is a surge in temperature, sea-level rise, and flooding.” (p. 20)  
• “As there are no short-term (5-20 year climate) models available to predict NJ TRANSIT’s extreme weather events, the report developed Indicators of Risk that quantify, on average, the increase in extreme weather events that will affect NJ TRANSIT over the next twenty years and beyond. These Indicators identify the scale of the risk associated with these impacts. They include Days over 90 Degrees Fahrenheit, Sea-Level Rise, and Storm/Flood Frequency.” (p. 21) |

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
</table>
| • Risk management strategies and cost estimates are identified in the study based upon information presented in the literature review with particular emphasis on FTA’s “Flooded Bus Barns and Buckled Rails” (August 2011) report and NJ TRANSIT operational experience relayed to the research team.  
• While these strategies do not appear to be innovative or non-standard, several strategies include minor modifications to operations and maintenance practices (such as increased snow removal) or inexpensive improvements (such as scour removal on rail bridges) that have value.  
• As noted above, while certain specific examples of NJ TRANSIT’s damaged infrastructure and response to Hurricane Irene are provided, no action-after report or comprehensive mitigation strategy is discussed.  
• No measures are deployed to avoid, minimize and mitigate adverse effects upon populations, including low- income and minority populations. |

<table>
<thead>
<tr>
<th>Captivating Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>This document is a call-to-action for NJ TRANSIT. “NJ TRANSIT can expect more frequent service disruptions over the next 20 years and must consider how the weather is affecting the state of good repair for its assets.” (p. 26)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>The next immediate step for NJ TRANSIT is to prioritize its critical assets and determine which resilience strategies it wants to implement.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Maker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Transit Corporation at the state level.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relevance</th>
</tr>
</thead>
</table>
| This document was selected because it provides an overview of potential climate impacts for NJ TRANSIT’s assets, including a vulnerability assessment and specific risk mitigation measures with cost estimates. The following accepted practices were mentioned for risk reduction:  
  • Install emergency generators or have supplemental power feeds  
  • Install high temperature shade shelters at platforms  
  • Increase ventilation in buildings  
  • Upgrade or replace building systems  
  • Repair or reconstruct seawall  
  • Relocation of assets |
- Repair or reconstruct roofs
- Additional snow removal
- Increase maintenance / cleaning and coating of exposes steel due to de-icing and salt corrosion
- Install additional drainage systems
- Cancel, slow or reduce service at certain locations
- Increase maintenance and scour mitigation measures
- Shorten maintenance schedule

**Status**

Need a status update on implementation. This study was released following Hurricane Irene but before Superstorm Sandy, which resulted in tremendous impacts to the NJ TRANSIT system. The study should be updated or subsequent studies produced to address implementation to date, and provide any relevant updates per Superstorm Sandy.

**Critical Assessment**

The methodology and resources are sound, but are outdated in 2015, and would benefit from an update. Additional information on existing conditions should be provided, such as length or frequency of service disruptions, and populations affected (e.g., low-income populations). More specifics should be provided for risk mitigation measures – e.g., rather than saying “substitute” or “slow” service, information should be provided about what impact that would have on the system and riders.

**Additional Comments**

N/A

**Essential Vocabulary**

Resiliency is not defined in the document.

**Potential Keywords**

- Resilience
- Asset Management
- Commuter Rail
- Climate Change Impacts
- Transit corporation
<table>
<thead>
<tr>
<th>Citation</th>
<th>ICF International. 2013. <em>Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects</em>. Washington, D.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website/Source</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>Research</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Engineers, Planners, MPOs, State DOTs, Transit Agencies</td>
</tr>
<tr>
<td>Abstract</td>
<td>The report outlines the state of practice for addressing climate adaptation by transportation agencies. It further illustrates current efforts by various transit agencies as they relate to climate adaptation and mitigation initiatives. Through the outline of best practices, this report clarifies the relationship between vulnerability assessments and adaptation planning. It further provides practices regarding cost and benefit analysis of the various adaptation strategies to support agencies in their efforts moving forward.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>N/A</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>Current practices in the areas of asset management, long-range planning, design and construction, operations and maintenance as well as emergency preparedness; Best practices for incorporating adaptation through a variety of efforts including establishment of metrics, prioritization of strategies and planning; Cost-benefit processes and evaluation; and Barriers to climate adaptation.</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>National with some examples from London</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Transportation in general</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Heat, sea-level Rise and Intense Storms</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The primary goal of this study was to look into what agencies are to address climate adaptation and to share those best practices to in-kind agencies and stakeholders looking to address the anticipated changes to climate including temperature fluctuations, intense storms which bring intense precipitation and sea-level rise.</td>
</tr>
<tr>
<td>Context</td>
<td>N/A</td>
</tr>
<tr>
<td>Tools</td>
<td>Report references the Transportation Research Board Report: Methodologies to Estimate the Economic Impacts of Disruptions to the Goods Movement System,</td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
O FEMA Benefit-Cost Analysis Tool ("The tool consists of guidelines, methods and software modules for estimating the benefits and costs of mitigation strategies to a range of major natural hazards, including wildfire, floods, hurricanes, and tornadoes.") [Page 23],
O Economics of Climate Adaptation (ECA).

- Shaping Climate-Resilient Development:
  O A Framework for Decision-Making
  O Guidelines for Preparing Economic Analyses, and the Economic Analysis Primer. ("FHWA document is a brief overview of principles, concepts, and methods for performing economic analyses of highway projects.") [Page 22]

The report also briefly touches on a variety of risk communication tools to support communicating climate adaptation to the public and to stakeholders.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>The report outlines a series of recommended activities and provides a list of actions already underway by some agencies. Under the areas of focus for this project, the activities include:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Asset Management: Agencies should incorporate climate change objectives into the asset management system, collect data relating to the costs of addressing extreme weather, and include risk and vulnerability rankings/ratings into the asset management system. Actions underway include:</td>
</tr>
<tr>
<td></td>
<td>O MARTA is adding a field into its asset management system and decision-making framework;</td>
</tr>
<tr>
<td></td>
<td>O Washington State DOT has incorporated “climate change into its bridge management system” (Page 10);</td>
</tr>
<tr>
<td></td>
<td>O Vermont Agency of Transportation (VTrans) has developed a tool to allow for targeting adaptation priorities regarding its culverts and bridges;</td>
</tr>
<tr>
<td></td>
<td>O MD State Highway collected various climate data and incident data and aggregated it into a single GIS database;</td>
</tr>
<tr>
<td></td>
<td>- Long-range Transportation Planning: Agencies should incorporate climate change considerations into long-range transportation plans, specifically TIP addressing climate through utilization of climate data to inform project prioritization.</td>
</tr>
<tr>
<td></td>
<td>O Boston MPO developed tool to determine if projects are located in at risk areas;</td>
</tr>
<tr>
<td></td>
<td>O Hampton roads MPo address climate change impacts on infrastructure in its 2034 LRTP;</td>
</tr>
<tr>
<td></td>
<td>O “The U.S. Forest Service at Olympic National Forest (ONF) evaluated ways to incorporate climate change conditions into the Road Management Strategy (RMS)...” to “help (sic) prioritize roads for maintenance, upgrading, and decommissioning... because funding allocated for road maintenance is limited.” (Page 11);</td>
</tr>
<tr>
<td></td>
<td>O VDOT “developed a multi-decision model to rank and reprioritize the LRTP’s proposed transportation projects and multimodal policies based on future climate factors and other non-climate planning considerations.” (Page 11)</td>
</tr>
<tr>
<td></td>
<td>- Design and Constructions: The report outlines that agencies are hesitant to update design standards due to rising project costs and uncertainty surrounding climate projections. However, agencies have:</td>
</tr>
<tr>
<td></td>
<td>O Rebuilt and retrofitted infrastructure in response to extreme weather events;</td>
</tr>
<tr>
<td></td>
<td>O Improved stormwater management infrastructure including culvert enhancements;</td>
</tr>
<tr>
<td></td>
<td>O Ensure best climate and weather data is utilized;</td>
</tr>
<tr>
<td></td>
<td>O Design based on worst case scenario event;</td>
</tr>
<tr>
<td></td>
<td>O CalTrans evaluates roadway projects for potential impacts by sea-level rise;</td>
</tr>
<tr>
<td></td>
<td>O New England area agencies are coordinating the development of culverts to allow for ecosystem benefits;</td>
</tr>
<tr>
<td></td>
<td>O ConnDOT is evaluating its hydraulic design standards for bridge and culverts;</td>
</tr>
</tbody>
</table>
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

| Captivating Value | “Early steps that agencies can take to adapt to climate changes or prepare themselves to implement adaptation measures... include: tracking performance metrics, incorporating climate change considerations in asset management programs, setting up frameworks to enable opportunistic adaptation, developing adaptation priorities, and developing system-wide...” |

- Iowa DOT is retrofitting bridges to address local flooding as well as built a channel to direct flood waters away from infrastructure; and
- Crossrail construction in London accounted for extreme temps and extreme flooding.

- Operations and Maintenance
  - Prioritize maintenance activities that reduce damage during extreme weather events;
  - Shift construction and maintenance activities towards cooler times of the day;
  - Deploy “quick maintenance” patrols; and
  - Plant drought and heat resistant plant species for erosion control;
  - Amtrak is updating overhead wires to address extreme heat;
  - Transport for London paints bus tops white to reflect heat;

- Emergency Management
  - “The Metropolitan Transportation Authority (MTA) Hurricane Plan details maintenance operations protocols such as moving equipment (e.g., rail cars and buses) from low-lying areas or vulnerable outdoor tracks; staging recovery equipment such as generators and chainsaws near areas where they would be needed; and clearing catch basins and sewer lines (NYC MTA 2012a).” (Page 16)
  - Use of real-time communications strategies to inform customers.
  - Use ICS to support response efforts.

Appendix A provides additional details of example efforts.

Cost-Benefit Practices
- NYS has incorporated estimated impact and adaptation costs into the statewide adaptation strategy;
- NT MTA, SEPTA, VTrans and CTA have used historical costs from weather impacts to estimate future adaptation costs;

Best Practices for estimating costs and benefits of adaptations include:
- Development of an information/knowledge base;
- Improving access to data;
- Monitoring and tracking costs to extreme weather events including documenting the damages and repair/replacement costs;
- Establish decision-making criteria and processes;
- Engaging with stakeholders.

Barriers
1. Resources – Include climate change into regular business processes to eliminate the need for separate funding vehicles;
2. Political and regulatory roadblocks – Use existing programs as vehicles to push climate change (e.g. county hazard mitigation plans) but its recognized that federal guidance is needed;
3. Information availability – State and local drivers can simply things. Some agencies have directed agencies to use climate data from specific resources as opposed to requiring agencies to select the data. The report does highlight some research is needed related to engineering guidance;
4. Stakeholder engagement;
5. Interdependencies among sectors – Form interagency groups for coordination efforts.
approaches to adaptation.” (Page 17)

“The appropriate approach to estimating adaptation costs and benefits, and the manner in which the information is used, will depend both on the resources available to the decision maker and the needs of the adaptation planning process.” (Page 22)

The report also gives a thorough description of cost-benefit analyses and the issues and considerations that go into the variety of methods for determining costs and benefits of mitigation efforts.

<table>
<thead>
<tr>
<th>Decision Question</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Relevance         | - Outlines best practices across various areas of focus including asset management, emergency management, operations and maintenance as well as design and constructions;
                  | - More comprehensive examples of current efforts for incorporating climate change into these areas;
                  | - Potential case study examples;
                  | - Cost-Benefit descriptions and guidance;
                  | - Identification of potential tools for further research. |
| Status            | Various |
| Critical Assessment | The report provides a comprehensive review of current efforts underway or completed by all types of transportation agencies, not just transit. However, many of the efforts may be applied across agency types. Additionally, the report outlines a detailed description of cost-benefit analyses topics and considerations agencies should consider when embarking on such processes for including climate change. |
| Additional Comments | N/A |
| Essential Vocabulary | N/A |
| Potential Keywords | Cost Benefit, Climate Change, Adaptation, Best Practices, Current Practice |
|--------------|--------------------------------------|------------------|-------------------------------------------------|-----------------|-----------------------------|-----------------------------------------------|

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Research document.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended Audience</td>
<td>FHWA Office of Operations, transportation agencies.</td>
</tr>
<tr>
<td>Abstract</td>
<td>The research document is a white paper outlining projected impacts of climate change across the country. Further, the white paper briefly describes how these changes may impact transportation sectors' assets and options for agencies to take in assessing their vulnerability to climate change.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>US population, TMC (Traffic Management Center)</td>
</tr>
</tbody>
</table>
| Topics Covered | • Anticipated climate change in regards to temperature, precipitation, etc. by US regions.  
• Potential impacts from the anticipated climate change projections.  
• Some strategies to be prepared for climate change. |
| Type of Sponsoring Agency or Organization | Federally sponsored. |
| Geographic Distribution | National |
| Type of Transit Mode(s) | The report is not designed to address and single modal administration or transportation agency but to cover all surface transportation modes in general. However, the report does identify CTA specifically within. |
| Type of Vulnerability | Heat-high Days, Extreme Cold, Severe Storm Events, Coastal Storms, Flooding/Sea-level Rise, Winter Storm (Heavy Snow/Ice), Wildfires, Other (Landslides, Dust Storms) |
| Goals and Motivations | The motivation of this white paper was based on listening sessions with FHWA staff as a topic of interest and priority. |
| Context | There is no single agency focused but a broader scope to help agencies understand the projections of climate change regionally within the United States. |
| Tools | N/A |
| Noteworthy Aspects | • Identification of dust storms and landslides is unique to certain areas of the country and could provide for interesting context as far as impacts and climate change adaptation strategies.  
• Provides a snapshot of climate change by U.S. region and the potential impacts those changes may bring. A table (p. 16) is presented with a breakdown of the impacts of climate change for transportation providers. These impacts include system maintenance needs: |

---

Copyright National Academy of Sciences. All rights reserved.
### Impacts to operations: (p. 19)

<table>
<thead>
<tr>
<th>Climate Change Effects</th>
<th>Climate Change Impacts</th>
<th>System Maintenance Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Event Impacts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased coastal and</td>
<td>Greater frequency of</td>
<td>Increased staff and</td>
</tr>
<tr>
<td>inland flooding;</td>
<td>flooded, blocked</td>
<td>resources to monitor</td>
</tr>
<tr>
<td>increases in intense</td>
<td>(e.g., trees, landslides)</td>
<td>vulnerable routes and</td>
</tr>
<tr>
<td>precipitation events</td>
<td>washed out roads</td>
<td>provide traveler</td>
</tr>
<tr>
<td>Increase in magnitude</td>
<td>Greater risk of</td>
<td>Altered construction and</td>
</tr>
<tr>
<td>and duration of severe</td>
<td>structural damage to</td>
<td>maintenance schedules</td>
</tr>
<tr>
<td>heat waves</td>
<td>bridge joints and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pavement, e.g.,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>buckling or rutting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Higher temperatures may</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inhibit construction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>activities during</td>
<td></td>
</tr>
<tr>
<td></td>
<td>certain months, or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>times of day</td>
<td></td>
</tr>
<tr>
<td>Climate Change Effects</td>
<td>Greater frequency of</td>
<td>Increased staff and</td>
</tr>
<tr>
<td></td>
<td>reduced visibility</td>
<td>resources to monitor</td>
</tr>
<tr>
<td></td>
<td>conditions</td>
<td>vulnerable routes and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>provide traveler</td>
</tr>
<tr>
<td></td>
<td></td>
<td>information</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Climate Change Effects</th>
<th>Climate Change Impacts</th>
<th>System Maintenance Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Event Impacts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased recurring</td>
<td>Mandatory diversion to</td>
<td>Increased staff and</td>
</tr>
<tr>
<td>coastal and inland</td>
<td>more robust alternate</td>
<td>resources to monitor</td>
</tr>
<tr>
<td>flooding; rising sea</td>
<td>routes, reducing route</td>
<td>vulnerable routes and</td>
</tr>
<tr>
<td>levels</td>
<td>options/redundancy</td>
<td>provide traveler</td>
</tr>
<tr>
<td></td>
<td></td>
<td>information</td>
</tr>
<tr>
<td></td>
<td>Increased staff and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>resources to monitor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vulnerable routes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and provide traveler</td>
<td></td>
</tr>
<tr>
<td></td>
<td>information</td>
<td></td>
</tr>
<tr>
<td>Broader preparedness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for potential evacuation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in intensity</td>
<td>Increased TMC staff and</td>
<td></td>
</tr>
<tr>
<td>of tropical cyclones;</td>
<td>Intelligent Transportation</td>
<td></td>
</tr>
<tr>
<td>increased occurrence</td>
<td>System (ITS) resources</td>
<td></td>
</tr>
<tr>
<td>of wildfires</td>
<td>to provide traveler</td>
<td></td>
</tr>
<tr>
<td></td>
<td>information during</td>
<td></td>
</tr>
<tr>
<td></td>
<td>evacuations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More frequent disaster</td>
<td></td>
</tr>
<tr>
<td></td>
<td>preparation, operations,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and recovery actions</td>
<td></td>
</tr>
<tr>
<td>Climate Trend Impacts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in energy</td>
<td>Increased need for</td>
<td></td>
</tr>
<tr>
<td>demand for air</td>
<td>more resilient TMC</td>
<td></td>
</tr>
<tr>
<td>conditioning</td>
<td>communications and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>backup power to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maintain real-time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>information feeds</td>
<td></td>
</tr>
</tbody>
</table>
And, Changing Travel Behavior (p. 21)

<table>
<thead>
<tr>
<th>Climate Change Effect</th>
<th>Changes to Travel Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Event Impacts</td>
<td>Less consistent mode shift impacting day-to-day congestion and safety issues</td>
</tr>
<tr>
<td>Increased exposure to hazardous driving conditions (e.g., flooding, road surface conditions, smoke from wildfires)</td>
<td>Potential mode shift to/from alternate modes, e.g., using transit, biking, or walking</td>
</tr>
<tr>
<td></td>
<td>Increased TMC monitoring of more reliable routes to provide enhanced traveler information</td>
</tr>
<tr>
<td></td>
<td>Increased emphasis on carpooling and teleworking to reduce impacts to highways</td>
</tr>
<tr>
<td></td>
<td>Investigate regional climate change impacts to understand how impacts may affect traveler mode and route choice in both the short- and long-terms</td>
</tr>
</tbody>
</table>

Climate Trend Impacts

Human health effects

|                                                            | Potential mode shift from alternate modes, e.g., transit, biking, or walking |
|                                                            | Increased emphasis on carpooling and teleworking to reduce impacts to highways |

- The white paper addresses the need for agencies to “absorb” impacts from climate change as part of its adaptation. To address climate change and its impacts, the white paper outlines that transportation agencies are responsible for increasing its ability to respond to more incidents and extreme weather events. To do this, the white paper suggests:
  - Increasing monitoring of weather and systems. This may include mobile monitoring or use of social media to support agencies.
  - Integrate weather information into operation centers to enhance situational awareness and forecasting capabilities.
  - Increase in stakeholder coordination.
  - Establishment of response teams which may be rapidly deployed to respond to incidents such as flash flooding debris removal and other needs.
  - Develop mechanisms internally to be more flexible in resource allocation so increase ability to respond to impacts.
  - Cross train staff to support response to an assumed increased number of incidents while assuming staffing levels does not increase.
  - Train for the unexpected. (p. 24-25)

- The white paper concludes that linking climate and weather events is not simple but that the role of operations in preparing for climate change “needs to be emphasized” as challenges are posed long term.

**Captivating Value**

While questions may remain about climate adaptation, agencies should consider: “Introducing risk assessment in transportation operations planning” and “integration with other adaptation efforts.” This may be a great way for new agencies to become immersed in the topic and to become more knowledgeable, but also build off and benefit from other efforts going on in and around the area.

**Decision Question**

N/A

**Decision Maker**

N/A
### Relevance
- Provides considerable data by US region on anticipated climate changes.
- Identifies a series of potential impacts climate change may have on the transportation sector.
- Highlights responsibilities of agencies to begin adapting to climate change.
- Addresses emergency response in a number of ways including integration of operations in the development of evacuation procedures.

### Status
N/A

### Critical Assessment
This is a fairly high-level white paper which begins to outline climate change and climate change impacts to transportation sector. This was its intent. It may provide a good background for the impacts to transportation to include some events (e.g. dust storm) which have not been considered by the team in depth. The beginning strategies are of higher level nature but may help frame some of the detailed recommendations in other reports.

Mainly focused on climate change but touches on other areas such as communications, asset monitoring and weather monitoring, funding and planning. It also provides some initial steps for agencies just getting into the area of climate change planning.

### Additional Comments
N/A

### Essential Vocabulary
N/A

### Potential Keywords
- climate change
- transportation systems operations
- adaptation
- climate change impacts
- operations
- maintenance
| Document Type | FTA Adaptation pilot study outlining tools which may be used to integrate climate adaptation into operations, infrastructure planning and business practices. |
| Intended Audience | Transit Agencies and practitioners within those agencies. |
| Abstract | The overall purpose of the pilot project was the development of tools and methods for assessing the impact of extreme weather on operations and critical infrastructure. In the case of CTA, the agency implemented a methodology for surveying and analyzing system vulnerabilities. With the knowledge gained through this analysis, the agency was then able to outline adaptation approaches which may enhance resilience for those areas focused on by the agency. Utilizing a cost-benefit model, the CTA was able to derive the best solution for addressing extreme weather and climate change while factoring sensitivities of the scientific data surrounding climate change. The final piece to the report outlines a high-level approach that CTA may apply to integrate climate change adaptation into standard business practices. |
| Populations Referenced | Customers, Engineers, Planners |
| Topics Covered | • System Vulnerability Outlook to Extreme Weather  
  o A method for quantifying the costs on CTA for the impacts from extreme weather instances experienced recently;  
  o A method for quantifying future costs from impacts from extreme weather;  
    ▪ Both methods include the development of cost estimates related to damage and labor. Impacts included impacts to service as well as impacts to general ridership during weather incidents.  
  o The development of climate data projections for application to future impact analysis;  
  o An overall risk matrix of the agencies infrastructure and operations vulnerabilities based on the types of vulnerabilities studied from CTA survey participants;  
  • Method for prioritization of vulnerabilities for further investigation. The priority areas became the basis for case studies on incorporating those improvements into the capital project planning of the organization using scenario planning methods (e.g. build and no-build scenarios) Prioritization included the consideration of:  
    o Severity of impacts;  
    o Frequency of impact;  
    o Capital costs increases;  
    o Operating cost increases;  
    o Project/site-issues;  
    o Process-specific issues;  
    o Assets under CTA control; & |
| **Type of Sponsoring Agency or Organization** | FTA sponsored. City-based transit agency and consultant prepared report |
| **Geographic Distribution** | Focused on the CTA, a major urban environment with application to national systems. |
| **Type of Transit Mode(s)** | Heavy Rail, Bus/Commuter Bus |
| **Type of Vulnerability** | The report identified the following vulnerabilities: Heat-high Days, Extreme Cold, Severe Storm Events, Coastal Storms, Flooding, Winter Storm (Heavy Snow/Ice) |

However, further investigation into specific vulnerabilities on high heat and flooding occurred within the report. The flooding aspects focused on ROW flooding. Extreme heat focused on the impacts of heat kinks as well as signal house overheating. These are examples specific to CTA they moved forward as part of the study.

| **Goals and Motivations** | Due to the expected increase in extreme weather and their impacts on the CTA system such as winter weather, precipitation and extreme temperatures, this report provides a framework assessing the agencies vulnerability to such events in an effort to understand the potential impact. It further highlights adaptation strategies which may be implemented to increase the systems resiliency and outlines high-level steps which may be taken to incorporate the consideration of climate change and extreme weather into business practices. In doing so, the report outlines a series of methods and tools to support decision-making and prioritization of capital improvement planning activities. |

| **Context** | The focus of this report outlines the potential impacts from climate change on the CTA system. With the methodology and tools presented, CTA has developed a framework for increasing institutional awareness of climate change. This includes the inclusion of considerations into capital project planning and the agencies established Enterprise Asset Management (EAM) system [Complete for rail, being built for bus as part of 2011 grant]. |

“The Chicago Transit Authority (CTA) is an independent governmental agency created by state legislation. The CTA began operating on October 1, 1947, after it acquired the properties of the Chicago Rapid Transit Company and the Chicago Surface Lines. On October 1, 1952, CTA became the sole operator of Chicago transit when it purchased the Chicago Motor Coach system.” (CTA website) As of 2013, (per the National Transit Database) directly operates 1,663 bus vehicles in maximum service with a total of 1,872 available for maximum service. CTA operates 1,070 heavy rail vehicles in max service with a total of 1,228 available. The rail system has a total of 207.8 fixed guideway directional route miles. |

| **Tools** | The methodology framework used in the vulnerability analysis piece is a different approach in that the agency did not conduct a vulnerability assessment. The CTA researched prior events to determine impacts in terms of cost and surveyed stakeholders. This data fed directly into the cost-benefit model which considers the frequency of these types of events to support the output of costs to do nothing or cost to implement an adaptation strategy. |

It used varying approaches to determine if vulnerability will have impacts on the system. Although the report does not detail the analysis completed for its results of the project number of events by vulnerability reviewed, examples may be gleaned. For example, CTA used an urban heat island map to determine likely locations of heat impacts to rail assets one high-heat days. In
some of these efforts, the agency used “global models” without much explanation though it appears research had been done in the city on a larger climate project.

However, the report does detail the used of what was called the Develop Life-Cycle Cost Model (LCCM). It “was constructed to compare the infrastructure investment costs (i.e., build scenarios) against the costs of no action (no-build scenarios). The model was developed in a manner to provide flexibility to allow for different weather event frequencies and cost assumptions to be tested to determine the sensitivity of the model to inputs for a given scenario. This flexibility also allows for future modification of inputs to support additional case studies.”

In using the mode, the report outlines best practices. These are summarized as:

- “LCCA level of detail should be consistent with level of detail of investment” (p.61);
- Only need to consider “differential costs among alternatives”, as common costs cancel out(p. 61);
- “All LCCA factors should be addressed (even if limited to explanation for non-inclusion of eliminated factors)” (p. 61);
- “Sunk costs should not be included” (p. 61);
- LCCA time horizon should “reflect long-term cost differences associated with reasonable design strategies.” (p. 62)
- Use net present value (NPV) to allow for today and future dollar comparisons of present capital costs versus future operating costs. (p. 62)
- Use of historical trends to determine discount rates. (p.62)
- Annual maintenance should be equally applied across all alternatives since its impacts have only “marginal” effect. (p. 62)

Model results in the identification of appropriate adaptation strategies based costs factoring in various items including extreme weather event frequency. Study suggests revisiting model as more local climate change data becomes available. Sensitivity existed to many inputs in addition to climate change. LCCA result showed that at baseline projections, that the investment to adapting the issues reviewed is not beneficial, though at higher frequencies, the adaptation strategies are mostly beneficial.

Overall, the architecture outlines inputs being the severe weather frequencies and the outputs in terms of the NPV in 2050. A list of assumptions has been made as well.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• It appears an emphasis was placed on stakeholder identification of impacts rather than a complex geographic analysis of assets and extreme weather events. Though some background research was conducted.</td>
</tr>
<tr>
<td>• Although the report dedicates a section of incorporation of climate change into standard business practices, it outlines multiple approaches but does not illustrate how CTA plans to move forward on integration into their EAM system. The approaches take into consideration the things one may similarly consider for vulnerability and risk assessment such as exposure (“the nature and degree of exposure to climate impacts”), sensitivity (“the degree to which materials and systems are effected by exposure”), and adaptive capacity (“ability for system to respond to climate change”). (p. 77)</td>
</tr>
</tbody>
</table>

The first approach is an impact-focused approach, or a risk assessment approach, where as an agency may outline the impacts to infrastructure. This would outline climate impacts, infrastructure impacts, other asset impacts, severity and frequency of impacts, customer impacts and a summary vulnerability index number. (p. 77) The second approach would be to take an asset-focused approach where as new field are created in
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>The LCCM model has potential but is sensitive to a variety of factors relying on available data; this includes the issue of reliable climate change data and how it impacts on the local level. This issue won’t be solved in this report, so a closer look at the LCCM provides some guidance on developing cost-benefit analysis as a consideration component for advancing adaptation strategies. Furthermore, prioritization of the improvements should not be performed exclusively from an LCCA analysis; additional factors must be considered to ultimately prioritize climate-adaptive improvements based on historical performance and available projection data.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Question</td>
<td>Should an investment be made now to reduce weather impacts to the system?</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>CTA</td>
</tr>
<tr>
<td>Relevance</td>
<td>Scope of climate change impacts.</td>
</tr>
<tr>
<td></td>
<td>• Identification of impacts through survey of stakeholders;</td>
</tr>
<tr>
<td></td>
<td>• Identification of impacts through prior reports for geographic boundary;</td>
</tr>
<tr>
<td></td>
<td>• Identification of impacts through background research.</td>
</tr>
<tr>
<td>Integration of climate change impacts into business practices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Developed a cost-benefit model to provide input into the capital planning process;</td>
</tr>
<tr>
<td></td>
<td>• Outlined potential steps for inclusion into the asset management system;</td>
</tr>
<tr>
<td></td>
<td>• Outlined of a model to project future maintenance costs and resource needs to support budgeting and planning</td>
</tr>
<tr>
<td>Status</td>
<td>CTA does not address a timeline for integrating climate and weather impacts into the EAM system but does identify that going through LCCM exercise with other assets with an academic partner is worthwhile. So value was found by CTA in doing the LCCM analysis.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>It looks as though the report was really missing a vulnerability assessment which leads me to believe that the referenced materials includes Chicago’s Adaptation Plan which likely addresses many of the data needed to back up the results of the vulnerability survey. However, it’s just not clear. Additionally, some approaches though different and may have some value such as mapping urban heat island areas, does not necessarily project future impacts as heat island effects may change moving forward and other citywide adaptation of green infrastructure could change the heat island pattern. This highlights the need for transit agencies to coordinate with local governments on their plans which could impact the assumptions made by the transit agency.</td>
</tr>
</tbody>
</table>

The LCCM seems to have promise but without hands-on use, it’s difficult to determine if the simplicity ignores factors of a complex issue. The work put into developing useful model results through evaluating different strategies was well done though. Worth a look for transit agencies.
but the report leaves the gap of which proposed approach the agency will take to integrate climate into the EAM system.

One of the most interesting aspects may be the operational/finance impact framework model that took up just a couple pages of the entire report. It appears this effort was not part of the pilot but an earlier project CTA was working on.

Overall, the report provides considerable meaningful methodologies and tools to support transit agencies beyond CTA but there are some gaps in the framework which need to be understood on why some methods were choose over others.

<table>
<thead>
<tr>
<th>Additional Comments</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Potential Keywords  | Asset Management  
Climate Adaptation  
Standard Business Practice  
Capital Planning  
Long-range Planning |
**Citation**  

**Website/Source**  
http://www.fta.dot.gov/about/12351_8850.html

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Document Type**  
Pilot study research report.

**Intended Audience**  
Practitioners, especially other transit agencies, and policy makers.

**Abstract**  
The SEPTA system is increasingly dealing with severe weather in terms of increased and prolonged flooding on parts of its system, extreme heat, power outages, strong winds and tropical storms/hurricanes. It has always had to deal with snow, including blizzards. What is different is that severe storms are becoming more frequent and lasting longer. Traditional flood areas are remaining flooded for longer periods and the opportunities for service disruption from falling trees, water and strong winds have the potential for lasting longer. The Pilot has afforded SEPTA to look at its rail system from the perspective of climate and adaptation and its effects on its system and customers at various time frames

“The study analyzes the risks from extreme weather and climate change in the context of service delays, train annulments, and costs to SEPTA. Projected risks are grounded in historical data on service disruptions and costs from weather events, including labor, materials, and equipment. Finally, we identified, screened, and analyzed adaptation strategies with stakeholder input. This report presents the results of these analyses, including detailed process information and lessons learned for future transit adaptation efforts.” (p. 7)

**Populations Referenced**  
N/A

**Topics Covered**  
Executive Summary  
Section 1: Introduction  
Section 2: Current Climate Hazards  
- Observed Weather Events and Related Disruptions on the Manayunk/Norristown Line  
- Weather-Related Service Disruptions  
- Costs of Major Weather-Related Disruption Events  
- Sensitive Locations and Asset Types  
- Thresholds for Weather-Related Disruption  
Section 3: Future Climate Hazards  
- Climate Change and Projected Changes in the Frequency and Intensity of Extreme Weather  
- Potential Future Frequencies and Costs of Service Disruptions  
- Potential Changes in Sensitive Locations and Assets  
Section 4: Key Vulnerabilities  
- Vulnerabilities to High Temperatures  
- Vulnerabilities to Heavy Rain Events
### Section 5: Adaptation Strategies
- Process for Identifying Adaptation Strategies
- Adaptation Strategies for High Temperatures
- Adaptation Strategies for Heavy Rain Events
- Adaptation Strategies for Snow
- Adaptation Strategies for Tropical Storms
- Cross-Cutting Adaptation Strategies
- Recommendations

### Section 6: Lessons Learned

#### Appendix A: Detailed Approach for Analysis of Baseline Service Disruptions

#### Appendix B: Detailed Approach for Analysis of Weather-Related Costs

#### Appendix C: Detailed Approach for Analysis of Baseline Weather Conditions

#### Appendix D: Detailed Approach for Analysis of Future Climate Projections

<table>
<thead>
<tr>
<th>Type of Sponsoring Agency or Organization</th>
<th>FTA sponsored the pilot and study report.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>SEPTA provides transit service (commuter rail, bus, subway, and paratransit service) in the Philadelphia region of Pennsylvania, extending service into nearby states. The pilot study focuses on the single rail line of Manayunk/Norristown (M/N).</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>The pilot study focuses on the regional rail line of Manayunk/Norristown (M/N).</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Future weather-related events are examined and tables are produced to present frequency, intensity and duration, and the effects on service, equipment and costs based on previous experience scaled up to represent expectations for the future: high heat days, heavy rains, tropical storms, and winter storm/snow events.</td>
</tr>
<tr>
<td></td>
<td>- High Temperature Events</td>
</tr>
<tr>
<td></td>
<td>o For the region the most disruptive future weather event will be heat: “In such high temperatures, the M/N line (and other rail lines) would be vulnerable to sagging wires, equipment stress, and track buckling. In addition, these temperatures create harsh working conditions that can make it difficult to assess or repair damages.... High temperatures primarily affect SEPTA’s power system. Temperatures affect power lines and wires, and high temperatures can cause wires to sag. Older wires are especially vulnerable. Not only are they more prone to sagging, they are also more likely to break if tightened. The regional power grid may also be stressed and subject to brownouts during periods of high heat.” (p. 34)</td>
</tr>
<tr>
<td></td>
<td>- Heavy Rain Events</td>
</tr>
<tr>
<td></td>
<td>o “The M/N line is highly vulnerable to flooding from heavy rain events. When rain falls, it combines with runoff from upstream and can overwhelm culverts and cause severe flooding on the line.... During heavy rain events, SEPTA is often forced to close sections of track. This, in turn, disrupts service and may require rescue buses for some passengers, single tracking, and changes to service schedules.” (p. 35-36)</td>
</tr>
<tr>
<td></td>
<td>- Tropical Storms events</td>
</tr>
<tr>
<td></td>
<td>o “The M/N line is highly vulnerable to damage from the tropical storms that affect the Philadelphia area. Tropical storms combine high winds and high precipitation volumes and, therefore, can cause not only flooding but extensive infrastructural damage. Even more so than heavy precipitation events, tropical storms are likely to cause</td>
</tr>
</tbody>
</table>
downed trees, damage to catenaries, power outages, and damage to signals. Some tropical storms can also cause severe flooding,” (p. 37)

SEPTA represents the vulnerabilities to weather events on power, track, signals, track beds, bridges, communications and staff on the M/N line in a simple Table 4-1: SEPTA’s Vulnerabilities to Weather Events and Projected Climate Changes on the Manayunk/Norristown Line (organized by weather event and SEPTA department) (p. 39)

<table>
<thead>
<tr>
<th>Goals and Motivations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal</strong>: Develop Cross-Cutting Adaptation Strategies</td>
</tr>
<tr>
<td>• “Incorporate climate change vulnerability into the asset management program.</td>
</tr>
<tr>
<td>• Document and disseminate institutional knowledge.</td>
</tr>
<tr>
<td>• Incorporate climate risk management into SEPTA planning, construction, operations, and maintenance processes.</td>
</tr>
<tr>
<td>• Continue to enhance communication systems.</td>
</tr>
<tr>
<td>• Create and monitor performance indicators.</td>
</tr>
<tr>
<td>o Weather-related costs</td>
</tr>
<tr>
<td>o Heat and speed restriction delays</td>
</tr>
<tr>
<td>o Real-time condition monitoring</td>
</tr>
<tr>
<td>• Acquire backup power systems</td>
</tr>
<tr>
<td>• Incorporate changing climate conditions into planning and budgeting process” (p. 63-64)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The FTA pilot projects (of which SEPTA is one) were chosen to advance the state of the practice for incorporating climate change and extreme weather considerations into existing decision-making paradigms and, ultimately, improving the resilience of transit assets and services to the impacts of climate change. These pilots, which focus on climate-related risks, are being conducted in the context of long-term goals to address state of good repair needs and enhance transit safety.” (p. 6)</td>
</tr>
</tbody>
</table>

SEPTA provides transit service (commuter rail (known as regional rail), bus, subway, trolley, and paratransit service) in the Philadelphia region of Pennsylvania, with limited service extending into New Jersey. SEPTA was developing its asset management system at the time of the report, including fleet assets, infrastructure assets and SOGR.

<table>
<thead>
<tr>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>In an effort to level the risk playing fields among the whether events, SEPTA developed the following:</td>
</tr>
<tr>
<td>• “Disruption Risk (in Delay Minutes) = (Probability of a Weather Event) × (Probability of Disruption Associated with that Event) × (Median Delay for that Event)</td>
</tr>
<tr>
<td>• Disruption Risk (in Annulments) = (Probability of a Weather Event) × (Probability of Annulment Associated with that Event) × (Median Number of Annulments for that Event)” (Page )</td>
</tr>
</tbody>
</table>

SEPTA recognized that there are many commonalities to responding to weather events. To address this. They developed:
| • “Cross-Cutting Adaptation Strategies |
|   o “Incorporate climate change vulnerability into the asset management program. |
|   o Document and disseminate institutional knowledge. |
|   o Incorporate climate risk management into SEPTA planning, construction, operations, and maintenance processes. |
|   o Continue to enhance communication systems. |
|   o Create and monitor performance indicators. |
|     ▪ Weather-related costs |
|     ▪ Heat and speed restriction delays |
|     ▪ Real-time condition monitoring |
|   o Acquire backup power systems |
o Incorporate changing climate conditions into planning and budgeting process” (p. 63-64)

Another useful tool/ methodology is cost identification, needed for potential reimbursement from FEMA or FTA.

- Costs

The initial cost data was derived from two sets of data:

- “Reimbursement information submitted to FEMA to cover costs associated with weather disasters. SEPTA provided information about recent submittals for five events ... These events are limited to major snowstorms and tropical storms.
- Weekly labor costs that have been coded as “weather-related” and that correspond to the same dates as the 28 major events days .... Although the payroll costs are available for the major weather disruption events (as opposed to FEMA reimbursements, which are limited to five events), they are limited to SEPTA labor and do not include costs for equipment, materials, or contracted labor service. (p. 11)

From the severe weather identification the next step was to determine how often severe weather events occur and their risk projection “Tropical storms occur less frequently, but when they do occur, they severely disrupt operations and in the recent past have prompted system-wide service annulsments. Non-tropical storm precipitation events cause median delays of 9–18 minutes 47 percent of the time they occur.” (p. 19) “The risk estimates represent the product of the probability of an event’s occurrence and the magnitude of an event’s consequences in terms of delays and annulsments. The estimates act as a measuring stick to compare the various weather risks. For example, snow and heat currently pose comparable risks to the system, roughly double the disruption risk associated with heavy rainfall.” (p. 21) SEPTA estimates “… the future risks of disruption and the costs associated with disruption by combining the projected changes in the frequency of extreme weather events with the known costs and service disruptions associated with these events.” (p. 30)

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
</table>
| SEPTA undertook a very different approach to the FTA request compared to the six other Pilot projects. The other Pilot projects undertook large-scale analyses of their rail and some bus services, climate modeling, various asset management analyses, emergency management efforts, etc. and the climate impacts on their systems currently and forecasted. Los Angeles Metro posed a critical asset question “If this service or asset were removed from the transit system, would the transit system be fundamentally different?” (LA Metro Pilot Report, Page 8) Answering the question requires an analysis of the whole. SEPTA believed you could understand weather’s disruptive impacts on one rail transit service and extrapolate to the whole.

SEPTA believed it could provide a viable climate adaptation and climate impact analysis by examining, in depth, the impact climate on SEPTA’s most weather affected rail corridor. Based on discussions with SEPTA O&M and planning staff the “the Manayunk/Norristown (M/N) line, was based on ridership and other objective metrics related to criticality, but subjective factors were equally important.” (p. 7) Of the 18.6 miles of the M/N line most runs along the Schuylkill River.

They then identified their assets that are currently vulnerable to severe weather events and assessed their service disruptions (p. 11). This base will be used to assess and estimate “… future risks of disruption and the costs associated with disruption by combining the projected changes in the frequency of extreme weather events with the known costs and service disruptions associated with these events.” (p. 30)

“With respect to climate model selection, unlike many of the climate change vulnerability studies underway, this study began with historical data and used observed/monitored weather data to drive decisions about which future climate variables to consider.” (p. 7)
Using historical data and current observations of weather, what weather events are causing the greatest delay, annulments, disruption and costs on the M/N line? SEPTA developed the following five questions to determine what weather events were the most harmful and disruptive:

“What types of weather events lead to service disruptions?

What is the magnitude and duration of disruption for different types of weather events?

How frequently do disruptive weather events occur?

What are the costs of different types of disruptive weather events?

Are there any “thresholds” for temperature or precipitation for which service disruptions consistently occur? If so, how often are such thresholds exceeded?” (p. 8)

The weather events were not a surprise, nor were the fact that snow was the leading culprit in causing delays and annulments. However, future weather projections will see fewer snow events, though their intensity may be severe.

The M/N line compared “…to the entire SEPTA Regional Rail system, ...experiences higher rates of impacts from heavy rain and flooding in addition to similar rates for all other weather-related delays. ....The M/N line appears to experience fewer heat-related delays compared to the full SEPTA system but similar rates for all other causes.” (p. 10)

Also noteworthy were the following, noted among lessons learned:

- Staff engagement
- Data
- Stakeholder engagement (p. 68)

**Captivating Value**

“The project design, both in approach and in scope, proved to be an effective way to analyze transit vulnerability and adaptation strategies. This project examines climate change vulnerability through the lens of current weather conditions and weather-related disruptions. This proved to be an invaluable aspect of the project. It allowed the project team to immediately engage SEPTA staff about their vulnerabilities without needing to broach more controversial climate change topics and without having to complete a full climate modeling effort beforehand. SEPTA staff from a range of backgrounds could therefore be engaged from the outset of the project.” (p. 67)

**Decision Question**

Identifying vulnerabilities and potential adaptive measures with heavy involvement from the frontline operating personnel.

Most of the recommendations are from the possible solutions to the problems identified in Table 5. They are in three areas:

- Two Capital Planning Strategies
- Seventeen Operation Strategies
- Ten Maintenance Strategies.

They range from the practical such as cleaning culverts before severe storm events to raising equipment to communicating with customers (p. 64-66).

**Decision Maker**

Most decisions are made at the agency level.

**Relevance**

“Noteworthy aspects” addresses the process. Other noteworthy relevant aspects are in the presentation and recommendations.

The tables provide succinct and fairly comprehensive summaries of the proposed adaptive solutions, that can be readily adapted to other transit agencies, as follows:

- Table 4-1 becomes the basis for adaptive solutions in Table 5-2 for Temperature (p. 44-46); Table 5-3 for Heavy Rains (p. 50-53); Table 5-4 for Snow (p. 55); and Table 5-5 for Tropical Storms; (p. 57-59)
- The measures emerged from conversations with SEPTA’s staff, literature review, knowledge from long time employees on the line, and conversations with other railroad personnel.
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 5-2</strong> identifies the problems, possible solutions, departments responsible and barriers to solutions. Nine temperature related problems are identified from “sagging wires and track buckling to harsh working conditions and passenger discomfort.” The solutions run from modernizing the catenary system to constant tension to “educate workers on stress and hydration.” Most of the nine problems have multiple solutions.</td>
<td></td>
</tr>
<tr>
<td><strong>Table 5-3</strong> identifies the problems, possible solutions, departments responsible and barriers to solutions. Nine heavy rain related problems are identified from “track wash outs to power outages.” The solutions run from “build flood resistant structures to emergency sand bagging.” Most of the nine problems have multiple solutions.</td>
<td></td>
</tr>
<tr>
<td><strong>Table 5-4</strong> identifies the problems, possible solutions, departments responsible and barriers to solutions. Five snow related problems are identified from “snow on the tracks to service disruptions.” The solutions run from “have third party personnel available to remove the snow to continue to improve customer communications.” Most of the five problems have multiple solutions.</td>
<td></td>
</tr>
<tr>
<td><strong>Table 5-5</strong> identifies the problems, possible solutions, departments responsible and barriers to solutions. Twelve related problems are identified from “loss of power, downed catenary system and delays.” The solutions run from tree trimming, increased pumping and customer communications.” Most of the twelve problems have multiple solutions.</td>
<td></td>
</tr>
</tbody>
</table>

Recommended strategies that may have relevance for other transit agencies are as follows (p. 64-66):

- **“Capital Planning Strategies”**
  - Promote use of pervious surfaces.
  - Improve stormwater management on SEPTA property by installing green roofs and rainwater capture systems (e.g., rain barrels).

- **“Operations Strategies”**
  - Record climate- and weather-related vulnerability for assets in transit asset management program, beginning with most critical assets, if necessary.
  - Continue efforts to make institutional knowledge more resilient (e.g., through asset management program and other means).
  - Create and track performance indicators of resilience (e.g., frequency of FS1 restrictions, relationship of delays to weather conditions, labor hours spent on and costs of weather events, customer satisfaction).
  - Improve monitoring of water levels and possibly identify key thresholds for planning.
  - Continue to enhance customer communication and develop weather event communication protocols.
  - Incorporate changing climate conditions into planning and budgeting processes (projected number of heat events, tropical storm risk, etc.).
  - Prepare to adjust services as needed and communicate with riders (before, during, and after events).
  - Increase bus service in advance of predicted flood events to service flooded stations.
  - Develop policies and action plans to be taken when a heat wave is forecast (e.g., worker schedules, cooling stations, equipment readiness, backup power).
  - Put specialty equipment and staff on standby when storms or heat waves are forecast (e.g., high rail excavators, trucks loaded with stone and ballast, chain saws).
  - Educate workers about heat stress and hydration, especially in advance of summer months.
  - Store equipment in higher elevation areas in advance of potential flood events (and ensure it gets done by assigning tasks to specific people).
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

<table>
<thead>
<tr>
<th>Status</th>
<th>The pilot is complete, recommendations and action steps have been identified.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>If someone was approaching the issue of climate adaptation and rail transit for the first time this approach would be most useful. The Report was:</td>
</tr>
<tr>
<td></td>
<td>• Targeted and comprehensible.</td>
</tr>
<tr>
<td></td>
<td>• Used tables to correlate problems with possible solutions. The problems identified and many of the possible solutions are common sense and transferable to other SEPTA railroad lines and other railroad properties.</td>
</tr>
<tr>
<td></td>
<td>• Customers were recognized in terms of negative impacts and the need for communications.</td>
</tr>
<tr>
<td></td>
<td>• A simple cost calculation was established and can be quickly used to assess costs before more developed cost analyses are developed. The cost approach also underscores the need for using different accounts for each severe weather event to improve the reimbursement process from FEMA and FTA.</td>
</tr>
<tr>
<td></td>
<td>• Has performance measures.</td>
</tr>
<tr>
<td></td>
<td>• Limited utilization for bus operations.</td>
</tr>
<tr>
<td></td>
<td>• Minimal attention to new technologies and materials that could resolve problems.</td>
</tr>
<tr>
<td></td>
<td>• Recognized policy issues as an important part of addressing the vulnerabilities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Comments</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Vocabulary</td>
<td>No definition of resilience provided – closest was the recommendation to “Create and track performance indicators of resilience (e.g., frequency of FS1 restrictions, relationship of delays to weather conditions, labor hours spent on and costs of weather events, customer satisfaction).” (p.65.)</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>SOGR</td>
</tr>
<tr>
<td></td>
<td>• FSI Speed restriction (no definition given)</td>
</tr>
<tr>
<td></td>
<td>• performance metrics</td>
</tr>
<tr>
<td>Event</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td></td>
</tr>
<tr>
<td>high heat</td>
<td></td>
</tr>
<tr>
<td>asset management</td>
<td></td>
</tr>
<tr>
<td>flooding</td>
<td></td>
</tr>
<tr>
<td>snow</td>
<td></td>
</tr>
<tr>
<td>tropical storms</td>
<td></td>
</tr>
<tr>
<td>heavy rain</td>
<td></td>
</tr>
</tbody>
</table>
This study was intended to provide Gulf Coast transit agencies a source of reference to address climate change within their agencies. This source of information includes a broad range of climate change research and potential and actual weather-related impacts to Gulf Coast communities. This report further provides agencies a framework to address climate change at the agency level and tools and methodologies necessary to develop assessments and adaptation strategies.

More specifically, Island Transit, Houston metro and the Hillsborough Area Regional Transit were provided additional benefits as case studies through the application of the outlined framework and methodologies.

| | X | X | X | X | X | X |
| Document Type | FTA pilot Planning Study |
| Intended Audience | Gulf Coast Transit Agencies |
| Abstract | This study was intended to provide Gulf Coast transit agencies a source of reference to address climate change within their agencies. This source of information includes a broad range of climate change research and potential and actual weather-related impacts to Gulf Coast communities. This report further provides agencies a framework to address climate change at the agency level and tools and methodologies necessary to develop assessments and adaptation strategies.

More specifically, Island Transit, Houston metro and the Hillsborough Area Regional Transit were provided additional benefits as case studies through the application of the outlined framework and methodologies. |
| Populations Referenced | Gulf Coast Transit Agencies |
| Topics Covered | • Background information regarding climate change and the effect climate change may have on Gulf Coast transit agencies;
  ○ A survey of agencies about past severity of various weather events is provided to support the report and transit agencies alike.
• A conceptual framework for planning and adapting to climate change outlined in a multiple step process;
• Tools for the use of developing vulnerability matrices and the establishment of policies and practices;
• Application of the framework and tools through the three case study examples of previous/ongoing adaptation strategies; and
• A “detailed methodology using GIS spatial data to assess climate change vulnerability of transit assets.” |
<p>| Type of Sponsoring Agency or Organization | Federally sponsored by FTA with consideration of many Gulf Coast agencies. |
| Geographic Distribution | The study area consists of the entire Gulf Coast from the Texas/Mexico Border to southern Florida. 17 agencies throughout this entire region were surveyed. Case Studies for specific agencies: Island Transit in Galveston Texas, METRO in Houston and Hillsborough Area Regional |</p>
<table>
<thead>
<tr>
<th><strong>Type of Transit Mode(s)</strong></th>
<th>Transit.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Vulnerability</strong></td>
<td>All</td>
</tr>
<tr>
<td><strong>Goals and Motivations</strong></td>
<td>Heat-high Days, Sea-level Rise/Flooding, Other (High Winds), Coastal Storm</td>
</tr>
<tr>
<td><strong>Context</strong></td>
<td>Gulf of Mexico coastal transit agencies and their constituents are especially vulnerable to natural hazards resulting from extreme heat, flooding, and high winds. Study was to provide benefit to three specific project member transit agencies and to compile practical information for all Gulf Coast transit agencies.</td>
</tr>
<tr>
<td><strong>Tools</strong></td>
<td>Framework with steps to conduct assessment. “The eight steps of the process are:</td>
</tr>
<tr>
<td></td>
<td>1. Identify current and future climate hazards.</td>
</tr>
<tr>
<td></td>
<td>2. Conduct inventory of transit assets.</td>
</tr>
<tr>
<td></td>
<td>3. Characterize risk of climate change impacts.</td>
</tr>
<tr>
<td></td>
<td>4. Develop initial adaptation strategies.</td>
</tr>
<tr>
<td></td>
<td>5. Identify opportunities for coordination.</td>
</tr>
<tr>
<td></td>
<td>6. Link strategies to organizational structures and activities.</td>
</tr>
<tr>
<td></td>
<td>7. Prepare and implement adaptation plans.</td>
</tr>
<tr>
<td></td>
<td>8. Monitor and reassess. “</td>
</tr>
<tr>
<td></td>
<td>o Step 1 “must” happen to create the adaptation plan. This report highlights the need to refresh climate change and projection data with updated information as science and new data becomes available.</td>
</tr>
<tr>
<td></td>
<td>o Step 2 provides an initial look at incorporating climate change into operations and capital planning.</td>
</tr>
<tr>
<td></td>
<td>o Step 3 provides the vulnerability assessment aspect to the framework where those using such a process will outline the severity and frequency of events.</td>
</tr>
<tr>
<td></td>
<td>o Step 4 should allow stakeholders to begin brainstorming adaptation options to include cost and timing of the adaptation. This will provide agencies the ability to compare options and prioritize adaptation strategies.</td>
</tr>
<tr>
<td></td>
<td>o Step 5 highlights the importance to coordinate with partners and stakeholders. Planning in stovepipe may cause missed opportunities to leverage in-kind interest and adaptation strategies. Furthermore, actions which may impact interdependent infrastructure needs to be addressed ahead of time.</td>
</tr>
<tr>
<td></td>
<td>o Step 6 brings the entire agency into the discussion through linking adaptation strategies to various organization components responsible for that strategy. The report states the best way to incorporate this agency wide is into the asset management system.</td>
</tr>
<tr>
<td></td>
<td>o Step 7 outlines the selected strategies into a comprehensive adaptation plan including resource commitments, “metrics to measure success”, timelines, and other aspects.</td>
</tr>
<tr>
<td></td>
<td>o Step 8 create a cyclical process whereas monitoring and reassessing the adaptation plan calls on a looking at the process all over again using new information as it becomes available and as initial adaptation strategies are implemented.</td>
</tr>
</tbody>
</table>

The study worked to have a broad scope to the entire Gulf Coast Region whereas a survey was sent to any urban transit agency with a headquarters within 100 miles of the Gulf of Mexico coastline. Therefore, the focus is on an urban transit system but with a variety of contextual variability. 20 respondents representing all Gulf Coast states responded and the result are provided in an appendix to the report. Respondents consisted of county agencies such as Lee County, Florida up to major metropolitan authorities such as Houston and New Orleans.
- Assessment matrices addressing impacts and consequence scoring. Two evaluation tools are identified and provided. Agency System-wide Evaluation and
  - Agency System-wide Evaluation consists of asking agency staff and stakeholders to think about weather events, the likelihood and severity of impacts and provide the form back to the study team. Follow-up detail is also asked regarding asset criticality, value, etc.
  - The second tool is a baseline assessment tool. This tool details a list of questions which may be asked by each agency department, though the list of questions is an example and may not include all information desired.
- The report briefly identifies the Climate Change Vulnerability Index (CCVI) methodology. This methodology is a way of scoring climate change risks through the development of composite spatial data layers. It’s a simplistic way of developing an index number normalized across climate change “dimensions” (e.g. hurricanes, rainfall, sea-level rise, temperature changes). The CCVI developed did not weight scores to limit bias interpretation but such complexities are available to users. The numbers result in the identification of the most likely climate change dimension to impact the study area.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>- This report identifies four categories of successful climate change adaptation. These four areas include “maintain and manage” which is the ability for a system to “absorb increased maintenance and repair costs and improve real-time response to severe event.” This category would support the post-event resiliency through the agency’s ability to quickly act and respond to limit impacts to the system. The second category is to “strengthen and protect. This category addresses new design standards to infrastructure and other agency resources with the ability to withstand climate change. Such actions may include retrofitting “existing structures and facilities” and to “build protective features” such as flood walls. The third category is “enhance redundancy.” This category identifies the alternative solutions to climate change impacts such as rerouting bus service or the establishment of bus bridges should impacts to rail asset occur. Overall, it provides a regional mobility and modal options should one mode be lost of any period of time. Finally, “retreat” is a suggested strategy to relocate facilities in vulnerable areas to areas less likely to be impacted from the risks identified.</td>
</tr>
<tr>
<td>- The assessment tools are clear and seem to be easily implemented across agencies if used properly. It would not take expertise to implement the tools unlike others which call for model runs. Of course, there may be some bias relying completely on surveys and questionnaires but there seems to be some benefits to conducting an assessment this way.</td>
</tr>
<tr>
<td>- The CCVI may provide agencies a way to quantify frequency as part of the vulnerability assessment piece to the framework. Using the spatial data, it provides a more science based result than perception results an agency may see through surveys and questionnaires of staff and stakeholders.</td>
</tr>
</tbody>
</table>
| - A summary of strategies identified by participating case study agencies include:  
  - “For routes frequently affected by flooding, identify standard re-routes and acquaint the public with the alternative alignments used if street flooding is present (low cost)”  
  - “Establish a method to record site and street flooding impacts to maintenance, facilities, and service delivery for use during future planning processes (low/medium cost).”  
  - “Use operators as eyes on the street; informing community public works departments of blocked storm drains and other drainage issues (low cost). In addition, transit agency management can actively engage in local/regional drainage planning (low |
o “Plan for and setup contracts for staff meals, hotels for employee sleep quarters, street clearing equipment and services, and safe parking for the vehicle fleet (all require low, periodic investment to establish and maintain contracts).”

o “Identify core bus routes that serve emergency medical facilities, evacuation centers, and other critical first-response locations, ensure contracts for route clearing assistance focus on core routes (low cost).”

o “Arrange to accommodate fueling needs during storm recovery, including fuel reserves and established contracts and practices to maintain fuel availability, as well as the ability to get fuel to wherever vehicle fleet may be located during recovery (low to high cost).”

o “Identify and disseminate clear information internally and to stakeholders about key personnel during emergency operations and an order of succession in case a key individual becomes unavailable (low annual cost, due to planning).”

o Specific to HART.

<table>
<thead>
<tr>
<th>Adaptation Strategy/Practice</th>
<th>Relative Cost to Implement (Low, Medium, or High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities should have at least one access/egress route not prone to flooding</td>
<td>Medium</td>
</tr>
<tr>
<td>Participate in local and regional planning processes for flood mitigation projects when project lists may impact agency’s drainage at facilities</td>
<td>Low</td>
</tr>
<tr>
<td>Use agency and management operations experience to identify flood-prone route segments and then identify standard/preferred alternatives or procedures</td>
<td>Low</td>
</tr>
<tr>
<td>Educate riders about agency policies using public service announcements and operator/ rider dialogue</td>
<td>Low</td>
</tr>
<tr>
<td>Identify standard operating procedures to reduce impact of street flooding on vehicle maintenance (i.e., slow speeds, avoid known trouble areas), agency property (i.e., passenger amenities), private property (i.e., reducing vehicle speed to limit forcing water up onto/into private property)</td>
<td>Low</td>
</tr>
<tr>
<td>Think about local occurrences, such as sinkholes in Florida, and create similar mantras as HART has: “If you can’t see the road through the standing water, don’t drive across it.” Establish a method of recording useful information to quantify impacts of site/street flooding on facilities, vehicle maintenance, and operating costs to inform future decisions (i.e., such as deciding between plywood floors vs. water resistant material).</td>
<td>Low</td>
</tr>
<tr>
<td>Establish method of recording useful information to quantify impacts of street flooding on facilities, vehicle maintenance, and operating costs to inform future decisions.</td>
<td>Low</td>
</tr>
</tbody>
</table>

o Specific to Island Transit

<table>
<thead>
<tr>
<th>Adaptation Strategy/Practice</th>
<th>Relative Cost to Implement (Low, Medium, or High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure all new operations/vehicle maintenance facilities are outside 100-year floodplain or at another higher level of flood resistance, such as 500-year floodplain.</td>
<td>Low (not always feasible, depends on jurisdiction, alternative is elevate vehicles)</td>
</tr>
<tr>
<td>If not possible to construct key facilities in naturally-safe locations, transit agency should design site plan with buildings raised sufficiently high as to avoid all foreseeable flood risk.</td>
<td>High</td>
</tr>
<tr>
<td>Work with public works departments from local jurisdictions to ensure that storm sewers for flood prone areas are kept clear; transit operators can help to spot problems early as they have more eyes on streets.</td>
<td>Low</td>
</tr>
<tr>
<td>Use agency and management operations experience to identify flood-prone route segments and then identify standard/preferred alternatives or procedures.</td>
<td>Low</td>
</tr>
<tr>
<td>When possible, educate riders about typical reroutes or agency procedures using route brochures, public service announcements, and operator/rider dialogue.</td>
<td>Low</td>
</tr>
<tr>
<td>Identify standard operating procedures to reduce impact of street flooding on vehicle maintenance (i.e., slow speeds, avoid known trouble areas), agency property (i.e., passenger amenities), private property (i.e., reducing vehicle speed to limit forcing water up onto/into private property).</td>
<td>Medium</td>
</tr>
<tr>
<td>Establish method of recording useful information to quantify impacts of street flooding on facilities, vehicle maintenance, and operating costs to inform future decisions.</td>
<td>Medium</td>
</tr>
</tbody>
</table>
### Specific to Houston METRO (Focus on Hurricane/Tropical Storm)

<table>
<thead>
<tr>
<th>Subject Area / Adaptation Strategies and Practices</th>
<th>Relative Cost to Implement (Low, Medium, or High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Communications Regarding Service Cut-off Times</td>
<td>Low</td>
</tr>
<tr>
<td>Establish clear-cut-off times for service when bracing for a storm.</td>
<td></td>
</tr>
<tr>
<td>Communicate cut-off times to stakeholders, especially local decision-makers, because agency gets a poor reputation with media and public when agency personnel provide different cut-off time than provided by local politicians.</td>
<td></td>
</tr>
<tr>
<td>Contracts in Place (important to have certain contracts set up in advance of a storm)</td>
<td>Low (periodic)</td>
</tr>
<tr>
<td>METRO set up contracts with restaurants on west side of town for catering services for METRO staff during emergencies.</td>
<td></td>
</tr>
<tr>
<td>METRO set up contracts with local hotels for employees working at George R. Brown Center (hub for evacuation operations) to rest and sleep in.</td>
<td></td>
</tr>
<tr>
<td>METRO set up contract with KER for industrial equipment to clear core bus routes as needed.</td>
<td></td>
</tr>
<tr>
<td>METRO set up agreement with City of Houston Public Works to clear streets on core bus routes.</td>
<td></td>
</tr>
<tr>
<td>METRO Police setup agreement with UH Downtown to park vehicles in garages to protect from the storm.</td>
<td>Low</td>
</tr>
<tr>
<td>Bank Accounts</td>
<td></td>
</tr>
<tr>
<td>METRO set up separate internal accounts for emergency response expenses. When event occurs, agency transfers money into these accounts and emergency items are charged to these accounts.</td>
<td>Low</td>
</tr>
<tr>
<td>METRO established cash fund, maintained by finance department, for use during emergency events.</td>
<td>Medium</td>
</tr>
<tr>
<td>Community Support</td>
<td></td>
</tr>
<tr>
<td>METRO under contract to provide 30 buses to help evacuate Galveston during off-peak hours.</td>
<td>Low</td>
</tr>
<tr>
<td>Safe and Secure Schools and METRO learned to assist City of Houston and Harris County during evacuations.</td>
<td>Low</td>
</tr>
<tr>
<td>METRO considers building relationships within community as critically important to preparing for emergency events and make sure everyone is “on the same page” related to METRO’s role.</td>
<td>Low</td>
</tr>
<tr>
<td>Fuel Availability and Procurement (during recovery fuel availability may be an issue)</td>
<td></td>
</tr>
<tr>
<td>METRO has agreement for priority fuel pickup at Shell during evacuations, important as evacuations as people fill up their vehicles and fuel becomes scarce.</td>
<td>Low</td>
</tr>
<tr>
<td>Fuel in all METRO facilities is topped off at 95% capacity before occurrence of a known emergency event, such as a hurricane.</td>
<td>Low</td>
</tr>
<tr>
<td>METRO purchased three tankers and two tractor trucks designed to pull these tankers. Prior to an emergency event, these tankers are filled with fuel and staged at various facilities.</td>
<td>High</td>
</tr>
<tr>
<td>After an emergency event, fuel is tracked hourly and replenished as follows: METRO has priority at fuel rack and utilizes only third party delivery service or its own tankers to pull fuel from the rack to replenish operating facilities.</td>
<td>Low</td>
</tr>
<tr>
<td>METRO also has leased fuel storage capacity on an offsite terminal facility.</td>
<td>Medium</td>
</tr>
<tr>
<td>METRO Police provide accords to fuel deliveries as necessary.</td>
<td>Low</td>
</tr>
<tr>
<td>Interoperable Communications</td>
<td></td>
</tr>
<tr>
<td>METRO’s Service Delivery department maintains satellite phones for emergency communications if their radio and phone systems become inoperable.</td>
<td>Medium</td>
</tr>
<tr>
<td>METRO Police, METRO Rail and METRO bus operations operate their radios through Harris County’s Regional Radio System.</td>
<td>Medium</td>
</tr>
<tr>
<td>METRO participates with the rest of the region in using WebEOC for intra-agency communications during emergency events.</td>
<td>Low</td>
</tr>
<tr>
<td>Order of Succession and Delegation of Authority</td>
<td></td>
</tr>
<tr>
<td>METRO identified its key personnel for emergency operations.</td>
<td>Low (annual price)</td>
</tr>
<tr>
<td>METRO identified an order of succession in case a key individual becomes unavailable.</td>
<td>Low (by emergency manager)</td>
</tr>
</tbody>
</table>

### Captivating Value

The following quote shows how wide of a net that needs to be cast to be sure climate adaptation is being considered holistically. —

“Common types of plans or documents that do or can pertain to climate change adaptation at Gulf Coast transit agencies include, but are not limited to, the following:

- Emergency management plans
- Risk improvement plans
- Catastrophe risk analysis
- Sustainability plans
- Continuity of operations plans
<table>
<thead>
<tr>
<th>Decision Question</th>
<th>Transit Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance</td>
<td>Scope of climate change</td>
</tr>
<tr>
<td></td>
<td>Provides an overview of Gulf Coast impacts and projections but furthers the importance of scoping the impacts through the first step of the framework developed.</td>
</tr>
<tr>
<td></td>
<td>Assessing climate risks</td>
</tr>
<tr>
<td></td>
<td>Report defines a framework for addressing climate change which could be applied nationally even though the reports intended audience is the Gulf Coast.</td>
</tr>
<tr>
<td></td>
<td>Provides methods for assessing vulnerabilities.</td>
</tr>
<tr>
<td>Integration of climate adaptation into standard business practices.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outlines steps in the framework forcing agency cooperation where without input form varying departments on risks and vulnerabilities and well as assigned responsibilities for adaptation, the efforts would be for not.</td>
</tr>
<tr>
<td>Status</td>
<td>Available for use by other transit agencies.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Overall, the report is a high-level outline of the things to think about when an agency is looking to incorporate climate change adaptation into business practices. The report provides easy to understand and use assessment tools and a framework that requires continuing planning and discussions throughout the agency.</td>
</tr>
<tr>
<td></td>
<td>Chapters 1 through 3 generally review the background on risk assessments and the literature review conducted as part of the project. Chapter 3 outlines a conceptual framework that many of the reports follow. The results from the literature search highlight the need for updated design standards and to conduct further research into longer term horizons as a place to implement adaptation to infrastructure. It also highlights general land-use issues, technological needs and impacts to operations. Chapter 4 provides a basic assessment outline while Chapters 5-7 outline case studies with limited information. Chapter 7 specifically focuses on response and recovery. Chapter 8 highlights the need to understand spatial asset vulnerability and more localized predictions as far as sea-level rise. Chapter 9 reviews the vulnerabilities and potential impacts. Chapter 10 provides a crash course on how GIS may be used to get to the CCVI score.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>Case studies examples going through some of the methodologies described include:</td>
</tr>
<tr>
<td></td>
<td>1. Island Transit – Galveston, TX</td>
</tr>
<tr>
<td></td>
<td>2. Hillsborough Area Regional Transit (HART) – Tampa Bay, FL</td>
</tr>
<tr>
<td></td>
<td>These case studies seemed that each agency was approached as part of this research effort to discuss issues they encounter and to identify some adaptive measures they may look at. Each</td>
</tr>
</tbody>
</table>
case study provides business practices as well as standards and infrastructure design recommendations.

3. Houston Metro – Houston TX (Chapter 7 focuses specifically on tropical storm and hurricanes. Seems to focus primarily on disaster recovery.)

<table>
<thead>
<tr>
<th>Essential Vocabulary</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential Keywords</td>
<td>Climate Change</td>
</tr>
<tr>
<td></td>
<td>Gulf Coast</td>
</tr>
<tr>
<td></td>
<td>Climate Change Vulnerability Index</td>
</tr>
<tr>
<td></td>
<td>CCVI</td>
</tr>
<tr>
<td></td>
<td>Case Study</td>
</tr>
<tr>
<td></td>
<td>Natural hazards</td>
</tr>
<tr>
<td></td>
<td>Gulf Coast transit</td>
</tr>
<tr>
<td></td>
<td>Emergency transportation</td>
</tr>
<tr>
<td></td>
<td>Asset management</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source
N/A

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Pilot study research report.

### Intended Audience
Policy makers, internal staff, coordinating agencies and practitioners, especially other transit agencies.

### Abstract
In the beginning, metro states that the Pilot will build upon their existing work: “Climate Action and Adaptation Plan (CAAP) and Environmental Management System (EMS), and asset management systems—the Environmental Information Management System (EIMS) and the Maintenance and Materials Management (M3)” (p. 1) The EMS will become the document to integrate the Pilot recommendations throughout Metro, where appropriate. (p. 2). Because of Metro’s early and continuing efforts in the above stated areas, Metro’s Pilot builds upon its earlier efforts and proposes that the Pilot “goes beyond the issue of identifying risks and proposes viable implementation strategies to incorporate climate adaptation into established programs and initiatives within the agency.” (p. 1) By doing so Metro hopes that there will be a new synergy among the various early separate work efforts and the Pilot. (p. 2) Metro asks a critical asset question: “If this service or asset were removed from the transit system, would the transit system be fundamentally different?” (p. 8) Answering this fundamental question should have value for all Climate Management Plans.

### Populations Referenced
Los Angeles Metropolitan Area and Metro customers

### Topics Covered
Executive Summary  
Section 1: Metro Background  
Section 2: FTA Pilot Program Background and Objectives  
Section 3: Metro Pilot Project Summary  
- Background  
- Metro’s Climate Change Adaptation Pilot Overview  
- EMS Integration/Asset Management  
- Metrics Development  
- Outreach Strategies and Climate Adaptation Roundtable  
Section 4: Lessons Learned  
Section 5: Next Steps  
Appendix A: Los Angeles Metro Survey  
Appendix B: EMS Integration/Asset Management Report  
Appendix C: Metric Development Report  
Appendix D: Outreach Elements

### Type of Sponsoring
FTA sponsored the pilot and study report.
“Metro is the state-chartered Regional Transportation Planning Agency (RTPA) and public transportation agency for Los Angeles County (California). Metro serves as the transportation planner and coordinator, designer, builder, and operator for Los Angeles County. The county has the largest population among all counties in the United States (about 9.8 million people, which represents about 26% of the total population of California). Los Angeles County’s population would make it equivalent to the ninth largest state in the country, just behind Michigan. It includes people from 140 countries that live and work in 88 cities and unincorporated areas. Metro’s service is essential for meeting the travel needs of people with very diverse socioeconomic and demographic backgrounds. According to the 2010 U.S. Census, the demographic profile of Los Angeles County consists of 47.7 percent Hispanic, 27.8 percent White, 13.7 percent Asian-Pacific Islander, 8.3 percent African-American, and 2.5 percent people from other ethnic groups. Metro’s service area is currently 1,433 square miles (35% of the area of Los Angeles County) and is located within the Los Angeles-Long Beach-Santa Ana Urbanized Area (UAZ). “ (p. 4)

“The services that Metro provides include heavy rail (Red Line and Purple Line), light rail (Blue Line, Gold Line, Green Line, Expo Line), and bus service (local, limited, express, shuttles and circulators). Metro also operates Bus Rapid Transit (BRT) service (Metro Rapid, Orange Line, Silver Line) and a vanpool program. It also provides funding for local and highway improvement projects as well as subsidy for commuter rail and other municipal transit service.” (p. 4)

Weather vulnerabilities, (e.g. High Temperatures, Wind, Severe Rain Storm Events, Coastal Storms, Flooding/Sea-level Rise, and reference to Dust Storms and Wildfires)

“The key components of the project include the following:

- Task 1: Development and implementation of a plan for the integration of adaptation principles into Metro’s Environmental Management System (EMS) that can be applied agency wide.
- Task 2: Development of a tool or modification of an existing software application to evaluate and track climate risks associated with Metro’s fixed and rolling assets.
- Task 3: Development of adaptation set of metrics to measure and assess Metro’s progress in addressing adaptation.
- Task 4: Development of an outreach plan to create internal and external stakeholder awareness of Metro’s adaptation efforts.

The goal is for “these results can be used by other agencies as deemed appropriate.” (p. 15)

“The FTA pilot projects (of which Metro is one) were chosen to advance the state of the practice for incorporating climate change and extreme weather considerations into existing decision-making paradigms and, ultimately, improving the resilience of transit assets and services to the impacts of climate change. These pilots, which focus on climate-related risks, are being conducted in the context of long-term goals to address state of good repair needs and enhance transit safety.” Prior to the natural disaster there was an Asset Management System, Operation and Maintenance system, and levels of resilience planning in place. However, these system plans are currently ongoing and evolving measuring up to a state of good repair.

Metro has a wealth of plans and studies. Metro’s M3 product was chosen to be an integrator for this Pilot.

“Metro’s M3, is a commercial-off-the-shelf (COTS), fully integrated public transit Enterprise Asset Management software suite. It is designed to integrate with commonly-used transit systems such as fuel and fluids management, automated vehicle location (AVL), human resources, finance, and procurement. The technical design is multi-tier client/server that allows access from all Metro locations to a central data system. Its reporting capabilities track Metro’s key performance

<table>
<thead>
<tr>
<th>Agency or Organization</th>
<th>Geographic Distribution</th>
<th>Type of Transit Mode(s)</th>
<th>Type of Vulnerability</th>
<th>Goals and Motivations</th>
<th>Context</th>
<th>Tools</th>
</tr>
</thead>
</table>
| Metro | “Metro is the state-chartered Regional Transportation Planning Agency (RTPA) and public transportation agency for Los Angeles County (California). Metro serves as the transportation planner and coordinator, designer, builder, and operator for Los Angeles County. The county has the largest population among all counties in the United States (about 9.8 million people, which represents about 26% of the total population of California). Los Angeles County’s population would make it equivalent to the ninth largest state in the country, just behind Michigan. It includes people from 140 countries that live and work in 88 cities and unincorporated areas. Metro’s service is essential for meeting the travel needs of people with very diverse socioeconomic and demographic backgrounds. According to the 2010 U.S. Census, the demographic profile of Los Angeles County consists of 47.7 percent Hispanic, 27.8 percent White, 13.7 percent Asian-Pacific Islander, 8.3 percent African-American, and 2.5 percent people from other ethnic groups. Metro’s service area is currently 1,433 square miles (35% of the area of Los Angeles County) and is located within the Los Angeles-Long Beach-Santa Ana Urbanized Area (UAZ). “ (p. 4) | “The services that Metro provides include heavy rail (Red Line and Purple Line), light rail (Blue Line, Gold Line, Green Line, Expo Line), and bus service (local, limited, express, shuttles and circulators). Metro also operates Bus Rapid Transit (BRT) service (Metro Rapid, Orange Line, Silver Line) and a vanpool program. It also provides funding for local and highway improvement projects as well as subsidy for commuter rail and other municipal transit service.” (p. 4) | Weather vulnerabilities, (e.g. High Temperatures, Wind, Severe Rain Storm Events, Coastal Storms, Flooding/Sea-level Rise, and reference to Dust Storms and Wildfires) | “The key components of the project include the following:

- Task 1: Development and implementation of a plan for the integration of adaptation principles into Metro’s Environmental Management System (EMS) that can be applied agency wide.
- Task 2: Development of a tool or modification of an existing software application to evaluate and track climate risks associated with Metro’s fixed and rolling assets.
- Task 3: Development of adaptation set of metrics to measure and assess Metro’s progress in addressing adaptation.
- Task 4: Development of an outreach plan to create internal and external stakeholder awareness of Metro’s adaptation efforts.

The goal is for “these results can be used by other agencies as deemed appropriate.” (p. 15) | “The FTA pilot projects (of which Metro is one) were chosen to advance the state of the practice for incorporating climate change and extreme weather considerations into existing decision-making paradigms and, ultimately, improving the resilience of transit assets and services to the impacts of climate change. These pilots, which focus on climate-related risks, are being conducted in the context of long-term goals to address state of good repair needs and enhance transit safety.” Prior to the natural disaster there was an Asset Management System, Operation and Maintenance system, and levels of resilience planning in place. However, these system plans are currently ongoing and evolving measuring up to a state of good repair. | Metro has a wealth of plans and studies. Metro’s M3 product was chosen to be an integrator for this Pilot.

“Metro’s M3, is a commercial-off-the-shelf (COTS), fully integrated public transit Enterprise Asset Management software suite. It is designed to integrate with commonly-used transit systems such as fuel and fluids management, automated vehicle location (AVL), human resources, finance, and procurement. The technical design is multi-tier client/server that allows access from all Metro locations to a central data system. Its reporting capabilities track Metro’s key performance |
Indicators, and the system includes a search engine for ease of use, searching, and printing reports. M3 supports asset management, inventory, and warehouse management, as well as bus, rail, and facilities maintenance. It is integrated with Metro’s purchasing and financial systems to create a seamless environment and eliminate duplication of data. The system uses and resides on computer hardware accessible at all Metro locations. ...Metro’s case study through this project shows how Metro and any transit agency can address asset risk from climate change by identifying the criticality and vulnerability of assets over time, using Metro’s EMS Adaptation Plan and Metro’s M3 as a template. Building on Metro’s ISO 14001:2004-certified EMS and CAAP at the Red Line Yard (RLY), First Environment developed a methodology to screen for the assets at risk. In particular the methodology provides a tool for a transit agency to:

- Identify assets
- Screen assets for criticality
- Screen assets for vulnerability to precipitation, heat, and wind
- Screen for indicator of risk over time – rate of change
- Assess the risk on the asset” (p. 24-25)

Metro then screened for asset criticality and vulnerability.

“Metro worked alongside the Urban & Environmental Policy Institute (UEPI) at Occidental College to determine key metrics that the agency could use to track its progress of implementing any adaptation strategies... There were 109 possible metrics generated through the literature review, related research, and discussions with various Metro departments and staff. The metrics fall into four categories: Planning, Operations, Adaptation, and Riders.” (p. 31-32)

The 109 possible metrics were reduced to 20 and then 7. The 7 metrics are:

1. “Has vulnerability assessment been conducted?
2. Have adaptation actions been prioritized?
3. Have vulnerable assets been mapped with transit-dependent and low-income populations?
4. Number of injuries/medical emergencies to workers and riders by temperature and rainfall.
5. Does the agency have overheating standards for public transport facilities and rolling stock?
6. Capacity to monitor weather and temperature conditions in real time at key locations in service area.
7. Extreme weather impacts on service delays and cancellations.” (Page 33)

“These metrics serve to:

- Determine the completeness of Metro’s current climate mitigation and adaption efforts
- Identify the extent of implementation of Metro’s mitigation and adaption strategies
- Indicate the level of employee and customer consideration in the implementation of such strategies
- Understand and monitor the extent of EMS implementation and integration efforts that need to be performed
- Gauge the agency’s engagement and commitment for continual improvement as a function of its core mission of moving people safely and reliably regardless of external potentially impactful conditions” (p. 33)
<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>Metro has taken initiative to understand parts of resiliency and sustainability by analyzing various other plans and documents assembled by several distinct entities that, too often, were stand-alone documents. Their effort was to integrate the various documents and plans to achieve a more universal approach/plan. One of the future take always from the Pilot is to use the Pilot for a “Climate Adaptation Roundtable.” “The audiences targeted include the Metro Board of Directors, elected officials, and service area residents, as well as transit-dependent riders and discretionary riders. Metro staff will use this messaging strategy when developing outreach materials to aid in developing appropriate and relevant messaging techniques to particular audiences.” (p. 35) “Creation of a Metro Climate Adaptation Webinar with a focus on: Building off of the roundtable discussion to share additional information on Metro’s climate efforts • Identifying and outlining existing and forthcoming policies, programs, and resources available to transportation agencies for climate adaptation planning • Creating an accessible forum to increase audience engagement and participation.” (P. 41-42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captivating Value</td>
<td>The project design was to integrate the various public documents with respect to climate adaptation. This is an important approach as many public agencies have multiple plans, regulations, studies that end up being siloed documents. An integrated approach makes more sense.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>“If this service or asset were removed from the transit system, would the transit system be fundamentally different?” (p. 8)</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Metro and their reports and plans, political leaders, and regional organizations.</td>
</tr>
<tr>
<td>Relevance</td>
<td>LA Metro is one of the major transit systems in the United States located in a region that is and will continue to be affected by extreme weather and natural events, such as earthquakes. This has required the region and the public sector to develop plans. Assembling literature to illustrate the relationship between plans and integrating them with respect to climate adaptation is an important approach that may be duplicated elsewhere. “One of the project’s key objectives was to develop valuable messaging strategies for communicating to various audiences (i.e., internal staff, external agencies, private investors, elected officials, county residents, and riders) on how Metro is preparing for climate change and severe weather impacts and how each of these stakeholders may help Metro to prepare for and mitigate these impacts.” (p. 2) The development of the metrics and the reduction from 109 to 7 has value in terms of decision-making approach. The recognition of customers. Unfortunately customers are not a focus in the Pilot and it really isn’t until Section 5 that Next Steps customers reemerge in a post-pilot plans. (p. 44-45) Recognition of the importance of employee buy-in and that it takes a great deal of effort. (p. 43) as staff has many immediate issues and problems to address. For Metro the Pilot effort also revealed an unexpected correlation: “independent research by Metro staff found a correlation between weekly temperature averages and weekly bus breakdown averages, even with preventive maintenance. While this challenge was not critical to the success of the project, it is an ongoing issue that Metro staff will continue to address. (p. 43) “A regional approach to adaptation is needed, but coordination and resources to facilitate this dialogue remain a challenge.” (p. 44)</td>
</tr>
<tr>
<td>Status</td>
<td>The pilot is complete, recommendations and action steps have been identified.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>N/A</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>• There is no financial analysis to assist in the prioritization of climate adaptation- they could learn a great deal from the SEPTA approach.</td>
</tr>
</tbody>
</table>
Customers are basically an afterthought as they are in the 7 Pilots. I think this is unfortunate. If one starts with the customer and assess their needs in climate change, there is likely to be some different priorities. For example for Metro bus shelters and station or their lack: a 95 F degree requires bus patrons to have adequate shelters. Metro O&M staff are rightly concerned about A/C on the buses, but is an at-risk transit-dependent person has no protection then Metro starts with a bigger cooling problem Shelters and stations are also critical with respect to heavy rainfall and flooding. Are the shelters and stations in flood zones? Can customers get to them safely? FTA and Metro are concerned about the large capital projects and equipment. Unfortunately shelters are not significant enough.

The report is more of a policy platform and self promotion then an implementation document.

Metro undertook a survey of their regional operation and maintenance employees, asking them about their responses and mitigation of climate impacts. Appendix A provides the survey and response. It is very revealing. Flooding, A/C and power are major concerns, but the body of the document hardly mentions the concerns. Fueling stations underwater will have long-term consequences for getting service restored.

There are no performance measures for the metrics and no indication of what happens if the climate goals are not met. It is unclear who is responsible for implementing this program.

No mention of addressing on Demand services and how they and staff may be affected by severe weather.

No effort to create weather event coding so that Metro will have a better understanding of their full costs and not simply labor and capital assets.

Metro basically dismissed sea-level changes and surge because the overwhelming numbers of services are not affected. Sea-level changes could have domino impacts on the more inland communities.

Little recognition is given that climate adaption requires a community response, other than to indicate in the Next Steps that regional approach remains an issue. However, the Report did not indicate that they sought to integrate their EMIS with the communities Emergency Management System or with non-profits. Major emergencies affect whole communities and each agency has a critical part to play in order to effectively manage the emergency.

The Report was too dense and requires the reader to have an understanding of past and current policies and documents to fully understand the Report material. Furthermore, the Report spends considerable time praising Metro and how they are national leaders on the environment etc. It is an appeal to authority that does not work here.

No training and no apparent response to the survey responses provided in Appendix A.

No use of social; media and telecommunications as part of their solutions, even in emergencies. In fact technology is extremely limited in the conversation.

<table>
<thead>
<tr>
<th>Essential Vocabulary</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential Keywords</td>
<td>N/A</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Planning Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended Audience</td>
<td>Transit Agencies and policy drivers.</td>
</tr>
</tbody>
</table>

**Abstract**

“Evaluate the impacts of climate change on the San Francisco Bay Area Rapid Transit District (BART) infrastructure and to develop and implement adaptation strategies against those impacts. Climate change hazards considered are sea-level rise, downpours, and flooding. The study focuses on four specific types of assets: station and maintenance facilities, track and aerial structures, train control, and traction power. Adaptation strategies are developed and linked to various departments within the organization.” (p. iii)

The report provides tools used to develop a risk assessment, prioritize adaptation strategies based on cost/benefit analysis and a life-cycle cost analysis. It further provides linkages of adaptation strategies to departments within the transit agency thereby initiating the incorporation of climate adaptation into business practices.

<table>
<thead>
<tr>
<th>Populations Referenced</th>
<th>Executives, planners, designers &amp; engineers, emergency managers &amp; responders, maintenance managers &amp; staff, and asset managers &amp; staff</th>
</tr>
</thead>
</table>

**Topics Covered**

- Climate Adaptation Assessments using Climate Hazard Scenarios
  - Vulnerability & Risk Assessment
- Addressing specific rail infrastructure such as station & maintenance facilities, track & aerial structure, train control and traction power
- Adaptation Strategies
- Organizational Structure & Activities
- Asset Management and Life-Cycle Cost Analysis

**Type of Sponsoring Agency or Organization**

Regional made up of county and city jurisdictions sponsored by Federal

**Geographic Distribution**

San Francisco/Oakland, CA Region

The project study area focuses on the East Bay coastline of the San Francisco Bay Area. The project study area spans from West Oakland to Hayward.

**Type of Transit Mode(s)**

Heavy Rail

**Type of Vulnerability**

Severe Storm Events, Flooding/Sea-level Rise

**Goals and**

The purpose of this report was to analyze available data to determine the potential impacts from...
| Motivations | climate change. Once outlined, adaptation strategies are to be developed and linked to the various departments at BART. Evaluate the impacts of climate change on the San Francisco Bay Area Rapid Transit District (BART) infrastructure and to develop and implement adaptation strategies against those impacts. |
| Context | Focused on Heavy Rail |
| | BART is a special governmental agency created by the State of California consisting of Alameda County, Contra Costa County, and the City and County of San Francisco. San Mateo County, which hosts six BART stations, is not part of the BART District. It is governed by an elected Board of Directors with each of the nine directors representing a specific geographic area within the BART district. BART operates 209 miles of heavy rail fixed guideway with up to 666 vehicles available as of 2013 (per the National Transit Database). Other assets include stations and maintenance yards, tracks including areal, with train control and power traction needs which is the focus of this report. Funding availability has created limitations but other strategies which require limited funding such as business practices and agency coordination was identified as immediate options with limited funding needs. Currently, the agency estimates that “$6B in investments over the next 10 years to maintain good performance and bring these assets into an acceptable or normal state of good repair. If funding levels are not changed, this number is expected to grow by an estimated 30 percent over the next 10 years.” (p. 80) |
## Tools

- Repeatable methodology for evaluating and assessing assets vulnerability and risks. The approach defines risk criteria such as likelihood of events for the events studied and consequence and places these definitions into a risk matrix. It provides an interesting approach whereas each scenario has its own set of probability definitions.
  - The consequence scales provided fit across all hazards and focuses on two concepts: repair costs to physical damage and revenue service downtime. These two consequence definitions are combined to provide a single output score for consequence.
- Provides a prioritization of adaptation strategies based on cost and benefits.
  - In a similar manner to risk assessment, the report outlines a matrix which place cost and benefits along the two axis. Each strategy was characterized as have low, medium or high cost and benefit and a corresponding score was assigned. Benefit scores were “determined by calculating the difference between the baseline risk score and the residual risk score.” (p. 59) The residual risk score is developed by staff opinion and is defined as the “risk after implementation of the adaptation strategy.” (p. 32) Costs were assigned “based on interpolations from projects of similar scope and scaled” (p. 58) inventoried at BART. To support decision makers, a time scale was also provided as part of the output with the cost-benefit score to help decision makers.
- Provides framework for Life-Cycle Cost Analysis
  - This particular LCCA considers climate adaptation “and the operations and maintenance activities that would reduce risk to the asset over the life cycle thereby improving asset and system resiliency. Adaptive maintenance and operations activities would reduce risks to performance and safety and extend service life. Similarly, adaptive capital improvement activities are expected to not only reduce risks but also O&M costs. The O&M activities (as well as capital work) would be designed to reduce the impact of time on condition and hence treatment cycles (see Figure 6-2).” (p. 84) A framework based on US DOT LCCA methodology is outlined as follows: (p. 84)

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Establish alternative scenarios</td>
</tr>
<tr>
<td>Step 2</td>
<td>Determine activity timing</td>
</tr>
<tr>
<td>Step 3</td>
<td>Estimate costs (agency and user)</td>
</tr>
<tr>
<td>Step 4</td>
<td>Compute life-cycle costs</td>
</tr>
<tr>
<td>Step 5</td>
<td>Analyze the results</td>
</tr>
</tbody>
</table>

- Step 1 assumes an asset has already been selected and a list of alternative adaptation measures is ready for analysis though both an adaptive scenario and a scenario in which the adaptation does not occur. (p. 85)
- Step 2 requires the agency to select maintenance schedules and the length of time each of the scenarios should play out in terms of lifetime design.(p. 85)
- Step 3 is the development of costs estimates based on both direct and indirect costs.(p. 85)
- Step 4 involves computing life-cycle costs while keeping the valuation of a dollar in mind.(p. 86)
- Step 5 is the final step in which an analysis is conducted to determine if adjustments to the adaptation strategies need to be made or if move forward with the final recommendation of action.(p. 86)
<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A risk assessment was done on each of the four BART assets and was generally based on guidance from ISO 31000: 2009 Risk Management—Principles and Guidelines</td>
</tr>
<tr>
<td>• The adaptation strategies are aimed at increasing the resiliency of the assets and realign BART’s business practices to better respond to the climate change impacts. These adaptation strategies fall into one of four categories: Land Use and Planning, Design and Construction, Operations, and Maintenance. A complete list of the 35 potential strategies reviewed is included in Appendix B-1. (Pg. 146 of the pdf.)</td>
</tr>
<tr>
<td>• Provides a framework for comparatively evaluating the costs to implement adaptive strategies on a life-cycle basis. Using a case study example, the framework is applied on a programmatic level to inform prioritization and budgetary decision-making processes.</td>
</tr>
<tr>
<td>• “Education (Op7) is a critical element to mainstreaming a successful climate change adaptation program. By increasing awareness and informing employees of the climate change impacts and adaptation strategies, they will be able to assist and take responsibility in achieving strategy objectives. Because climate change adaptation strategies connect with different business functions, staff will have different educational needs.” (p. 69)</td>
</tr>
<tr>
<td>• The report briefly outlines roles executives, planners, designers &amp; engineers, emergency managers &amp; responders, maintenance managers &amp; staff, and asset managers &amp; staff play in climate change adaptation. Activities such as simply putting this section of the report together have created discussions within the organization on the topic of climate change.</td>
</tr>
<tr>
<td>o Staff general responsibilities are as follows:</td>
</tr>
<tr>
<td>▪ “Executive managers—allocate resources and funding to adaptation efforts</td>
</tr>
<tr>
<td>▪ Planners—inclusion of climate change in the planning phase</td>
</tr>
<tr>
<td>▪ Designers and engineers—modifications to BFS and design approach</td>
</tr>
<tr>
<td>▪ Emergency managers and responders—response to catastrophic storm event scenarios</td>
</tr>
<tr>
<td>▪ Maintenance managers and staff—modifications to maintenance protocols</td>
</tr>
<tr>
<td>▪ Asset management managers and staff—climate change considerations in the asset management program” (p. 69)</td>
</tr>
<tr>
<td>o Under Outreach and Education, all departments will have assigned responsibility to implement climate change adaptation.</td>
</tr>
<tr>
<td>o Under Land Use and Planning, the planning department will need to incur added responsibilities including the considerations of climate change in future planning and to coordinate with partners with other ongoing efforts which may impact the agency. Finally, the department will need to seek funding for such planning efforts which will take climate change into consideration.</td>
</tr>
<tr>
<td>o Under Design and Construction, the Bart Facility Standards, which address environmental design and sustainability, architecture, civil, electrical, mechanical, electronics, and structural standards, will all need to be updated to take climate change into consideration. However, at this time, BART is not under taking this effort and changes will be limited to the results of this study. The changes in the study outline changes to station entrance design, track portal design, train control room design, and traction power substation design.</td>
</tr>
<tr>
<td>▪ Any change to standards requires review by committee and further education on climate change and adaptation strategies may be required for such meetings and tasks.</td>
</tr>
<tr>
<td>o Under Operations, the department responsible for emergency plans and response are required to revise plans with respect to climate change. One item to address is communication with flood control districts that may have additional information on historical and real-time data and trends. Additionally, the agency is to look into technological improvements such as early warning systems to support the operations</td>
</tr>
</tbody>
</table>
branch.

- Under Maintenance, implementation of storm drain maintenance program is identified as well as maintenance programs related to equipment. Finally, maintenance and engineers alike will be required to update the criteria used to evaluate projects so that it reflects climate change as a priority.

- Additionally, the asset management team will be responsible for incorporation of climate change into the asset registry and coordinate activities with stakeholders and regional entities on best practices for making such changes. Chapter 6 dives heavily into asset management and where adaptation can fit into the system at an enterprise level. Opportunities at the enterprise level are identified in the below table which includes status of efforts undertaken by BART. (p. 82)

<table>
<thead>
<tr>
<th>Asset Management Component</th>
<th>Opportunities to Integrate Climate Adaptation</th>
<th>BART Status / Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset Management Policy and Strategy</td>
<td>Consider climate change in asset management goals, policies, and/or plans.</td>
<td>▪ Climate change considerations to be added to asset registry</td>
</tr>
<tr>
<td>Risk-Based Asset Management Approach</td>
<td>Map areas vulnerable to projected climate risks. Inventory critical assets, create risk profiles, and develop risk mitigation strategies.</td>
<td>SLR maps completed for ART East Bay area Prioritized list of SOGR assets identified</td>
</tr>
<tr>
<td>Asset Management Activities</td>
<td>Develop adaptation strategies at enterprise, asset-class and lifecycle asset management planning levels.</td>
<td>AMPS for 5 asset classes are underway</td>
</tr>
<tr>
<td>Financial Requirements</td>
<td>Incorporate climate risk mitigation strategies into short- and long- range plans, capital and/or O&amp;M budgeting processes.</td>
<td></td>
</tr>
<tr>
<td>Continuous Improvement</td>
<td>Monitor asset condition in conjunction with climate change indicators to determine if/how climate change affects performance.</td>
<td></td>
</tr>
</tbody>
</table>

Opportunities at the asset level are: (p. 83)

<table>
<thead>
<tr>
<th>Life Cycle Management Component</th>
<th>Opportunities to Integrate Climate Change Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roles and Responsibilities</td>
<td>Identify resource (person, organization, or program) for climate risk data and how it will be maintained.</td>
</tr>
<tr>
<td>Asset Inventory</td>
<td>Overlay or relate inventory to climate-related data.</td>
</tr>
<tr>
<td>Condition Assessment &amp; Performance Monitoring</td>
<td>Document condition and performance monitoring in conjunction with climate conditions to understand how an asset performs under various climate extremes and if a climate risk mitigation strategy that has been implemented is effective and responsive.</td>
</tr>
<tr>
<td>Preventive/Reactive Maintenance Plan</td>
<td>Update preventive and reactive/corrective maintenance practices to address different operating conditions.</td>
</tr>
<tr>
<td>Asset Policy and Strategy</td>
<td>Include goals for level of service requirements and climate change-related outcomes.</td>
</tr>
<tr>
<td>Asset Lifecycle Management</td>
<td>Consider climate risks to asset throughout each phase: (1) Design/procure, (2) Use/operate, (3) Maintain/monitor, (4) Rehabilitate, (5) Dispose/reconstruct/replace.</td>
</tr>
<tr>
<td>Capital Programming and O&amp;M Budgeting</td>
<td>Consider costs of climate-related strategies (incl. costs to replace vs. retrofit vs. abandon) and the value or benefit of the measure to facilitate prioritization.</td>
</tr>
<tr>
<td>Performance Modeling</td>
<td>Conduct performance modeling in conjunction with climate conditions.</td>
</tr>
<tr>
<td>Continuous Improvement</td>
<td>Update asset lifecycle management plans as conditions and performance change.</td>
</tr>
</tbody>
</table>

Captivating Value

BART recognizes that there is no “one size fits all” solution to climate change adaptation. (p. 68)

As indicated in Element 2, vulnerability can vary for each asset depends on the location and the type of the asset. In addition, some BART assets are more critical to BART operations than others. For example, open spaces and parking lots are less critical than tracks and train control assets. Non-critical assets may be allowed temporary flooding at acceptable frequencies and may not require climate change adaptation. Climate change adaptation will likely require the implementation of an array of strategies dependent on the location and asset type.

Decision Question

How to incorporate climate adaptation into decision-making and what immediate actions can be made now to begin addressing the identified adaptation strategies.

Decision Maker

Transit Agencies
| Relevance | • Provides insight on how the agency is beginning to incorporate climate adaptation into standard business practices.  
• Outlines methods for assessing climate change risk and prioritization and analysis of adaptation strategies.  
• Outlines a number of adaptation strategies, though specific to this study, may help build a larger inventory of adaptation strategy options. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>“As an immediate step following this study, a funding plan should be devised so that a comprehensive, system-wide, vulnerability and risk review of BART operating systems and assets can be performed. It is a value-added approach by leveraging the findings from several regional and federal climate change adaptation projects, by applying the methodologies developed through this pilot, and by continuing the broad teamwork that came together during this pilot.” (p. 101)</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>This report provides a detailed example of applying a simple vulnerability assessment of infrastructure and considerations for adaptation and where adaptation fits into asset management.</td>
</tr>
</tbody>
</table>
| Additional Comments | In regards to the developed risk/vulnerability assessment methodology, something to think about is the approach to defining probability in general and not just this report. The risk assessment approach to defining probability on varying time scales is likely common but it may be of interest how these play out in planning. “Downpour” is broken into 5 categories from “Improbable” to “Frequent”. “Improbable” is defined as “Unlikely during the next 25 years”. Contrarily, sea-level rise uses estimates for impacts at 2050 and 2100. Is it appropriate for the risk scales to be defined by the timeframe of the data is provided in? How does one compare downpours being improbable by 2038 with sea-level rise being frequent by 2050? In simply terms, 1 event is improbable to occur in about 25 years while another event is will occur in about 35 years. On the probability scale, one is scored 1 while the other 5. Is this appropriate for transit agency planning or should the probability follow agency planning horizons?  

There needs to be clear distinction between risk assessments and vulnerability assessments for terminology purposes and how they are the same and different. |
| Essential Vocabulary | N/A |
| Potential Keywords | Climate Adaptation  
Rail  
Asset Management  
Business Practice  
Climate change  
Adaptation  
Rail transit  
Flooding  
Sea-level rise  
Precipitation  
Risk assessment  
Bay Area |
### Citation
Binder, L., Tohver, I., Snover, A., Shatzkin, A. Sound Transit Climate Risk Reduction Project, FTA Report 0075, September 2013

### Website/Source

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Research document

### Intended Audience
Transit Agencies

### Abstract
“The Climate Risk Reduction Project assessed how climate change may affect the Central Puget Sound Regional Transit Authority’s (Sound Transit) commuter rail, light rail, and express bus services. The project identified potential climate change impacts on agency operations, assets, and long-term planning; [more than 70] options for strengthening the agency’s resilience to these impacts; and opportunities for integrating climate change considerations into agency decision-making processes.” (p. viii) Assessment involved a survey to gauge staff’s initial understanding of the climate change impact and more than a dozen vulnerability assessment workshops with transit staff. Workshops used a combination of presentations, existing asset mapping and inventories, and structured workgroup activities to stimulate discussions about climate change impacts and risks. A ranking of climate change impacts was developed using three levels: minor, moderate or significant. The ranking was based mostly on how a climate change impact could affect service delivery. Potential significant impacts are those that could cause frequent, extended or permanent service cancellations, require expensive infrastructure repairs, and/or reduce customer confidence. “The project concluded that many climate change impacts will likely be minor to moderate, although potentially significant impacts are possible with higher rates of sea-level rise and mudslide activity.” (p. viii)

### Populations Referenced
Transit agency technical staff and managers

### Topics Covered
- Phases in planning for climate change impacts
  - Preparation of technical materials
  - Vulnerability assessment, adaptation and integration workshops and meetings
  - Synthesis and assessments
- Prioritization of climate change impacts
  - Potential (expected and possible) impact on service delivery
  - Geographic distribution
  - Potential cost (qualitative) of responding to the impact
  - Probability of climate change impact occurring
- Prioritization of services (or stations) to be adapted
  - Type of climate change impacts potentially affecting the service
  - Range of potential issues
  - Geographic extent
  - Ease of adaptation
- Adaptation to strengthen resilience
  - Adjustments to infrastructure
### Type of Sponsoring Agency or Organization
Sponsoring agency is federal agency; Report is written by transit authority and an academic research group.

### Geographic Distribution
- Washington State’s central Puget Sound region
- Large (3 million service area population)

### Type of Transit Mode(s)
Rail, Light Rail, and Express Bus

### Type of Vulnerability
High heat days, Flooding, Other (extreme winter precipitation, drought)

### Goals and Motivations
The goal of the project were as follows:
- “Identify climate change impacts on Sound Transit operations, assets, and long-term planning
- Identify options for strengthening the agency’s resilience to these impacts
- Identify opportunities for integrating climate change considerations into agency decision-making processes
- Create a process and a model for assessing and planning for climate change impacts that is transferable to transit agencies across the United States (FTA Climate Change Adaptation Pilot Program)
- Provide a state-to-local testing ground for WSDOT’s pilot use of the Federal Highway Administration’s (FHWA) climate change vulnerability assessment methodology.” (p.1)

The motivation for this Project was that Sound Transit was already experiencing service disruptions and increased maintenance cost due to mudslides, flooding, poor drainage and storm surge and that research shows that climate change could potentially have significant impact on the region, which would make transit problems worse. In addition, Sound Transit was in the planning and design phases of various aspects of its service expansion plan (ST2), which offered the opportunity to integrate information on potential climate change impacts into long-term planning and asset management decisions.

### Context
- Sound transit offers rail, light rail, and express bus. There are a few other agencies in the region providing bus service and there is ferry service.
- Sound Transit is a young transit system that began between 1999 and 2009 so design is relatively recent.

### Tools
Report describes the framework for assessing vulnerabilities and prioritizing climate change adaptation measures that they developed and used to develop a baseline scenario for Sound Transit.

### Noteworthy Aspects
The service expansion plan offered a window of opportunity to start incorporating climate change impacts.

### Captivating Value
Effective adaptation is an ongoing effort; there are opportunities for integrating climate adaptation in a wide variety of agency processes.

### Decision Question
“Decisions about if, when, and where adaptation measures in design, construction or operations standards may be warranted.” (p. 5) Opportunity to consider adaptation are present in many
<table>
<thead>
<tr>
<th>Decision Maker</th>
<th>Transit agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance</td>
<td>Report describes methodology of 18 month project that focused on reducing climate change risk by considering its impacts a wide variety of processes.</td>
</tr>
<tr>
<td>Status</td>
<td>Research report is completed. Authors indicate that they will develop a formal set of recommendations that will outline the steps that Sound Transit should take to address the report’s findings.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Comprehensive well-documented report of 18 month study. However, document does not include survey instrument or check list or other materials that would help replicate the methodology by other agencies.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Essential Vocabulary

- **Resilience**: “A capability to anticipate, prepare for, respond to and recover from significant multi-hazard threats with minimum damage to social well-being, the economy and the environment” (FTA definition) (p. 2)
- **Adaptation**: “Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.” (p. 2)
- **Vulnerability**: “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.” (p. 2)

### Potential Keywords

- Climate Adaptation
- Vulnerability Assessment
- Workshops
- Prioritization
- Decision-Making Processes
"This report applies transit asset management principles to climate change adaptation using the Federal Transit Administration’s “Asset Management Guide.” Climate change adaptation generally involves understanding potential impacts of the changing climate on an agency’s services and assets and taking necessary actions to avoid, reduce, or manage anticipated impacts. For transit agencies, this involves identifying vulnerable assets and their associated risks and prioritizing improvements to develop more resilient systems while achieving other system performance objectives. Principles from the “Asset Management Guide” are applied to demonstrate how a public transit agency can adapt to extreme weather events or changes in climate using the Metropolitan Atlanta Regional Transit Authority (MARTA) as a case study.” (p. 1)

“The report outlines procedures for identifying the climate hazards and vulnerable assets and their associated risks in a transit agency’s service area. It identifies opportunities to integrate climate adaptation strategies in a transit asset management system at the enterprise and asset levels and then link the resulting information to appropriate business units to manage risks while undertaking continual improvement and updates in the lifecycle management of assets. Addressing climate change through asset management programs can help agencies achieve system resilience simultaneously with other system performance objectives such as safety, mobility and the state of good repair.” (p. 1)

The premise of the report is that “addressing climate change through asset management programs can help agencies achieve system resilience simultaneously with other system performance objectives such as safety, mobility and the state of good repair.” (p. 1) To support that premise the report provides:

- a framework for addressing climate adaptation in transit asset management based on FTA’s “Asset Management Guide”
- a process for identifying climate hazards in the Metro Atlanta area and the MARTA service area
- an overview of MARTA’s Asset Management System that outlines opportunities to incorporate climate change adaptation considerations in the system
- a discussion on the integration of climate adaptation into MARTA’s decision-making processes
- possible adaptation strategies based on the climate hazards identified for the transit
![Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies](TCRP A-41: Literature Review)

<table>
<thead>
<tr>
<th>Type of Sponsoring Agency or Organization</th>
<th>This research report was sponsored by the Federal Transit Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>National</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>“This report makes a case for using transit asset management programs to adapt to climate change, discusses key elements of the process using Metro Atlanta’s public transit system as a recurring example and presents guidelines and a case study for using risk-based transit asset management procedures to adapt to climate change, using FTA’s “Asset Management Guide.”” (p. 9) MARTA operates a fleet of buses, on-demand services and rail service.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>“Identifying present and future climate hazards in the transit agency’s service area is an important starting point for adapting to climate change” (p. 27) and the report provides a process to identify climate hazards. Discussions with MARTA regarding weather-related incidents that affected operations in the past revealed that the two climate stressors affecting MARTA’s operations and assets the most, are higher temperatures for longer periods of time and higher-intensity precipitation in storm events.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>“With the growing intensity and frequency of extreme weather events, such as hurricanes Irene and Sandy, several public transportation agencies have begun to adapt their systems to make them more resilient to the changing climate conditions.” (p. 1) This report makes a case for “addressing climate change through asset management programs to help agencies achieve system resilience simultaneously with other system performance objectives such as safety, mobility and the state of good repair” (p. 1) using Metro Atlanta’s public transit system as an example.</td>
</tr>
<tr>
<td>Context</td>
<td>“A transit agency adapting to climate change refers to adjusting its assets, systems and management practices in a way that moderates potential damage, copes with consequences, or finds opportunities to build system resiliency and maintain a minimum level of service.” (p. 11) From the viewpoint of the Metropolitan Atlanta Rapid Transit Authority (MARTA), “climate change adaptation involves understanding the potential impacts of the changing climate on the agency’s services and assets and taking the necessary actions to avoid, reduce, or manage anticipated impacts.” (p. 1) “The implications of the climate change assessment is that those assets most vulnerable to flooding (at lower elevations near streams or creeks, or that depend on well-maintained drainage systems to remove runoff from the facility) and those whose performance can be affected by longer exposures to higher temperatures, as well as a wider variation in temperatures (signal and communications equipment and perhaps tracks and pavements), are those in most need of monitoring. This monitoring could entail actual condition monitoring of individual assets, or keeping track of maintenance records associated with certain types of assets (and introducing different design or maintenance strategies once a certain threshold level is reached).” (p. 35) “The MARTA rail system began operating in 1979. The agency operates 132 bus routes, covering approximately 1,000 route miles with 621 buses. ... The agency also operates approximately 175 paratransit vehicles and 450 non-revenue vehicles. MARTA’s system includes 4 lines serving 38 stations. It also includes approximately 48 miles of track and operates with 318 rail vehicles. Annual ridership is more than 105 million trips (approximately half a million per day).” (p. 36)</td>
</tr>
<tr>
<td>Tools</td>
<td>The report did not specifically introduce any tools or metrics.</td>
</tr>
</tbody>
</table>
### Noteworthy Aspects

The report contained several noteworthy items including:

- "Lifecycle management plans are developed at the design/procurement stage to ensure that the asset is designed and/or manufactured in a way that considers its performance requirements (including resilience to extreme weather and climate risks) and total cost of ownership. The contents of a lifecycle management plan may vary based on the asset management maturity level of an asset class." (p. 20)

- "There is a broad range of preventive and reactive maintenance strategies addressing climate change adaptation for specific asset classes and climate stressors (e.g., drought, extreme heat, flooding, increased precipitation, more frequent high winds, etc.). At a more detailed level, these adaptation strategies are often linked to specific business unit operations, asset classes, specific climate risks, and other details such as when and where the strategy will be implemented, and how much the strategy will cost." (p. 25) The report recommends prioritizing these strategies to identify short-term versus longer-term strategies.

- A number of examples of preventive and reactive maintenance measures to reduce the impacts and consequences of climate change implemented by MARTA include:
  - **Preventive Maintenance Strategies**
    - Explore integration of real-time video feeds from agency vehicles into operations decisions
    - Incorporate technology, such as sensors, that can detect changes in pressure and temperatures in materials to alert when damage thresholds are near approaching
    - Review and augment cross-training in emergency response and maintenance tasks
    - Review and update culvert maintenance, storm water management, and tree-trimming programs
    - Design for larger drainage capacity
    - Maintain and update automated system for detecting traffic signals affected by power outages, and monitor the battery back-ups at the intersections that would require traffic officers in case of outages
    - Adjust design parameters based on detailed asset-specific vulnerability analyses for the most critical assets and layout the possible effects on the transportation system
    - Establish a bus rerouting procedure for flood-prone areas and a communication plan for affected customers
    - Establish modified railcar and bus washing plans for varying degrees of drought
    - Update design standard for new railcars to have heat resistant materials where feasible, increased ventilation for electrical components, and more durable air conditioning systems
    - Identify potential landscape designs (natural or man-made) that can reduce or better withstand greater wind velocities
  - **Reactive Maintenance Strategies**
    - Revisit the design or location of an asset to be replaced or rehabilitated if damaged due to climate change or extreme weather events
    - Provide real-time detour route information to drivers during incidents, and explore establishing a 511 travel service (especially for trucks and

---

Copyright National Academy of Sciences. All rights reserved.
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

### Captivating Value

“In essence, climate change adaptation can be viewed as building resilience to climate change.” (p. 7)

### Decision Question

Transit agency leader must decide how to “expend limited funds on climate-related issues in the face of other critical priorities such as SGR backlogs and operational safety. This is where an asset management platform can be a very useful and effective approach to providing appropriate decision support in the face of multiple decision-making objectives.” (p. 8)

The research document was written to make a case to transit agencies for using transit asset management programs to adapt to climate change using Metro Atlanta’s public transit system as a recurring example.

### Decision Maker

Transit agency leadership

### Relevance

This report provides a case study using the examples from MARTA on the process to use a transit asset management program in adapt to climate change and improve the resiliency of the transit system. The report characterizes an asset management focused adaptation process by “three broad steps: 1) define scope of climate adaptation, 2) assess and address climate risk, and 3) integrate into decision making." (p. 11)

“Defining the scope of climate adaptation involves two key actions:
1. Identification of current and future climate risks
2. Identification of critical transit assets based on number of people affected, mobility, or access needs in the event of an emergency or extreme weather event” (p. 12)

“Assessing climate risk also required two key actions:
1. Assessing the vulnerability (sensitivity or level of exposure) of the asset to a particular climate stressor
2. Conducting a risk assessment, evaluating the severity or consequences of a climate impact in combination with the likelihood that the asset will experience that particular impact “ (p. 13)

“Integrating the adaptation plan and risk management strategies occurs at two levels:
1. At the enterprise level, where the adaptation plan is the overall strategy providing direction for cross-asset business decisions related to processes and capital expenditures
2. At the asset class level, where the adaptation plan provided direction to managers regarding capital improvements that strengthen and protect and/or enhance redundancy” (p. 15)

The report stated that preventive and reactive maintenance plans and strategies play a key role in adapting a transit asset or system to changes in the climate and noted that “MARTA expects maintaining SGR to be a continuing challenge in the future. This implies that climate change considerations will likely occur within the context of SGR decision making, making the agency’s asset management program an appropriate platform that can be used to adapt MARTA’s services and system to anticipated climate changes. Therefore, the report concluded that asset management platforms will be highly useful decision-making systems in which to address climate changes."

Copyright National Academy of Sciences. All rights reserved.
change issues by balancing SGR needs with the risks of climate hazards and the need for system resiliency.” (p.23)

<table>
<thead>
<tr>
<th>Status</th>
<th>Research project is complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The report provides value by demonstrating how the principles of transit asset management can be successfully incorporated within the organizational framework and operational practices of a transit provider use MARTA as the case study. The report contains meaningful examples from MARTA to illustrate the steps an agency undertakes towards implementing an adaptation plan to make their system more resilient. The report also provides MARTA’s initial adaptation strategies mapped to the appropriate business units within the agency demonstrating the extent to which resiliency can be infused throughout an agency’s culture.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Essential Vocabulary | The report contained the following definitions and terms:  
  - “Resilience represents the ability of a system to react to stresses that challenge its performance. A resilient system is able to adjust its functioning prior to, during, or following changes and disturbances, so that it can continue to perform as required after a disruption or a major mishap, and in the presence of continuous stresses. Resilient systems have the ability to recover from sudden and severe stresses in a dynamic environment.” (p. 10)  
  - “Criticality relates to how critical an asset is to the fulfillment of the agency’s objectives.” (p. 10)  
  - “Vulnerability Assessment refers to the process of identifying, quantifying, and prioritizing the vulnerabilities in a system.” (p. 9)  
  - “Risk Assessment refers to an integrated evaluation of the likelihood and consequences of climate change impacts on the performance of the transit asset or system.” (p. 9)  
  - “Climate Change Adaptation or Climate Risk Mitigation Strategies are actions taken to adapt to expected changes in the climate. In essence, climate change adaptation can be viewed as building resilience to climate change” (p. 9)  
  - “Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle.” (p. 3) |
| Potential Keywords | Climate change  
Adaptation  
Asset management  
Risk management  
Vulnerability assessment |
### Citation

### Website/Source

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Plan

### Intended Audience
USDOT stakeholders

### Abstract
In a follow-up to the US DOT Policy Statement on addressing climate change, the US Department of Transportation has developed a Climate Adaption Plan for the federal agency which applies to its modal units within.

The plan provides an outline of steps the agency is undertaking to address climate change as well as the roles the modal units play under the plan pursuant to Executive Orders 13514 and 13653.

### Populations Referenced
USDOT and its modal administrations. These include:
- Federal Aviation Administration (FAA)
- Federal Highway Administration (FHWA)
- Federal Transit Administration (FTA)
- Federal Railroad Administration (FRA)
- Federal Motor Carrier Safety Administration (FMCSA)
- Maritime Administration (MARAD)
- Pipeline and Hazardous Materials Safety Administration (PHMSA)
- Saint Lawrence Seaway Development Corporation (SLSDC)

### Topics Covered
- Identification & Assessment of Climate Change Impacts;
- Programs, Policies, and Plans put in place;
- Agency response to climate change risk;
- The process of how US DOT will incorporate climate change into its own agency including the use of various tools;
- And highlights of accomplishments by modal administrations under DOT including FTA;
- Potential impacts of climate change.

### Type of Sponsoring Agency or Organization
Federal, U.S Department of Transportation

### Geographic Distribution
National applications under USDOT.

### Type of Transit Mode(s)
Those agencies which report to, are funded by, and depend upon the modal units within USDOT.

### Type of Vulnerability
Heat-high Days, Extreme Cold, Severe Storm Events, Coastal Storms, Flooding/Sea-level Rise, Winter Storm (Heavy Snow/Ice), Earthquakes, Wildfires, Other

### Goals and
This plan is an updated version which addresses a requirement to develop and implement a
### Motivations

climate adaption plan per executive order. Although it fulfills a requirement, then plan works to address safety, state of good repair and sustainability issues.

### Context

The U.S. DOT is required to develop and implement a climate adaptation plan. This document is updated form a 2012 version which reviews the past successes of the department modal unit successes and activities.

### Tools

Identification of Common Support Services – Weather (CSS-Wx) – However, this is aimed at aviation.

Identifies that FHWA has multiple tools available an under development to assist agencies in identifying climate change vulnerabilities:

- “Climate Change and Extreme Weather Vulnerability Assessment Framework (Complete FY 2013)—This is a comprehensive resource and guidebook for transportation agencies conducting vulnerability assessments and it includes discussion, resources, and in-practice examples of the major tasks involved. The Framework is an update of a draft version that FHWA released in FY 2010.” (p. 20)

- “Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects (Complete FY 2014) - This report highlights adaptation actions that transportation agencies are pursuing and articulates a growing set of best practices for implementing adaptation. The report also discusses strategies, examples, and best practices for evaluating the costs and benefits of adaptation. The purpose of the report is to provide transportation practitioners with a guide to the current "state of practice" in this field.”(p. 20)

- “Transportation Climate Change Sensitivity Matrix (Expected FY 2014) - This Excel file documents how different climate stressors affect several types of transportation infrastructure. The tool contains a macro-based user interface that allows users to generate reports related to specific stressor-asset combinations per their needs.” (p. 20)

- “CMIP Climate Data Processing Tool (Expected FY 2014) –This tool processes raw climate data, which users download from a third party site. Outputs are projected temperature and precipitation changes in a local area. The tool provides a relatively quick and easy way for users to determine the potential magnitude of certain changes in their area”(p. 20)

- “Vulnerability Assessment Scoring Tool (VAST) (Expected FY 2014) – This Excel tool allows users to design and structure a score-based vulnerability assessment. Once complete, users will have a relative vulnerability score for each asset evaluated.”(p. 20)

- “Webinar Series on Planning for Climate Change Adaptation –(Complete FY 2013) FHWA held a four-session webinar series aimed at state and local governments, which included sessions on:
  - Determining assets to study and climate information;
  - System-level vulnerability assessments;
  - Applying vulnerability assessment results into decision making; and
  - Lessons learned from Superstorm Sandy. FHWA is planning an additional webinar series in FY 2014 focused on roll out of the Department’s Gulf Coast Phase 2 study. Recordings of the FY 2013 webinars are available on FHWA’s website.”(p. 20)

### Noteworthy Aspects

- The department has instructed modal administrators to have grantees consider climate change into asset management. Stakeholders are further encouraged to incorporate adaptation and mitigation efforts into land-use planning, capital projects, retrofitting existing infrastructure, relocation of infrastructure, system redundancies and increased ability to absorb impacts to quickly recover form an incident.

- The document breaks down FY12-13 accomplishments through categorically organizing
work by planning, outreach, tools, funding, etc. for each modal administration under US DOT agencies may take advantage of. Seems to be useful base of knowledge and resources to agencies.

- Document also outlines notable impacts form climate change to transportation infrastructure.

Captivating Value

The document breaks down FY12-13 accomplishments through categorically organizing work by planning, outreach, tools, funding, etc. for each modal administration under US DOT agencies may take advantage of. These are listed under tools and may provide a series of useful methods for incorporation of climate change into business practices.

Decision Question

N/A

Decision Maker

N/A

Relevance

- A number of tools, research and other efforts are documented as available for use.
- An assessment framework and incorporation of climate change into policy decisions and funding elements is addressed.
- Funding for the years reported on focused on resilience following post-disaster from Superstorm Sandy. This funding is limited in geographic scope.
- DOT is working to incorporate climate variability and impacts into asset management and planning.
- An outline is provided on potential climate impacts on transportation infrastructure. Those are briefly summarized as:
  - Flooding of tunnels;
  - Shortened infrastructure life;
  - Degradation of infrastructure such as pavement and asphalt;
  - Increased maintenance and construction costs;
  - Decrease driver performance;
  - Increased risk to vehicle accidents;
  - System delays and downtime increases;
  - Drainage infrastructure impacts.

These impacts are results from temperature changes, increased precipitation events, storms and storm surges, and general increase in weather events which may impact risks. This is highlighted by vehicle accidents and driver performance as operated vehicles in adverse weather is likely to increase risk of an accident.

Status

N/A

Critical Assessment

A great summary of what the various modal administrations are working on but limited as far as guidance for how to incorporate climate change into agency governance and funding for such activities.

Additional Comments

N/A

Essential Vocabulary

Tools, Climate Change, Executive Order, Climate Adaptation Plan, Modal, Transit, Impacts

Potential Keywords

Transportation
Climate Change Adaptation
Policy
Tools
Impacts
Resilience
DOT

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Outreach</th>
<th>Education</th>
<th>Planning</th>
<th>Asset Management</th>
</tr>
</thead>
</table>

Copyright National Academy of Sciences. All rights reserved.

www.trb.org/Main/Blurbs/169781.aspx

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Research Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended Audience</td>
<td>Transportation professionals, state DOTs</td>
</tr>
</tbody>
</table>

Abstract

“The objectives of this project were to (1) synthesize the current state of worldwide knowledge regarding the probable range of impacts of climate change on highway systems by region of the United States for the period 2030–2050; (2) recommend institutional arrangements, tools, approaches, and strategies that state DOTs can use to adapt infrastructure and operations to these impacts and lessen their effects; and (3) identify future research and activities needed to close gaps in current knowledge and implement effective adaptive management.” (Foreword)

“The project examined adaptation to climate change on three scales of application—road segment, corridor, and network—including the types of impacts likely to be faced in coming years and the different design, operations, and maintenance strategies that can be considered. The report discusses adaptation planning in the United States and in other countries, with special consideration for the approaches taken in developing adaptation strategies. An eight step diagnostic framework for adaptation assessment is presented.” (Foreword)

The document consists of two major project deliverables:

- A Practitioner’s Guide to conducting adaptation planning from the present through 2050
- A research report that summarizes the research results supporting the development of the Practitioner’s Guide and provides recommendations for future research.

Populations Referenced

The report focuses on the effect of climate change on highway systems and the impact those effects have on highway users.

Topics Covered

“The guide was developed to help transportation professionals understand the changes in climate that may affect the future (and, in the case of extreme weather events, the current) transportation system and how assets and activities can be adapted to provide transportation system resiliency in the face of changing environmental conditions.” (p. 3) It accomplishes this by providing:

- a framework for undertaking an adaptation assessment
- a tutorial on the basics of climate change modeling
- information on the likely impact of different climate stressors on the highway system and the types of strategies that can be considered as part of an agency’s adaptation efforts
- approaches and methods for considering the risk to infrastructure of changing climatic conditions and extreme weather events
- discussion regarding institutionalizing adaptation into the project development process
<table>
<thead>
<tr>
<th>Type of Sponsoring Agency or Organization</th>
<th>The research was sponsored by the American Association of State Highway and Transportation Officials in cooperation with the Federal Highway Administration.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>National and International (Adapt Planning)</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>The guide identifies likely impacts on the highway system and is therefore most applicable to those modes that utilize the highway, such as: Bus Rapid Transit, Bus/Commuter Bus and Demand Response. However, the principles contained in the guide are applicable to all modes of transit.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>The guide does address a specific vulnerability but presents different strategies that can be used to minimize or avoid climate change-related disruptions. As used in the document “an asset is vulnerable to climatic conditions if conditions such as intense precipitation and extreme temperatures and their aftermath (e.g., a flood exceeding certain stages and consecutive days of higher than 100F temperatures) result in asset failure or sufficient damage to reduce asset functionality.” (p. 5)</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>“Transportation officials and practitioners need a sound foundation on which to plan for the near-term impacts of climate change.” (Foreword)</td>
</tr>
<tr>
<td></td>
<td>“From a resiliency/adaptation planning perspective, knowing whether the location and/or design of the facility presents a high level of risk to disruption due to future climate change is an important part of the design decision. For existing infrastructure, identifying high-risk assets or locations provides decision makers with some sense of whether additional funds should be spent to lower future climate change–related risk when reconstruction or rehabilitation occurs. This could include conducting an engineering assessment of critical assets that might be vulnerable to climate stressors and in essence, “piggybacks” adaptation strategies on top of other program functions (e.g., maintenance, rehabilitation, reconstruction, etc.).” (p. 59)</td>
</tr>
<tr>
<td>Context</td>
<td>The guide was developed in the context of helping “transportation professionals understand the changes in climate that may affect the future (and, in the case of extreme weather events, the current) transportation system.” (p. 3) Its focus is on providing guidance on incorporating adaptations into operations and maintenance practices, construction activities, and the planning and (re)design of new and existing infrastructure. For the purposes of the guide, “adaptation consists of actions to reduce the vulnerability of natural and human systems or to increase system resiliency in light of expected climate change or extreme weather events.” (p. 3) The implication is that “the result of adaptive action either decreases a system’s vulnerability to changed conditions or increases its resilience to negative impacts.” (p. 11) Although the framework focuses on the technical aspects of adaptation planning, a challenge to implementation was noted in the document. “Many of the state officials participating in the testing of the framework noted that, while there are several reports on how to do adaptation planning technically; there is a dearth of guidance and materials for helping DOTs to implement adaptations in the context of shrinking budgets and public skepticism.” (p. 25)</td>
</tr>
<tr>
<td>Tools</td>
<td>A diagnostic framework for undertaking an adaptation assessment is presented. “This framework includes the steps that should be taken if transportation officials want to know what climate stresses the transportation system might face in the future; how vulnerable the system will likely be to these stresses; and what strategies can be considered to avoid, minimize or mitigate potential consequences.” (p. 3)</td>
</tr>
</tbody>
</table>
“The main tools used to simulate global climate and the effects of increased levels of greenhouse gases (GHGs) are called “general circulation models” (GCMs). The guide provides advice on how to use climate models and model output.” (p. 5)

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Several noteworthy points are contained in the document, including the following:</td>
</tr>
<tr>
<td>• Recognition that “one of the most valuable roles an asset management system could have for an agency is its continuous monitoring of asset performance and condition.” (p. 9)</td>
</tr>
<tr>
<td>• “Transportation agencies ... should link adaptation planning efforts to existing agency processes and procedures.” (p. 22) The guide describes how adaptation considerations can be incorporated into a typical transportation planning process.</td>
</tr>
<tr>
<td>• A discussion of the relationship between vulnerability and risk noted that:</td>
</tr>
<tr>
<td>• An asset is vulnerable to climatic conditions if these conditions (such as intense precipitation and extreme temperatures) and their aftermath (e.g., a flood exceeding certain stages and consecutive days of higher than 100°F temperatures) result in asset failure or sufficient damage to reduce asset functionality. The vulnerability can thus be measured as the probability that the asset will fail given climate stressors (e.g., “there is a 90 percent chance the bridge in its current condition will fail with a 500-year flood”). Vulnerability primarily focuses on the condition of the asset.” (p. 56)</td>
</tr>
<tr>
<td>• Climate-related risk relates to not only the failure of the asset but also to the consequences or magnitudes of costs associated with that failure. “In this case, a consequence might be the direct replacement costs of the asset, direct and indirect costs to asset users and, even more broadly, the economic costs to society given the disruption to transportation caused by failure of the asset or even temporary loss of the asset’s services (e.g., a road is unusable when it is under water).” (p. 187)</td>
</tr>
<tr>
<td>• Putting it all together, the complete risk equation is thus: “Risk Probability of Climate Event Occurrence × Probability of Asset Failure × Consequence or Costs” (p. 5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Captivating Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Adaptation consists of actions to reduce the vulnerability of natural and human systems or to increase system resiliency in light of expected climate change or extreme weather events.” (p. 11)</td>
</tr>
<tr>
<td>“Ultimately, a wide range of activities can be considered “adaptation,” from relatively simple operations and maintenance actions, such as ensuring culverts are clear of debris, to complex and costly planning and engineering actions, like re-locating a road alignment away from a flood-prone area.” (p. 11)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation professionals are being asked to utilize the practitioner’s guide to adapt assets and activities to provide transportation system resiliency in the face of changing environmental conditions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Maker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation professionals and state DOT policy makers.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The result of adaptive action either decreases a transportation system’s vulnerability to changed conditions or increases its resilience to negative impacts.” (p. 11)</td>
</tr>
<tr>
<td>The guide points out that “the types of actions that can be taken to reduce a transportation system’s vulnerability to changing environmental conditions could include; avoiding, withstanding, and/or taking advantage of climate variability and impacts.” (p. 11)</td>
</tr>
<tr>
<td>• “Thus, for roads and other transportation facilities, avoiding areas projected to have a higher risk of potentially significant climate impacts should be an important factor in planning decisions.” (p. 11)</td>
</tr>
<tr>
<td>• “If such locations cannot be avoided, steps need to be taken to ensure that the transportation infrastructure can withstand the projected changes in environmental conditions. For example, the potential for increased flooding might be a reason to increase bridge elevations beyond what historic data might suggest.” (p. 11)</td>
</tr>
</tbody>
</table>
The adaptive strategies noted in the guide to either reduce the impact or reduce the consequences of climate impacts are analogous to strategies suggested to improve resiliency. Additionally, the approach taken to provide transportation practitioners a sound foundation on which to plan for and implement adaptive strategies is readily transferable to efforts to improve the resiliency of transit agencies.

The document contains a “diagnostic framework that provides highway agency staff with a general step-by-step approach for assessing climate change impacts and deciding on a course of action.” (p. 14) Those steps include:

- Establishing the overall focus and approach of the adaptation study
- Determining the likely future climatic and weather conditions
- Determining the vulnerability of targeted assets to selected climatic stresses
- Determining the level of risk associated with the possibility of an asset failing, once the assets that are most vulnerable are known
- Identifying, assessing, and costing alternative strategies for protecting the high-risk assets

With respect to barriers to implementing effective resiliency methods, it is reasonable to anticipate similar challenges to resiliency will be experienced as those noted for adaptation. Apparently, “many of the state officials participating in the testing of the framework noted, that while there are several reports on how to do adaptation planning technically, there is a dearth of guidance and materials for helping DOTs to implement adaptations in the context of shrinking budgets and public skepticism.” (p. 25)

<table>
<thead>
<tr>
<th>Status</th>
<th>This research project is complete.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The document is comprehensive in identifying the likely impacts of climate change on planning, design, construction, operations and maintenance of infrastructure assets in the United States. It also fully develops an eight step framework to incorporate adaptation into the context of transportation agencies activities. Because the primary focus of the report is the effect of climate change and extreme weather events on the highway system discussion regarding transit systems is limited. Although, the guiding principles and framework provided are transferable to the transit industry, impacts to the unique assets of transit systems are not addressed by the report.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Essential Vocabulary | The document contains the following terms and definitions:

- “Adaptation consists of actions to reduce the vulnerability of natural and human systems or to increase system resiliency in light of expected climate change or extreme weather events.” (p. 3)
- “An asset is vulnerable to climatic conditions if conditions such as intense precipitation and extreme temperatures and their aftermath (e.g., a flood exceeding certain stages and consecutive days of higher than 100°F temperatures) result in asset failure or sufficient damage to reduce asset functionality.” (p. 5)
- “Climate-related risk relates to not only the failure of that asset but also the consequences or magnitudes of costs associated with that failure.” (p. 5) |
- “Climate sensitivity is defined as the eventual (equilibrium) warming that would occur if the amount of CO₂ in the atmosphere were doubled.” (p. 30)
- “A climate is defined as an average of 20 to 30 years of observations.” (p. 40)
- “Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives.” (p. 91)

| Potential Keywords | Climate Change  
|--------------------|-----------------  
|                    | Extreme weather  
|                    | Adaptation  
|                    | Vulnerability  
|                    | Risk  

Copyright National Academy of Sciences. All rights reserved.
**Citation**

**Website/Source**
ISSN 1977-8449  
doi:10.2800/56672

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

**Document Type**
Research document.

**Intended Audience**
This document addresses governments, primarily. This report aims to provide information of relevance to most of these stakeholders:
- European institutions - how adaptation is making progress throughout Europe, and how it is being integrated within transport policy and practices.
- National and sub-national governments - information on actions taken in some countries, which could be replicated by others.
- Practitioners and researchers - how adaptation needs are being identified and assessed in different contexts, and how actions are prioritized, as guidance for revising or expanding their professional or research activities in this field.

**Abstract**
As an initial step towards the necessary widespread mainstreaming of climate change adaptation into transport planning and decision making, this report aims to shed light on initial adaptation practices in the transport sector across Europe while providing a perspective on the emerging challenges and opportunities. The purpose of the report is to stimulate discussion. The factual information collected is based on data available in the Climate-ADAPT (1) information platform, a literature review, case studies provided by many stakeholders, and a questionnaire on transport and adaptation addressed to EEA member countries in 2013. A total of 23 country representatives answered this questionnaire and provided information on the variety of national approaches to adaptation in transport.

**Populations Referenced**
Stakeholders such as infrastructure developers and managers, service providers — within a mode or integrating various transport modes — and manufacturers of vehicles, trains, airplanes, ships and equipment.

**Topics Covered**
This report explores current climate change adaptation practices concerning transport across European countries and provides:
- a summary of the challenges
- an overview on the state of adaptation action concerning the transport sector and system
- a review of a number of inspiring initiatives in different countries
- conclusions on a potential way forward

**Type of Sponsoring Agency or Organization**
Over the last 15 years, the EEA has published annually the Transport and Environmental Reporting Mechanism (TERM) report looking into specific topics of sustainable transport, such as air quality, noise or urban transport, and tracked progress towards the EU achievement of environmental targets in this sector.

**Geographic Distribution**
All of Europe.

**Type of Transit**
Commuter Rail, Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, Demand Response,
<table>
<thead>
<tr>
<th>Mode(s)</th>
<th>Ferryboat, Other</th>
</tr>
</thead>
</table>
| **Type of Vulnerability** | • Rising temperatures and extended heatwave periods increase the problems of rail buckling, pavement deterioration and thermal comfort for passengers in vehicles.  
• Weather extremes generating floods or landslides can lead to short-term delays and interruptions but also long-term interruptions and detouring needs in the event of destroyed infrastructure. Sea-level rise can threaten harbors and other transport infrastructure and services in coastal areas.  
• Air transport can be challenged by changing wind patterns, flooding of airport infrastructure, and other weather events. In addition, climate impacts that trigger changes in the organization of society and economy, like different tourist destinations or agricultural productions, can impact upon transport demand. |
| **Goals and Motivations** | Identification of challenges to adaptation planning and implementation as well as best practice. |
| **Context** | • Highly variable context of existing transit and resilience planning across western and eastern European countries.  
• Multiple modes – all.  
• National rail, extensive interdependencies.  
• Highly interconnected, networked.  
• High levels of expertise.  
• Different languages and systems for estimating weather, issues, etc.  
• Sophisticated asset management and operations and maintenance, but still exploring and growing in Adaptation planning.  
• Limited resilience planning. Beginning to examine cascading effects.  
A number of EU processes will encourage the emergence of this more resilient and sustainable transport system. These processes include the Europe 2020 program and the Commission’s White Paper Roadmap to a Single European Transport Area — Towards a competitive and resource efficient transport system (EC, 2011b). |
| **Tools** | • xGeo  
Cooperation between transport stakeholders, hydrological and meteorological experts in Norway The xGeo tool is an online tool for risk assessment and preparedness, and for monitoring and forecasting of floods, landslides and avalanches. It was developed by the National Public Roads Administration (NPRA) and the Norwegian Water Resources and Energy Directorate (NVE) in collaboration with the National Rail Administration (JBV) and meteorological services. The tool was developed under the auspices of the Climate and Transport project (2007–2010) led by the NPRA. The idea for combining different data sources such as hydro-meteorological data and maps of the road network in a single tool was developed after a major storm near the city of Trondheim in 2006 resulted in significant disruptions to transport infrastructure and operations. The mapping tool combines historical, present and forecast weather data with ground and road data, threshold values for natural hazards and data on road network events such as floods, landslides and avalanches. Use of historical time series data on weather conditions and events such as floods and landslides affecting the road and rail networks supports better use of forecast data through improved identification of conditions that increase the risk of damages and operational disruptions. The tool is primarily used for forecasting avalanche and landslide risks in the national alert system for landslides and avalanches. Alerts are issued by the NVE forecasting center and communicated to road and railway authorities as well as a range of other authorities and media outlets. Overall, cooperation of the involved actors was and will be key for the successful development of the tool and its adoption for practical use in the national alert system for landslides and avalanches.  
Source: Barfod et al., 2013; Devoli et al., 2013; xGeo, 2014. |
Examples of national information platforms and their support of adaptation efforts

Many countries have set up a climate change adaptation platform providing information — mainly on their national adaptation plans — to all agents interested in the subject, covering the transport sector, for example:

- **France: WIKLIMAT**
  WIKLIMAT is a platform for sharing knowledge between actors involved in climate change. It was created in July 2013 within the framework of the National Climate Change Adaptation Plan, and allows stakeholders to contribute on French adaptation initiatives and achievements. WIKLIMAT covers three main objectives:
  - To create a platform for gathering and sharing knowledge on adaptation and facilitating widespread dissemination of new ideas and innovative concepts.
  - To make updated experiences available to training actors.
  - To involve different contributors: public administrations at national and regional levels, municipalities and their technical services, consulting firms and companies, and nongovernmental organizations.
  WIKLIMAT includes one category on transport infrastructure. Documents and case studies are available for six sub-categories: ship design and boats, transport economics and logistics, management of navigation-related infrastructures, infrastructure and environment, and safety and e-navigation. [http://wiklimat.developpement-durable.gouv.fr/index.php/Cat%C3%A9gorie:Infrastructures_et_transport](http://wiklimat.developpement-durable.gouv.fr/index.php/Cat%C3%A9gorie:Infrastructures_et_transport)

- **Spain: The AdapteCCa Platform**
  The AdapteCCa Platform exchanges information on impacts, vulnerability and adaptation to climate change, and facilitates the coordination and transfer of adaptation information, knowledge and experiences among the different Spanish administrations and the scientific community, planners and managers, and other public and private agents, allowing multi-directional communication between them. The Platform includes transport among its main areas, and different transport-related reports and results are already available. [http://www.adaptecca.es/contenido/transporte](http://www.adaptecca.es/contenido/transporte)

- **Poland: The KLIMADA adaptation platform**
  The project 'Development and implementation of a strategic adaptation plan for the sectors and areas vulnerable to climate change', with the acronym KLIMADA, provides a website, which has become the main information platform of adaptation in Poland. Aside from information related to the Polish adaptation policy and local adaptation initiatives, it considers adaptation in different sectors, including transport. [http://klimada.mos.gov.pl/en/2013/04/15/transport](http://klimada.mos.gov.pl/en/2013/04/15/transport)

### Noteworthy Aspects

- **Delivering tomorrow: Logistics 2050** — A scenario study examines different scenarios (DHL, 2012) and illustrates a much broader and more forward-looking view as well as the analysis undertaken by Rossello (2011), exploring the potential climate change impact on air transport patterns. They demonstrate the need to consider not only changes in climate but also in society and the economy, as they generate different transport patterns and demand. Transport is a derived demand, and it could therefore be worth exploring more generally whether resilience can be attained in a more efficient way by revising some economic and social practices, which are at the origin of that demand, rather than acting exclusively on the transport system as such. This requires a broader perspective and out-of-the-box thinking well beyond single modes or even beyond the transport system.

- **Assessing adaptation options may also require the subsequent revision of standard project assessment practices, such as cost-benefit or financial analyses, in order to integrate the new risks identified in the evaluation of future investment alternatives by planners and decision makers (Cochran, 2009).** An area of common interest for planning and management/regulatory experts, on the one side, and operations and maintenance
experts, on the other side, emerges here, as vulnerability assessments would require input from both sides.

- Considering transport under a broader spatial perspective provides several benefits. Firstly, transport stakeholders may find it easier to develop and implement their adaptation actions if they can link to integrated adaptation strategies at the appropriate spatial level. Secondly, integrating transport within regional or city adaptation strategies also facilitates a discussion about how changes in climate can impact population flows and transport behavior. This broader framework may offer a better basis for a revision of current transport plans based on particular regional or local characteristics (including their socioeconomic developments). Useful knowledge can also be found in related policy areas, such as disaster-risk prevention or river-basin and flood-risk management.
- Mobilizing the cooperation of different stakeholders could help to overcome the fragmentation that exists in what is — ironically — a highly connected sector. An ambitious approach by the public authorities seems necessary to overcome these barriers. This approach has already been adopted in some countries, where the transport sector has been invited to participate in the formulation of national and regional adaptation initiatives.

Captivating Value

The transport system is of trans-boundary character and highly interconnected inside its modes and across modes; hence, disturbances in one part of the network might have a domino effect in other parts too. As such, effects usually extend beyond the transport system by hindering the ability to deliver reliable services, and jeopardizing the free movement of people and goods. Depending on the specific case, these indirect damage costs can be many times higher than direct costs to the transport sector itself.

Decision Question

Investments in effective transport systems are usually costly and with long return rates. Considering future climate trends now helps in keeping the costs for adaptation bearable and avoiding lock-ins into an unsustainable development path of the transport system. Many tools developed for natural disaster risk management or contingency plans can easily be made relevant for climate change adaptation too. Improving cooperation among different stakeholders and encouraging more out-of-the-box thinking would enable better benefiting from such synergies and low-cost options. Adaptation to climate change is a new policy area; the effectiveness of current steps should be evaluated in the future.

Decision Maker

Political and management decisions at the state, local, and national levels and national governments have a prominent role in enabling this integrated approach and cooperation by organizing exchanges of experience, facilitating the generation of tailored knowledge and tools, and stimulating solution-finding across the board.

Relevance

The prevailing approach among most stakeholders in the transport sector is still incremental improvements of transport infrastructure, operations and services based on past experience, to deliver valuable solutions that also work under the new conditions being created by climate change. However, given the magnitude of expected change, these approaches alone are likely to be insufficient. The anticipated impacts suggest long-term visions as well as thinking about solutions outside traditional paths in areas like spatial planning, relocations of infrastructure or regional flood risk management, and the exploration of transitional changes by organizing future accessibility differently. The report argues that prevalent transport paradigms such as efficiency need to be reconsidered together with alternative paradigms such as flexibility using, for example, multimodal concepts instead of uni-modal solutions, technology and redundancy.

Transport sector and adaptation challenges:

- Observed and projected climate change — such as increases in temperature, sea level, changes in rainfall, and the increase in frequency and intensity of some extreme weather events.
- Reducing GHG emissions (mitigation) and adaptation to unavoidable impacts are
complementary actions both needed to cope with climate change.

- Transport requires many costly and long-lasting investments in infrastructure, airplanes, trains, ships and other transport equipment. This calls for anticipatory planning approaches that consider future climate change but also other socioeconomic changes.
- Transport, is a very complex system with responsibilities distributed across many different stakeholders. This situation makes integrated adaptation approaches challenging to achieve and requires appropriate governance approaches.

More interesting to me than these points was the observation that transport demand is expected to change as a short-term reaction to delays and interruptions, but in addition long-term changes are also expected. This includes, for example, changes in tourism destinations and seasonal tourism caused by increasing temperature. Most stakeholders may only have a partial perspective of the system they manage or use. They might also have different interests in transport (Table 1.1). It is expected that, without overall strategies, the main stakeholders will react autonomously to the challenges of climate change. Given the broad challenges of climate change and the strong interconnectivity inside the transport sector and with other sectors and areas of society, such a fragmented approach seems unlikely to be efficient. It challenges the necessary consistency and coherence across the sector and system to address long-term challenges. The responsibility for adaptation action in the transport sector is often not clear. The providers of equipment and infrastructure will expect new standards and guidelines from regulators. Policymakers and regulators will look at researchers for collecting evidence and providing options. Implemented measures are often spontaneous and relatively isolated, often as a reaction to a weather-related disaster. Together with a relatively low awareness of the adaptation needs for the transport system, the lack of tailored knowledge, like adequate climate reference thresholds for the assessment of the vulnerability of transport infrastructure and services, capacities and resources, poses barriers to adapting the transport system.

Options and Opportunities:

- Most practical examples of adaptation action in the transport sector and system that can be found across Europe focus on early steps like collecting the knowledge, and tailoring climate change impact information and assessments.
- Tools and measures developed to manage risks and disaster from natural hazards, including early warning systems and contingency plans, can be useful for climate change adaptation too; however, there are only few examples of implementation in the transport sector/system.
- Most adaptation action focuses on climate-proofing transport infrastructures; relatively little attention is given so far to transport operations.
- Only a few examples are found that search for innovative solutions across different transport modes, transport as part of broader adaptation plans, or outside traditional paths — e.g. by considering relocation, building redundancies, or changing services to accommodate current and future accessibility demands.
- Effective cooperation between stakeholders inside and outside the transport sector can help to make use of the knowledge gained in other sectors and to find tailored, innovative and effective solutions to adapt transport.
- Integrating adaptation requirements into the design of new and upgraded infrastructure comes at lower cost than adding them at a later stage.

Highlights from Ways Forward

- Good adaptation action requires information and knowledge.
- Currently, greater attention is given to adapting transport infrastructure (rail tracks, ports, roads, etc.) than to adapting transport services (operation of infrastructure and equipment, use of staff, timetables and routing, contingency plans, communication of service options, etc.). More use could be made of this underused potential of transport
<table>
<thead>
<tr>
<th>Status</th>
<th>Recent – last half of 2014.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>Results obtained reflect the perceptions of a limited number of respondents. Transport adaptation but not transit specific.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>The European Commission proposes a Roadmap for moving to a competitive low-carbon economy in 2050 that foresees a reduction of at least 80% of GHGs by 2050 compared to 1990. Their thinking is that transforming transport behavior and transport demand could achieve not only lower emissions but, at the same time, offer opportunities either to build a more resilient transport system and services under climate change or to develop more flexible social and economic practices that could better accommodate eventual disruptions in the transport system. Some countries (e.g., France and Germany) have therefore adopted a top-down approach to transport adaptation in addition to bottom-up approaches by single stakeholders as a means to create the necessary conditions to facilitate the action of all these stakeholders in the future. Action is mainly in the hands of the national government and its associated public sector, by means of expanding the knowledge base and undertaking systematic assessment of current vulnerabilities in the system.</td>
</tr>
</tbody>
</table>
| Essential Vocabulary | • Adaptation: Adaptation consists of actions responding to current and future climate change impacts and vulnerabilities (as well as to the climate variability that occurs in the absence of climate change) within the context of ongoing and expected societal change. It means not only protecting against negative impacts of climate change, but also building resilience and taking advantage of any benefits it may bring (EEA, 2013).  
• Resilience: Simply put, resilience refers to a system's capacity to remain operational under different external pressures. In IPPC, 2014, resilience is defined as 'the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.' In the context of this report, resilience is used in reference to the transport system. However, as transport is an important pillar to maintain services and quality of life in society, this refers indirectly to a resilient society. Although the resilience concept refers to all type of possible pressures — economic, social and environmental — this report focusses on a resilient transport system adapting to the impacts of climate change.  
• Transport system versus transport sector: This report uses both terms. The distinction between them is not totally fixed. The transport system is a set of interacting components include all the transport modes, the physical elements, and the movements that contribute to the services provided by transport to the socioeconomic activity (Frybourgh, 1991). With transport sector the report instead refers to transport as a part of the economy, including its governance structure and regulating authorities.  
• Accessibility: This refers to the ability to reach desired goods, services, activities and destinations (collectively called opportunities). Access is the ultimate goal of most transport options, except a small portion of travel in which driving itself is the purpose (Litman, 2003).  
• Policy stages of adaptation: This report understands here the following stages: agenda-setting, policy formulation, decision to adopt policies, implementing measures foreseen in the policies and monitoring of the policy/action (EEA, 2014).  
• Further definitions of terms related to adaptation can be found in the glossary of the EEA Report National adaptation policy processes in European countries — 2014 (EEA, 2014b). |
<table>
<thead>
<tr>
<th>Potential Keywords</th>
<th>Adaptation</th>
<th>climate change</th>
<th>Existing and potential adaptation approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actors</td>
<td>Likely primary interest in transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Governments (acting for society as a whole)</td>
<td>• Ensure a well-functioning transport system is the backbone for economic activities and movement of people.</td>
<td>• Manage or support to ensure a stable transport system also under climate change and extreme weather events; • strategies, action plans, mainstreaming into other policies like Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), spatial planning, emergency plans, urban renewal, etc.; • ensure security through access to emergency aid in crisis situations.</td>
<td></td>
</tr>
<tr>
<td>Private and public users</td>
<td>• Need reliable, affordable transport for the exchange of goods; • commuting to work, study, daily life issues; • leisure and business trips.</td>
<td>• Switch to another provider; • switch to another mode; • access services without transport by ICT, telecommunication, etc.; • change their travel plans.</td>
<td></td>
</tr>
<tr>
<td>Private and public providers — service operation</td>
<td>• Business continuity by providing transport services; • provide transport services as a basic service for society.</td>
<td>• Adapt operation procedures; • request climate-proof infrastructures and vehicles/equipment; • change to other infrastructure and equipment providers if that is an option; • accept interruptions if the related costs are lower for the company than adapting (cost-benefit analysis for the company).</td>
<td></td>
</tr>
<tr>
<td>Private and public providers — infrastructure</td>
<td>• Business continuity by providing transport infrastructures to operators; • provide transport infrastructures to operators to ensure a well-functioning transport system.</td>
<td>• Proper maintenance of the infrastructure; • making infrastructure climate-resilient; • provide alternative routes (redundancies), if the related costs are lower for the company than adapting (cost-benefit analysis for the company); • otherwise accept interruptions and repair the affected infrastructure after a disaster; • insure against potential damages.</td>
<td></td>
</tr>
<tr>
<td>Providers — vehicles, aeroplanes, ships, trains, equipment</td>
<td>• Business continuity by providing vehicles and equipment to operators.</td>
<td>• Proper maintenance of the equipment, trains, etc.; • making equipment, trains, etc. climate-resilient (based on cost-benefit analyses for the company); • develop/provide climate-proof equipment according to the request if their clients (operators).</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Document Type</td>
<td>Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Transportation planners, asset managers, design engineers, and policy makers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstract</td>
<td>“The Federal Highway Administration (FHWA) conducted an international review to study how international transportation agencies are addressing issues related to adapting highway infrastructure to the impacts of climate change. This synthesis report highlights the state of the practice of how transportation agencies are addressing climate adaptation through the following: adaptation frameworks/strategies; climate change risk assessments; selecting adaptation measures and strategies; long-range planning and land use; changes in design standards; maintenance and operations; asset management; and research.” (Report Documentation Page)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Commuters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topics Covered</td>
<td>• Adaptation Strategy</td>
<td>• Climate Change Vulnerability ND Risk Assessment</td>
<td>• Long range Transportation Planning and land use</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>U.S. Department of Transportation</td>
<td>John A. Volpe National Transportation Systems Center</td>
<td>55 Broadway</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>US based, International</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Highways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Climate change effects, such as changes to long-term annual average temperatures and precipitation patterns, increased frequency and intensity of storm events and heat waves, and rising sea levels, have direct implications on the planning, design, construction, operations and maintenance of transportation systems.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>“The Federal Highway Administration (FHWA) conducted a virtual international review to study how international transportation agencies are addressing issues related to the adaptation of highway infrastructure to the impacts of climate change, and to identify innovative and best</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
practices that could be implemented in the United States to help advance the development and implementation of adaptation strategies.” (p. 1)

**Context**
“The activities of the international transportation agencies included in this review offer valuable insights into how to transportation agencies globally are beginning to adapt infrastructure to anticipated climate change impacts. The cost of adapting the transportation network to climate change is much greater than the funding currently available for adaptation. Additionally, each agency faces similar uncertainties in terms of climate models, unknown future carbon emission levels, and the timing and extent of anticipated impacts.” (p. 28)

**Tools**
An adaptation framework or strategy is a foundation for an organization to implement adaptive actions. Several of the transportation agencies that participated in the review are employing systematic methods to address some of the inherent uncertainties and to manage the associated risk. The purpose of a climate change risk and/or vulnerability assessment is to determine how climate change may impact an agency’s transportation assets and prioritize measures to maximize impact and minimize costs. Changes being implemented in long-range planning and land-use processes.

**Noteworthy Aspects**
The report highlights proactive actions that international transportation agencies are taking to address uncertainties connected to climate change and to manage the associated risks.

**Captivating Value**
“The adaptation efforts for transportation infrastructure underway in these countries are diverse in scope and application, reflecting a broad array of geographic, environmental, and societal conditions much like those found across the United States.”(p.1)

**Decision Question**
N/A

**Decision Maker**
N/A

**Relevance**
Adapting transportation infrastructure to anticipated climate change impacts is critical to avoiding or at least minimizing potential damage, disruption in service, and safety concerns.

**Status**
Stage of planning for US, Implementation internationally

**Critical Assessment**
N/A

**Additional Comments**
N/A

**Essential Vocabulary**
N/A

**Potential Keywords**
Climate Change
Adaptation
International Practices
Transportation planning
Strategic framework
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>Report to Congress of a performance audit</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Members of Congress</td>
</tr>
<tr>
<td>Abstract</td>
<td>GAO was asked by Congress to review transit system resilience to catastrophic events. GAO examined and reported on three areas: “(1) how DHS and DOT help transit agencies make their systems resilient; (2) actions that selected transit agencies take to make their systems resilient; and (3) the challenges transit agencies face with making their systems resilient.” (p. 3) “GAO examined documentation and interviewed officials from DHS and DOT, and officials from nine transit and five emergency management agencies. GAO did not make any recommendations in this report. DHS and DOT provided technical comments, which were incorporated as appropriate.” (Highlights) ...</td>
</tr>
<tr>
<td></td>
<td>“Although all the transit agencies GAO selected are taking resilience building actions, GAO also found that transit agencies face challenges with placing priorities on resilience and with certain aspects of some grant programs.” (Highlights)</td>
</tr>
</tbody>
</table>
| Populations Referenced | The Government Accounting Office “examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations and other assistance to help Congress make informed oversight, policy and funding decisions.” (p. 42) In this report GAO examined the role, responsibilities and grant programs of the following federal departments and administrations as they relate to transit agencies:  
- US Department of Transportation  
  - Federal Transit Administration  
  - Federal Highway Administration  
- US Department of Homeland Security  
  - Transportation Security Administration  
  - Federal Emergency Management Administration |
|               | In addition to these federal agencies, nine transit agencies and five local emergency management offices in five metropolitan areas were selected to be interviewed as a representative population on their observations on DOT and DHS assistance in helping transit agencies make their systems resilient to catastrophic events. |
### Topics Covered

“In response to the risks posed by man-made and natural disasters, such as acts of terrorism and severe weather over the past decade the federal government has emphasized the need to improve the resilience of the nation’s critical infrastructure.” (p. 5) This report examined the effectiveness of the activities of DHS and DOT to assist transit agencies with resiliency and provided:

- a summary of the federal policies that address resilience in the context of homeland security and natural disasters
- a review of the funding assistance available to transit agencies for resilience activities from DHS and DOT
- a summation of the variety of actions transit agencies take to make their transit systems resilient
- a summation of the most frequently cited challenges transit agencies face improving the resiliency of their systems including:
  - placing priority on resilience
  - with certain aspects of grant programs
- concluding observations

### Type of Sponsoring Agency or Organization

“The Government Accountability Office was requested by the US Congress to review transit system resilience to catastrophic events. The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people.” (p. 42)

### Geographic Distribution

All of the United States

### Type of Transit Mode(s)

Transit modes focused on in the GAO review included rail transit (light rail, heavy rail, commuter rail), bus, and ferry systems.

### Type of Vulnerability

All vulnerabilities affected by natural disasters including: Heat-high Days, Extreme Cold, Severe Storm Events, Coastal Storms, Flooding/Sea-level Rise, Winter Storms, Earthquakes and Wildfires,

### Goals and Motivations

Congress asked GAO to identify how public transit agencies make their systems resilient to catastrophic events and how DHS and DOT help transit agencies towards that end.

### Context

“To identify actions selected transit agencies take to make their systems more resilient, GAO reviewed documentation and interviewed officials from nine transit agencies and five metropolitan areas: Los Angeles Region, California; Miami, Florida; Philadelphia, Pennsylvania; Seattle/Puget Sound Region, Washington; and Washington, D.C. These areas are among the 10 largest metropolitan areas in terms of transit ridership and were selected to obtain variation in geography, types of risks and transit modes.” (p. 4-5)

The transit agencies interviewed by GAO identified a number of actions that help improve their systems’ resilience, including actions that help them prepare for, respond to, recover from, and mitigate the impacts of emergencies and catastrophic events. All nine transit agencies interviewed have developed plans to help make their systems resilient, which can be categorized as those that address all hazards or those that address specific hazard. Examples of plans include:

- Continuity of operations plans
- Emergency operations, management, or preparedness plans
- Hurricane plan
- Landslide mitigation action plan

GAO found that transit agencies perform assessments to identify risks to their transit systems so that they can make informed decisions to mitigate the risks and improve resilience.

Additionally, GAO was shown or told about efforts by the transit agencies to create “redundant
facilities or transit assets to help ensure continuity of service if a portion of a system or facility is damaged during catastrophic event.” (p. 22)

GAO was also told of a variety of challenges that make it difficult for transit agencies to place priority on resilience activities. The most frequently cited challenges include:

1. Resilience may not be a priority for transit agency managers because catastrophic events occur infrequently.
2. Resilience activities compete with other priorities for funding.
3. Federal funds are not always available for transit systems’ resilience and limits their ability to undertake activities that could help make their systems resilient.

To a lesser degree other challenges identified by transit agencies, “include (1) incorporating resilience into transit agency planning or project design; (2) limited ability for smaller transit agencies to address resilience because of their size (such as limited staff and funding resources); (3) limited flexibility in addressing local or transit agency risks; (4) limitations with federal grant requirements (such as a requirement to provide a percentage of non-federal funds to FEMA-funded projects); (5) aging infrastructure; and (6) duplication and redundancy across federal efforts.” (p. 28(footnote))

| Tools | The report cites numerous examples to clarify or validate statements and findings. For instance, GAO noted that “according to FTA officials, activities to build resilience in transit systems are eligible capital expenses under these programs.” (p. 14) The report then noted that as an example, “a transit agency could use Sections 5339 – Bus and Bus Facilities Program funds to build a new bus facility on higher land to make it less vulnerable to floods.” (p. 14-15) |
| Noteworthy Aspects | Several of the transit agencies interviewed have implemented strategies and/or initiatives that are noteworthy: |
| | • “Philadelphia’s SEPTA performs a six-stage risk assessment on all of its transit stations.” (p. 21) |
| | • “Los Angeles County Metropolitan Transportation Authority has conducted risk assessments to identify areas susceptible to mudslides and as a result, has funded the building of retaining walls and fences to stop debris from falling on to the rights-of-way in those areas.” (p.21) |
| | • “Several transit agencies have built, are building, or have requested funding to build backup command, control, or communications centers to direct transit operations in case the main center is affected by a catastrophic event. Some of these centers are mobile in nature so that they can change their location as needed.” (p.22) |
| | • “Los Angeles area’s Orange County Transportation Authority uses buses powered by natural gas to provide bus service, but this agency also maintains a small contingency fleet of diesel-powered buses in ready condition that can be placed into service immediately in an emergency should the supply of natural gas to the region be interrupted.” (p. 23) |
| | • “Seattle/Puget Sound Region’s Washington State Ferries has ferry terminals that are susceptible to damage during an earthquake. To ensure that ferry service can continue in the event of an emergency, this agency has built terminals with more than one berth to increase the chances that at least one berth will remain functional to some level following a major earthquake.” (p.23) |
| | • “Seattle/Puget Sound region’s King County Metro Transit has a memorandum of understanding with the City of Seattle’s Department of Transportation which defines and coordinates the actions each agency will take during snow events.” (p. 24) |
| | • “Miami-Dade Transit made changes to better protect its electrified third rail and reduce
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>It is difficult for transit agencies to place priority on resilience activities because managers may be reluctant to focus on resiliency when they compete with other priorities for funding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Question</td>
<td>GAO did not make any recommendations in this report to Congress.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>The report is directed to and for the benefit of Congress. The information received from the selected transit agencies and emergency management organizations provides a valuable resource for transit agency managers and emergency responders.</td>
</tr>
<tr>
<td>Relevance</td>
<td>This document was selected because the request of Congress to review transit system resilience to catastrophic events aligns closely with the objectives of this study, which include reviewing current research and developing guidelines, strategies and tools for public transit agencies to make their systems more resilient to natural disasters and climatic events. The document describes the activities of several transit agencies to improve the resiliency of their systems, which should be investigated further, as well as capturing obstacles identified by the transit agencies in implementing resiliency projects.</td>
</tr>
<tr>
<td>Status</td>
<td>The report is complete.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>This document contains valuable information with respect to the interaction of the Federal Government and transit agencies to improve transit system resilience to catastrophic events. GAO was provided unrestricted access to the federal agencies and the report reflects accurately the federal funding programs available to transit agencies for resiliency efforts. Though limited in number, the transit agencies interviewed are among the 10 largest metropolitan areas in terms of transit ridership and were selected to obtain variation in...</td>
</tr>
</tbody>
</table>

damage and replacement costs. This transit agency uses cover boards to protect the electrified third rail that supply power to its trains. Hurricane winds ripped off cover boards in some places, which prompted them to look for better solutions to protect the third rail. As a result, newly designed cover boards where installed that allow winds to flow through the cover, rather than catch the wind—thus allowing the cover boards and the third rail to better withstand hurricane winds.” (p. 25-26)

• “Philadelphia’s SEPTA changed its roadside curbs and subway vents to reduce subway flooding. Subway flooding occurs, in part, because water accumulates near roadside curbs that have deteriorated, thus allowing water to enter vents that provide air to the underground train system. To remedy the problem, the transit agency raised curbs or vents throughout the city to minimize water flow into the vents. Prior to implementing this renovation, the transit agency had previously relied on a strategy of covering vents susceptible to flooding with plywood and sand bags in advance of large storms, but this process was labor intensive and dependent on how much time was available before a storm.” (p. 26)
geography, types of risks and transit modes. Consideration should be given to ensure challenges and opportunities unique to small and mid-sized transit agencies are not overlooked in further study.

**Additional Comments**

Key GAO staff involved with this report should be interviewed and the transit agencies identified in the report considered for case studies.

**Essential Vocabulary**

The report contained the following definitions:

- “Resilience is the capability to prepare for, respond to, recover from, and mitigate the risk of catastrophic events.” (p. 2)
- “The Federal Transit Administration (FTA), under its Emergency Relief Program, defines ‘resilience’ as ‘the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions such as significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.’ (p. 2 (footnote))
- “FTA defines a ‘resilience project’ as “a project designed and built to address existing and future vulnerabilities to a public transportation facility or system due to a probable occurrence or recurrence of an emergency or major disaster in the geographic area in which the public transportation system is located, and which may include the consideration of projected changes in development patterns, demographics, or climate change and extreme weather patterns.” 49 C.F.R. § 602.5.” (p. 2 (footnote))

**Potential Keywords**

- Resiliency
- DHS
- Grants
- FEMA
- challenges
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Website/Source</strong></td>
<td><a href="http://njadapt.rutgers.edu/docman-lister/resource-pdfs/119-transportation/file">http://njadapt.rutgers.edu/docman-lister/resource-pdfs/119-transportation/file</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Document Type</strong></td>
<td>Current Practice Scan and Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intended Audience</strong></td>
<td>State and local decision-making officials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
<td>The NJ Climate Adaptation Alliance requested a transportation sector report on the current state of practice in the state on climate adaptation activities within transportation agencies. The report identifies a list of recommendations that transportation sector agencies may implement within their agency to enhance, improve and address climate change and to begin the process of incorporating such issues into business practices.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Populations Referenced</strong></td>
<td>Transportation agencies and decision makers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Topics Covered** | - Background on the transportation sector in New Jersey;  
- The approach used to conduct this practice scan to include description of those agencies the study team consulted with and invited to participate;  
- A summary of findings based on the interviews conducted and the challenges encountered during the process; and  
- Author insights on the following topics.  
  - Policy & Planning  
  - Infrastructure & Maintenance  
  - Hazard Mitigation & Infrastructure Adaptation |
| **Type of Sponsoring Agency or Organization** | The New Jersey Climate Adaptation Alliance, a nonprofit organization. |
| **Geographic Distribution** | The report is centric to New Jersey and those entities which operate or conduct business within the borders of the state. |
| **Type of Transit Mode(s)** | ALL |
| **Type of Vulnerability** | Heat-high Days, Extreme Cold, Severe Storm Events, Coastal Storms, Flooding/Sea-level Rise |
| **Goals and Motivations** | The goal of the report was to engage with stakeholders in the state to understand their current practice for addressing climate change and to identify recommendations agencies may implement to further the considerations of climate change into agency planning and decision making. |
| **Context** | The state of New Jersey is home to a number of transportation agencies and transit agencies including Amtrak, New Jersey Transit, SEPTA, multiple Ferry operators, private and public bus fleets, etc. The network complexity, combined with the current policy environment in New Jersey |
and divergent opinions of climate change and its potential impacts among political leaders, makes climate preparedness planning and adaptation in New Jersey a significant challenge. Though, context of climate change may allow for solutions.

<table>
<thead>
<tr>
<th>Tools</th>
<th>No tools were presented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noteworthy Aspects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• To address climate change, there was a need to couch the conversation in terms of extreme weather events. Climate change language was a non-starter for some agencies.</td>
</tr>
<tr>
<td></td>
<td>• The report provides a great introductory view on the topics which need to be discussed at the agency level.</td>
</tr>
<tr>
<td></td>
<td>• Weather events prompted action as opposed to proactively addressing extreme weather events through mitigation and planning efforts.</td>
</tr>
<tr>
<td></td>
<td>• There are a number of specific actions and adaptation strategies being undertaken which build towards a larger menu of strategies for agencies across the nation to consider.</td>
</tr>
<tr>
<td></td>
<td>• The report outlines specific policy and planning, infrastructure and maintenance and adaptation recommendations needed across the state.</td>
</tr>
<tr>
<td></td>
<td>• As part of the recommendations, the report highlights the need for staff to be able to communicate the importance of climate change to higher levels of decision makers and those decision makers which form boards with varying interest and power structures.</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>“The degree to which adaptation activity has advanced varies widely across agencies and modes. This may be a result of available resources (or lack thereof) and/or a matter of internal agency prioritization. Fiscal constraints and austerity have favored a focus on short-term needs over longer term resiliency. Activity also varies by geography, with more activity occurring among agencies and authorities in the northern New Jersey and among stakeholders responsible for infrastructure in coastal areas and along riverine corridors versus inland areas. This pattern is consistent with perceived vulnerabilities among stakeholders.” (p. 8)</td>
</tr>
<tr>
<td>Decision Question</td>
<td>What steps should be made to incorporate climate change into the discussion for making planning and infrastructure decisions?</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Transit agencies and authorities.</td>
</tr>
<tr>
<td>Relevance</td>
<td>• A list of recommendations was developed touching on the major headings of policy, design, finance, systems planning, and asset management.</td>
</tr>
<tr>
<td></td>
<td>• Some gaps or potential pitfalls agencies may run into include addressing political views and policy at the agency and decision-making levels, funding and knowledge of climate change data and vulnerabilities. Some solutions are to address climate change under the auspicious of extreme weather events and to seek federal and state legislation requiring climate change to be considered forcing funding to be allowed for such use.</td>
</tr>
<tr>
<td>Status</td>
<td>The report looked at several agencies that are all at varying stages of planning.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The reports intent was to identify the gaps and provide recommendations for filling those gaps. The list of recommendations follow closely to the proposed areas of focused in the TCRP project and may provide a great general baseline for things agencies need to consider ahead of outlining an approach to address climate adaptation.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Climate Change</td>
</tr>
<tr>
<td></td>
<td>Recommendations</td>
</tr>
<tr>
<td></td>
<td>Mitigation</td>
</tr>
<tr>
<td></td>
<td>Challenges</td>
</tr>
<tr>
<td></td>
<td>Policy</td>
</tr>
<tr>
<td></td>
<td>Planning</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Research/planning white paper

### Intended Audience
MTA Blue Ribbon Commission

### Abstract
An independent study outlining the necessary steps MTA should be taking to address climate change for later selected use by the MTA Blue Ribbon Commission as it develops its final report.

### Populations Referenced
Stakeholders (including jurisdictions), MTA, PATHNYNJ, Amtrak, NJTransit

### Topics Covered
- Steps in assessing climate change and adaptation;
- Climate change scenarios and projections;
- Vulnerability assessment and detailed impacts and adaptation options for consideration across multiple planning horizons;
- Detailed vulnerabilities by hazard type;
- A list of recommendations providing a path forward for establishing an MTA climate change adaptation plan and integration into the culture of MTA.

### Type of Sponsoring Agency or Organization
The authors are from the Lamont-Doherty Earth Observatory and the Center for Climate Systems Research at Columbia University.

### Geographic Distribution
What geographic area does this document address? Please consider:
- Regional
- Large Urban
- NY (NYC, Long Island), CT

### Type of Transit Mode(s)
Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, Demand Response, Ferry Stations

### Type of Vulnerability
Sea level rise, temperature changes including heat waves, precipitation changes including drought & flooding and coastal storm.

### Goals and Motivations
Climate change has affected MTA and therefore requires the agency to address the issue through adaptation.

### Context
MTA ad the region in general has several critical intersections of infrastructure and services including all modes. In addition to MTAs services, Amtrak, NJ Transit, PANYNJ and other service providers including various ferryboat agencies all cross serve customers and interact accordingly.

### Tools
N/A

### Noteworthy Aspects
- To begin the process of addressing climate change, agencies need to adopt a General Adaptation Policy to guide leadership and the agency. The policy “should include the mandate to develop a set of general performance standards for its facilities and
operations vis-à-vis climate change; the *implementation* of these policies will require, in turn, agency-wide *vulnerability assessments* of... physical assets and operations; an *engineering based feasibility assessment of remediation options* with estimates of the economic, environmental, and social costs and benefits associated with the various risk reduction measures; [Agency] actions may require extensive *cooperation and integration* with other stakeholders, agencies, governments, communities and planning organizations.” (p. 4)

- Climate change plans must be fully integrated into fiscal planning and long-range planning and capital spending plans.
  - The document recommends developing a solution “for different time horizons: a *short-term* horizon for the next decade or less; a *mid-range* horizon of several decades; and a *long-range* preview on the order of a century or even longer.” (p. 5)
  - The longer range planning would require a more integrated approach to planning to include land use as well as consider longer term climate change impacts such as sea-level rise.

- Outlines an “Adaptation Assessment” process:
  - Identification of assets/service subject at risk to climate change. This would entail an agency-wide inventory of infrastructure and operations, whereas at a minimum infrastructure is essential.
  - Identify main climate change impacts. Prior reports show the MTA is at risk to heat, increased intense precipitation, seal level rise and coastal storm surge. “The risks will be realized by changes in the frequency, intensity and duration of extreme events including heat waves, droughts, inland and coastal flooding, saltwater intrusion, and the effects of heat and humidity on people (customers and workforce), buildings and materials.” (p. 6)
  - Apply climate change scenarios into future time slots. Modeling and research can provide estimates into the future by timeframe to support analysis.
  - Characterize adaptation options (e.g. management, operations, policy, design and construction)
  - Conduct feasibility study of options. This may include a cost-benefit analysis which shows some options are more expensive than others which accomplish the same goal.

- The study outlines the projection and risk of climate changes focusing on temperature change, coastal storm inundation and sea-level rise and precipitation.

- Study recommends:
  - MTA leadership take an active role in addressing sustainability and climate change;
  - Immediately establish an internal Adaptation Team (white paper’s date is October 2008);
  - By mid-2009, MTA should establish a base adaptation policy;
  - By 2009, MTA should establish an Adaptation Priority Task Force;
  - By end-2009, MTA should have a Climate Adaptation Resiliency Evaluation (CARE) procedure established to evaluate any new or major infrastructure alterations occurs below ‘x’ elevation;
  - By 2010, MTA should establish a climate database containing information on future trends and parameters of climate data addressing the climate change vulnerabilities;
  - By 2012, MTA should complete a thorough vulnerability and risk assessment;
  - “a *systematic and quantitative assessment* of MTA’s vulnerabilities to varying current and future climate conditions using proven engineering and risk management methods” (p. 18) as opposed to simple/ad hoc surveying of selected infrastructure and personnel.
  - By 2015, MTA should complete a Strategic Climate Change Adaptation Master Plan;
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

RCR-41: Literature Review

| Captivating Value | Although it is independent, the study outlines a timeframe and process for establishing and integrating climate change into an agency. However, it starts at the top with leadership buying into the importance for climate change adaptation. |
| Decision Question | What process, procedures, and policies outlines within the white paper will MTA utilize in establishing a program that addresses climate change adaptation? |
| Decision Maker | MTA |
| Relevance | The white paper provides a framework for a detailed process for agencies to follow it address climate change adaptation as well as some early processes for developing vulnerability assessments. It is one of the first documents specific to transit which tackles climate change adaptation. |
| Status | This white paper was an initial piece of research in 2008 following a severe storm which impacted MTA. It identified the Blue Ribbon Commission as an entity looking at climate change which released a final report in 2009 (“Greening Mass Transit and Metro Region: The Final Report of the Blue Ribbon Commission on Sustainability and the MTA”). |
| Critical Assessment | The white paper seems a bit ahead of its time as many documents are from the last several years. However, the paper outlines a great timeline for agencies to consider in establishing climate adaption plans and reports. It also highlights significant considerations such as establishing leadership backing. The report also provides some steps in conducting what the author’s call an “adaptation assessment.” Many of these steps are including the current vulnerability assessment steps used by transit agencies, particularly those funded through the FTA Pilot Studies. However, I found the outline provided to have a bit more detail in some of the steps. |

By 2015, MTA Should establish a pre-disaster plan for post-disaster redevelopment in coordination with stakeholders;
- Close coordination with “many stakeholders and jurisdictions in the NYC metro region, based on risk assessment and feasibility-, engineering and financial studies that need to be performed at various degrees of detail commensurate with the importance of the issues at stake.” (p. 18)

Establish a checklist for mitigation projects which identifies how the project effects short and long-term planning horizons;
- The study outlines detailed list of potential impacts as well as short, mid and long-term solutions to those impacts addressing all modes. As just one example, the study outlines 8 temporary/short-term fixes, 4 mid to long-term options, and 6 long-term ideas just to address NYC subways and Staten Island Railway. These do not include options for bus operations, Metro-North and Long Island Rail Road, and bridges and tunnels, etc.

- Example adaptation options identified include:
  - Moving rolling stock prior to coastal storm;
  - Sandbagging low-lying buildings;
  - Developing evacuation plans/procedures;
  - Implementing fare suspension prior to pending storm;
  - Establish bus service with flexible routing;
  - Provide backup power at refueling locations;
  - Installation of floodgates and closure of grates during storms;
  - Raising curbs at ventilation gates and subway entrances;
  - Increase pump capacity to remove water from tunnels;
  - Establish capability of mobile pump capacity;
  - Increase stormwater capacity in coordination with other agencies;
  - Work with other agencies to establish codes, regulations and incentive programs to reduce runoff; etc.
Overall, the paper seems to accomplish its goal of providing significant background for the Blue Ribbon Panel to pull information from to craft their report.

<table>
<thead>
<tr>
<th>Additional Comments</th>
<th>N/A</th>
</tr>
</thead>
</table>
| Essential Vocabulary | Adaptation Assessment  
                        | Recommendations  
                        | Integration  
                        | Planning  
                        | Policy |
| Potential Keywords  | N/A |
| Document Type | Policy | X | X | X |
| Intended Audience | DOT modal transit administrators. |
| Abstract | USDOT Climate Adaptation Policy per EO 13514 outlining that the US DOT will integrate and consider climate change impacts into its planning, policies operations and programs at DOT. |
| Populations Referenced | DOT modal transit administrators. |
| Topics Covered | Federal stance on agency requirement to address climate change into business practices. |
| Type of Sponsoring Agency or Organization | Federal |
| Geographic Distribution | Applicable to DOT modal administrations. |
| Type of Transit Mode(s) | All |
| Type of Vulnerability | All |
| Goals and Motivations | Per Executive Order 13514 includes the direction that US DOT will address climate adaptation. |
| Context | N/A |
| Tools | See Relevance for framework. |
| Noteworthy Aspects | All agencies within DOT shall  
• “Analyze how climate change may impact its ability to achieve its mission, policy, program, and operation objectives.  
• Report annually on its accomplishments in implementing climate adaption strategies.  
• Coordinate actions with the Senior Official responsible for implementing climate adaptation and the Center for Climate Change Steering Committee member.  
• Implement climate change adaptation implementing instructions issued by CEQ.” (p. 3) |
<p>| Captivating Value | Provides government confirmation this should be done providing background information as to why this project is important - The United States Department of Transportation (DOT) shall integrate consideration of climate change impacts and adaptation into the planning, operations, policies, and programs of DOT in order to ensure that taxpayer resources are invested wisely and that transportation infrastructure, services and operations remain effective in current and future climate conditions. The climate is changing and the transportation sector needs to prepare for its |</p>
<table>
<thead>
<tr>
<th><strong>Decision Question</strong></th>
<th>The US DOT is issuing the policy statement in response to EO 13514. A decision is not really being made but recognizing the EO and outlining how the agency will address it.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decision Maker</strong></td>
<td>DOT transit administrators, transit agencies</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>Document outlines USDOT Guiding Principles to include:</td>
</tr>
<tr>
<td></td>
<td>- Adopt integrated approaches;</td>
</tr>
<tr>
<td></td>
<td>- Prioritize the most vulnerable;</td>
</tr>
<tr>
<td></td>
<td>- Use best available science;</td>
</tr>
<tr>
<td></td>
<td>- Build strong partnerships;</td>
</tr>
<tr>
<td></td>
<td>- Apply risk management methods and tools;</td>
</tr>
<tr>
<td></td>
<td>- Apply ecosystem-based approaches;</td>
</tr>
<tr>
<td></td>
<td>- Maximize mutual benefit; and</td>
</tr>
<tr>
<td></td>
<td>- Continuously evaluate performance. (p. 2)</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>Overall, it provides a basis as to why we’re doing this project. Perhaps information could be gleaned for the intro section of the synthesis report but won’t help too much with the detail.</td>
</tr>
<tr>
<td></td>
<td>An interesting note which I haven’t seen too much of in other documents is the application of eco-system-based approaches. Per the policy statement “Integrating the protection of biodiversity and ecosystem services into adaptation strategies will increase resilience of human and natural systems to climate and non-climate risks…” (p. 2)</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>Policy in reference to Executive Order (EO) 13514 –Federal Leadership in Environmental, Energy, and Economic Performance. The EO includes direction to address climate adaptation planning. Additionally, the Secretary of Transportation has authority under 49 United States Code (U.S.C.) Section 322 –General Powers.</td>
</tr>
<tr>
<td></td>
<td>The detail under the relevance section follows the FTA framework but the DOT policy has a bit more detail on what those principles include. That detail was not added as I did not think it provides additional understanding to what each principle step means.</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source

### Focus Area(s)
- **Policy and Administrative Procedures**
- **Systems Planning**
- **Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction**
- **Asset Management**
- **Operations and Maintenance**
- **Emergency Preparedness, Response, and Recovery**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Document Type
Research paper – Academic Thesis

### Intended Audience
The document was developed as part of an academic thesis paper and therefore intended for the authors academic institution but may be helpful for NY MTA and other transit agencies.

### Abstract
As a result of Hurricane Irene and Post-tropical Storm Sandy, the MTA was faced with challenges to respond to such events driving the agency to address climate change within the agency. The thesis paper compares the MTA to a number of other public transportation agencies throughout the eastern part of the United States to determine how MTA stacks up in addressing climate change. Success is measured by the progress and quality of the following criteria: “1) completing an asset inventory; 2) adopting an adaptation policy; 3) completing a risk assessment; 4) developing a plan for protecting infrastructure from flooding; 5) creating a plan for improving communication before and during extreme weather events.” (p. 12)

### Populations Referenced
Transit Agencies: NY MTA, New Jersey Transit, Hampton Roads Transit

### Topics Covered
- Best Practices in adaptation planning
- Vulnerability assessments
- Adaptation Planning Progress among transit agencies
- Government Policy Impacts

### Type of Sponsoring Agency or Organization
Columbia University as part of a research thesis paper.

### Geographic Distribution

### Type of Transit Mode(s)
Commuter Bus, Passenger Rail, Heavy Rail, Light Rail

### Type of Vulnerability
Coastal Storm, Flooding, Sea-level rise, Precipitation

### Goals and Motivations
To identify where NY MTA stands among fellow transit agencies in address climate change.

### Context
“The MTA in New York City operates subway, commuter rail, and bus service. It serves the New York City, counties north of the city, and two counties in Connecticut, and it has the highest ridership in the United States.” (p. 14)
“New Jersey Transit (NJT) is a statewide public transit agency and the largest statewide transit agency in the United States. It operates light rail, commuter rail, and bus service and is the third busiest transit provider in the country.” (p.14)

“Washington Metropolitan Area Transit Authority (WMATA) is a tri-jurisdictional agency formed by Maryland, Virginia, and Washington, D.C. and has the second highest ridership in the country. As its name suggests, it serves the Washington, D.C. metropolitan area. Like NJT, it operates light rail, commuter rail, and bus service.” (p. 14)

“Hampton Roads Transit (HRT) has a service area that includes seven cities—the largest being Virginia Beach, Norfolk, and Newport News—and 1.6 million residents. It operates light rail, bus, and ferry service.” (p. 15)

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>The paper highlights impacts to infrastructure (e.g. planning &amp; design, construction and maintenance) Operations (e.g. efficiency, safety, mobility, and externalities) and demand (e.g. location, timing and mode). More specifically, climate impacts can cause asset deterioration to accelerate, interrupt service, and damage infrastructure.</td>
<td>N/A</td>
</tr>
<tr>
<td>Identification of cost as a barrier to adapting infrastructure but identifies replacement at the end of life of asset as the best time to address climate change. This highlights asset management as a key to incorporating adaptation into organizations. Other strategies include inventorying assets to identify vulnerabilities and to inform asset management decisions based on life cycle of assets. This information can all lead into an asset management plan which utilizes the asset management system to incorporate asset vulnerability as a factor. Additional asset management system uses include:</td>
<td></td>
</tr>
<tr>
<td>(p. 10)</td>
<td></td>
</tr>
</tbody>
</table>

The literature reviewed as part of the paper identifies additional TRB recommendations including updates to design standards.

Planning issues identified include utilizing outdated climate or weather calculations. For example, scenarios using 100 year storms to identify worst case scenarios must consider that today’s 100 year storms may be worse than a decade ago and long term, today’s 100 year storm may be more closely seen as 1 in 50 years or less.

The MTA identified 16 steps to take following a 2007 storm prior to Irene and Sandy.

- “Create early warning and response capability
- Create an MTA Emergency Response Center
• Revise agency storm operating protocols
• Standardize storm category designations
• Formalize interagency coordination/notification plans
• Develop a bus service alternative plan
• Coordinate interagency service alternatives
• Standardize procedures for communicating with operating personnel, customers and other external stakeholders
• Dramatically improve customer information
• Develop capacity for near to real-time email and text messaging service alerts
• Provide cell phone service on subway platforms
• Increase website capacity, clarity, and access to service alerts
• Improve communication between ops centers and field personnel
• Advance public address and video screens technologies to better communicate with customers in system
• Expand MTA’s current inventory of wireless video displays
• Conduct six-month progress review” (p. 20)

The paper identifies incorporation of adaptation into asset management through simply addressing climate change through adapting the replacement infrastructure at the end of its life cycle.

As of this paper, NY MTA, NJ Transit, WMATA and Hampton Roads Transit had an adaptation related document. The findings show NY MTA is well ahead of other agencies in addressing the first three components of the criteria. However, it lacks a plan to address future impacts of flooding. Hampton Roads scored the second highest through the FHWA pilot study. However, adoption of the findings and incorporation into the agency planning. It detailed the impacts of flooding to infrastructure. Overall, no agency had a climate change adaptation plan.

| Captivating Value | The paper uses research to outline that adaptation planning filters down from higher level agencies (e.g. federal regulations and decisions affect planning at local levels) which can prioritize efforts). This includes the lack of funding to address the issue may encourage lack of attention towards the issue.
|                  | • To help, transit agencies need to get involved in master plans and jurisdictional plans addressing climate change instead of relying on local government to address transportation for the agency.
|                  | • Insured infrastructure may also create a culture that finds adaptation planning unimportant.
|                  | • In its conclusion, the paper states agencies should focus on short-term adaptation strategies until federal requirements and funding becomes available.
|                  | The paper find that MTA’s Blue Ribbon Sustainability Commission report is a best practice model agencies may use which addresses asset inventory, adaptation policy and risk assessment.
|                  | New Orleans used the cities Hazard Mitigation Plan for incorporating adaptation strategies in terms of hazard mitigation. Though the study found a lack of coordination, it may be another vehicle for agencies to address climate change. |

| Decision Question | N/A |
| Decision Maker   | N/A |
### Relevance
- Outlines use of asset management to address climate change;
- Identifies potential case studies for those agencies who have addressed adaptation; and
- Identifies one bests practices for starting to address climate change.

### Critical Assessment
The thesis outlines the current state of practice among public transportation agencies along the eastern part of the US resulting in the identification of a best practice to be used to begin the process of addressing climate change by transportation agencies.

### Potential Keywords
Climate change
Policy
Asset Management
| Document Type | Agency Report |
| Intended Audience | MTA including leadership |
| Abstract | A final report from a commission, initially charged in 2007, to develop a series of recommendations for MTA to follow in an effort to enhance sustainability through reduction in carbon footprint and energy consumption. |
| Topics Covered | • Energy/Carbon • Facilities • Smart Growth/Transit-Oriented Development • Materials Flow, Water Management; and • Climate Adaptation |
| Type of Sponsoring Agency or Organization | Metropolitan Transportation Authority |
| Geographic Distribution | What geographic area does this document address? Please consider: • Regional • Large Urban • NY (NYC, Long Island), CT |
| Type of Transit Mode(s) | Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, Demand Response, Ferry Stations |
| Type of Vulnerability | Sea-level rise, temperature changes including heat waves, precipitation & flooding and coastal storm. |
| Goals and Motivations | “expand the greening power of transit to more riders and communities, while managing and reducing the MTA’s per-rider energy consumption and environmental footprint.” (p. 5) |
| Context | MTA and the region in general has several critical intersections of infrastructure and services including all modes. In addition to MTAs services, Amtrak, NJ Transit, PANYNJ and other service providers including various ferryboat agencies all cross serve customers and interact accordingly. |
| Tools | N/A |
| Noteworthy Aspects | Key recommendations from the BRC report for climate adaptation are: • “The MTA should develop a climate adaptation decision matrix to identify options for protecting transit infrastructure from storm surge, extreme heat, and other manifestations of climate change. |
- The MTA should implement a Climate Adaptation Resiliency Evaluation procedure (CARE), which would be activated when any new projects or major alterations are undertaken where critical structural components are located in present or potential coastal surge flood zones.” (p. 11)

The report in 2009 identified the need for federal leadership and funding to address climate change adaptation plans, programs and strategies.

Recommendation from the TOD section identifies the promotion of transit as a “climate-stabilization strategy.” (p. 37)

Some potential adaptation strategies may be found through water management. Examples include raising grates to prevent tunnel flooding and utilize green roofs and other green infrastructure to reduce water runoff. Simply controlling runoff and managing wastewater by both MTA and other stakeholders may limit flooding impacts.

The report outlines 3 climate trends affecting MTA:
1) higher temperatures (The number of days over 100 degrees has increased from 2 in 1990 to 8 at the time of this report.);
2) sea-level rise and the associated storm surge (Even without storms, SLR will affect operations, emergency planning and facility design. Greatest impact is expected by subway tunnels and stations.); and
3) more severe precipitation events related to flooding (Most impact place on tunnels, tracks and water management [e.g. pump capacity]).

Adaptation options identified include:
- Integrate evacuation plans with plans to relocate and protect MTA assets and rolling stock during a storm;
- Inspection of existing or planned facilities within flood-prone areas;
- Reevaluation of internal insurance programs and the possible benefits of outside insurance;
- Utilize wastewater management practices with adaptation benefits;
- Increased pump capacity form tunnels;
- Raising subway entrances, curbing and ventilation grates;
- Tunnel sealing;
- Develop strategic barriers for the NYC harbor;

At the time of this report, adaptation efforts have been moving forward within the agency on an ad hoc basis but MTA is involved in several external task forces and groups looking at the problem through a coordinated effort.

As a result of a powerful storm which caused widespread impacts due to flooding, the MTA has begun addressing 17 initiatives based on a post-event report. Examples: “In operations, projects include the establishment of early warning and response capabilities, procedures, and teams; the creation of an MTA emergency response center (ERC); and a revision of the agency storm operating protocol. The engineering initiatives include corrective engineering and procedural measures at some of the most notorious flood-prone locations, often involving close cooperation with and capital expenditures by the New York City DEP and DOT. Communications initiatives include a contract to install wireless communication capabilities that will allow the use of cell phones in subway stations. Six subway stations are scheduled to be cell-operational by the end of 2010 and all 270 underground stations should be...
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>The recommendations for climate change are broken into “transformational” (or business practices) and near-term. Most are similar or the same as those outlined within the white paper by Jacob, et. al.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformational:</td>
<td>“Develop and implement a Climate-adaptation Decision-Making Matrix” (p. 59). This matrix example provided is an outline of a general risk matrix with value (consequence) and risk on the two axis. This is not necessarily the MTA matrix developed/being developed.</td>
</tr>
<tr>
<td>Near-Term:</td>
<td>1) “Adopt MTA Climate-Adaptation Policy Position” (p. 59) 2) “Implement Operational Climate Change Database” (p. 59). This entails a database of climate data and trends. 3) “Complete a Quantitative Vulnerability and Risk Assessment” (p. 60) 4) “Develop a Climate Change Adaptation master Plan” (p. 60) 5) “Establish a Pre-Disaster Plan for Post-Disaster Redevelopment (PDP-PDR)” (p. 60) 6) “Create an Adaptation Priority Task Force (APT)” (p. 60) 7) “Assign an MTA-Internal Adaptation Team (AT)” (p. 61) 8) “Prepare Adaptation/Mitigation Cross-Impact Checklists” (p. 61) 9) “Implement Climate Adaptation Resiliency Evaluation Procedure (CARE Trigger Elevation)” (p. 61) 10) “Provide Visible MTA Leadership on Climate Change Issues” (p. 61)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Question</th>
<th>What will MTA do next to address the report?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>MTA</td>
</tr>
<tr>
<td>Relevance</td>
<td>The result of an effort since 2007 to begin tackling an overall strategy for sustainability for the NYC MTA. This includes a section on climate change which highlights a series of recommendations for TA to consider and address in the future.</td>
</tr>
<tr>
<td>Status</td>
<td>Some recommendations have timelines such as having a Climate Adaptation Master Plan by 2015. The document leaves off with next steps for MTA to consider.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>A great document providing the agency context to review and to begin addressing climate change.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>“Mitigation refers to policies intended to reduce carbon emissions and other GHGs, the primary cause of global warming.” (p. 56) “Adaptation, as the term implies, refers to organizational planning, modification of built assets, and increased operational preparedness to address the anticipated effects of climate changes already underway.” (p. 56)</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Climate Change Adaptation Plan Water Sustainability Mitigation Greenhouse Gas Policy Planning</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source
https://www.panynj.gov/about/pdf/NYSA-Adaptation-Presentation.pdf

### Focus Area(s)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Presentation

### Intended Audience
New York Shipping Association and PANYNJ Stakeholders.

### Abstract
The presentation outlines the efforts the PANYNJ has been undertaking to address climate change. These efforts include policy

### Populations Referenced
Tenants at ports, customers which utilize PANYNJ assets and systems.

### Topics Covered
Sustainability Policy

### Type of Sponsoring Agency or Organization
N/A

### Geographic Distribution
Multistate authority in urban area with large resources and assets in the New York-New Jersey area.

### Type of Transit Mode(s)
Heavy Rail, Ferry

### Type of Vulnerability
Heat, Coastal Storm, Sea-Level Rise, Flooding, Precipitation and Wind

### Goals and Motivations
To present PANYNJ efforts to the NYSA on its adaptation program.

### Context
N/A

### Tools
Though not specified, the agency conducted a vulnerability assessment following similar steps as those outlined within the FTA Pilot studies.

### Noteworthy Aspects
- Established sustainability policy in 2008 aiming to reduce GHG emissions, promote sustainability and to “adapt facilities to reduce climate change risks”. (Slide 3)
- Developed a vulnerability analysis looking at climate change predictions related to temperatures and precipitation as well as sea-level rise. As part of the process, developed an internal inventory of assets and used federal grant to look at scenarios to prioritize funding based on weighing the risks.
- Developed sustainable design guidelines. Infrastructure design guidelines were in progress at time of presentation.
- Developed and coordinated externally.
- Briefly touches on insurance.
- Outlines various redundancy and resilience projects the PANYNJ is addressing agency wide. This includes other assets unrelated to transit (air ports, world trade center, etc.)
- Outlines challenges to adaptation to include:
Funding and budgeting (Outlined further in presentation specific to PANYNJ);
- Politics;
- Geographic and Operation Boundaries;
- Technology and Research; and
- Immediate Problem.
  - Economy, congestion and growth and aging infrastructure

- Recommendations include:
  - Adopt climate change projections to base decision on including state adopted projections.
    - Sea-Level Rise
    - Precipitation Rates
    - Temperature extremes and average
    - Wind directions
  - State and federal level guidance is needed.
  - State and federal funding is needed.

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>PANYNJ is moving forward to address resilience.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Installed flood gates to protect rail infrastructure;</td>
</tr>
<tr>
<td></td>
<td>- Sealed opening below 100 year flood plain;</td>
</tr>
<tr>
<td></td>
<td>- Built-in redundancy into substations and power grid;</td>
</tr>
<tr>
<td></td>
<td>- Spent $60M to purchase open space to preserve natural systems near infrastructure;</td>
</tr>
<tr>
<td></td>
<td>- New constructions built to reduce flood risk with flood gates and elevated structures.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Question</th>
<th>Adopt climate projections.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>Agency's</td>
</tr>
<tr>
<td>Relevance</td>
<td>An early work towards addressing climate change through sustainability efforts. The design guidelines are identified but further research is needed to see what those standards are.</td>
</tr>
<tr>
<td>Status</td>
<td>Several projects ongoing and completed. Adaptation being incorporated into major capital projects.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The resource is a presentation and further information from the PANYNJ is necessary to determine gaps in the projects and efforts outlined. It is a useful resource however to show that progress has been made, and efforts have not only started but began to be implemented in decisions.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Potential Keywords | Capital Projects
                    | Risk
                    | Climate Change
                    | Sustainable Design
                    | Flood |
| Citation | Los Angeles County Metropolitan Transportation Authority. 2012. “Climate Action and Adaptation Plan.” Los Angeles, CA. |
| X | X | X | X | X | X | X |
| Document Type | Climate Action and Adaptation Plan |
| Intended Audience | LCMTA Stakeholders |
| Abstract | Acknowledging climate change is occurring, LCMTA is working to establish a plan to further reduce GHG as well as prepare for and address the potential impacts of climate change on the agencies assets and services. The intent is to utilize the plan to prioritize efforts to reduce GHG emissions and to develop a process for addressing likely climate change impacts on the agency's system. The climate adaptation study does not provide concrete recommendations, only focuses on agency assets and focuses on system and line level assets. |
| Populations Referenced | Customers, Employees |
| Topics Covered | • Greenhouse Gas Emissions; • Asset Identification; • Climate change projections; • Vulnerability analysis; and • Identification of adaptation strategies. • Next Steps |
| Type of Sponsoring Agency or Organization | LCMTA |
| Geographic Distribution | Los Angeles County |
| Type of Transit Mode(s) | Commuter Bus, Heavy Rail, Light Rail, BRT |
| Type of Vulnerability | Heat, Precipitation, Sea-Level Rise |
| Goals and Motivations | Metro is responsible for protecting its system from the impacts of extreme weather and climate change and therefore it has developed a Climate Action and Adaptation Plan to reduce emissions and protect assets. |
| Context | N/A |
| Tools | Process for developing a climate adaptation strategy including: 1. Criticality Assessment – To reduce the “arduous” task of compiling a complete asset inventory, the agency focuses on system components required for providing service. (p. 37) Usually based on ridership or investment (p. 38) 2. Identification of Climate Impacts to Assets and Services – Focus on collecting data to identify likely climate change impacts and projections on environmental conditions (e.g. |
Additionally outline system impacts based on these projections. This may be supported by historical events such as periods of extreme heat, intense storms, etc.

3. Assess Vulnerability and Adaptation Strategies – As a function of its “exposure, sensitivity, and adaptive capacity” each asset or service can be examined. Once the vulnerability is identified, a list of potential adaptive strategies was developed to address the potential impact.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>Summary of Climate Impact and Adaptation Options (p. 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Service/Asset</strong></td>
<td><strong>Climate Impact</strong></td>
</tr>
<tr>
<td>Rail Operations</td>
<td>Equipment malfunction (electrical systems; air conditioning systems) during periods of extreme heat</td>
</tr>
<tr>
<td></td>
<td>Railway buckling during periods of extreme heat</td>
</tr>
<tr>
<td></td>
<td>Flooding of underground stations and tracks during heavy rainfall events</td>
</tr>
<tr>
<td>Bus Operations</td>
<td>Flooding of at-grade railways and (Bus Rapid Transit right-of-ways) during heavy rainfall events</td>
</tr>
<tr>
<td>New Construction/ Measure R Projects</td>
<td>Fleet breakdowns and maintenance during periods of extreme heat</td>
</tr>
<tr>
<td></td>
<td>Exposing new infrastructure to episodes of extreme heat and heavy rainfall events</td>
</tr>
<tr>
<td></td>
<td>Labor interruptions or delays during periods of extreme heat</td>
</tr>
<tr>
<td></td>
<td>• Integration of climate considerations in siting and alternatives decisions</td>
</tr>
<tr>
<td></td>
<td>• Modification of construction schedules, especially during summer months</td>
</tr>
</tbody>
</table>

As part of addressing GHG emissions, the plan calls for expanding pedestrian facilities, BRT and rail. Other strategies include vehicle technology improvements, building energy strategies, and water use strategies.

**Greenhouse Gas Emissions Next Steps include:**

- Establish agency working group to monitor implementation and progress to include using the “Sustainability Report to document strategies selected for implementation and monitoring”; (p. 61)
- Update the plan with new data and information to include future federal, state and local regulations.

**Climate Change Next Steps include:**

- Investigating climate with more precise and local data;
- Exploration of social and fiscal costs to adaptation strategies;
- Establish a communication plan; and
- Utilize FTA pilot program to explore implementing principles at operational levels.

**Captivating Value**

The use of identifying criticality or key elements to the system without assessing all assets. The criticality analysis results were provided but not the entire process. It would be interesting to see how that process unfolded and if it did not include fixed assets. It could be worth looking into to save some financial strain given the limited funding in the area of climate adaptation.

**Decision Question**

How should LCMTA move forward to address climate adaptation?

**Decision Maker**

Agency officials.
<table>
<thead>
<tr>
<th>Relevance</th>
<th>This is one of the only climate action plans for a transit agency found by the research team. It was finalized prior to the FTA pilot project being completed providing a chance for furthering already established method for proceeding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>See FTA Pilot Study as a follow-up to this study.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The plan states it’s to provide a process and not definitive recommendations. It provides a great outline of GHG emission reduction planning that has occurred at the agency and a way forward to begin addressing climate change.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>It would be interesting to see how LCMTA moved from this project into its pilot suggesting a complete asset inventory is too arduous but many pilot project recommend addressing climate change through the asset management system.</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>“For this analysis, “criticality” has been determined in a simple and qualitative manner: “critical” services and assets are those that are essential to transporting Metro’s customers. Essentially, we ask the question, “If this service or asset were removed from the transit system, would the transit system be fundamentally different?” A critical service or asset would be extremely difficult or costly to replace or to substitute.” (p. 38)</td>
</tr>
</tbody>
</table>
| Potential Keywords | Criticality  
Climate Adaptation  
Greenhouse Gas Emissions  
Impacts  
Forecast                                                                                                      |
Citation

Website/Source
https://smartech.gatech.edu/bitstream/handle/1853/48963/OHAR-DISSERTATION-2013.pdf

Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

Document Type
Partial fulfillment for dissertation and research document.

Intended Audience
Transportation agencies

Abstract
“This research develops a risk-oriented decision-making framework to identify vulnerable, higher-risk transportation infrastructure assets within the context of existing transportation asset management systems. The framework assesses the relative maturity of an agency’s transportation asset management system and provides guidance as to how an agency’s existing tools and processes can be used to incorporate climate change considerations. This risk-based decision-making framework is applied to three case studies: one at the Metropolitan Atlanta Rapid Transit Authority, another at the Metropolitan Planning Commission in Savannah – Chatham County, and a statewide case study at the Georgia Department of Transportation.” (p. xxii)

Populations Referenced
Transit agencies, FTA, FHWA, MARTA, numerous cities and states around the country, international cities and counties

Topics Covered
- Literature
- Climate Change Projections
- Criticality Assessment & Climate Change Impacts

Type of Sponsoring Agency or Organization
National Science Foundation funded this research under grant number DGE-0644493. This research was part of a PhD candidate’s dissertation out of the Georgia Institute of Technology.

Geographic Distribution
Utilized MARTA (Atlanta, GA) as the case study explored.

Type of Transit Mode(s)
MARTA operates a fleet of buses, on-demand services and rail service.

Type of Vulnerability
Seal level rise, extreme weather, heat, precipitation, artic warming, storm surge, hurricane/coastal storms, drought, cold

Goals and Motivations
“This research seeks to develop a risk-oriented decision-support framework to identify infrastructure assets that are vulnerable to potential climate change impacts within the context of existing transportation asset management systems. More specifically, the goals of this research are:
1. Review the state of practice as it relates to transportation-related climate change adaptation in the context of asset management systems,
2. Develop a risk-oriented methodology that utilizes existing transportation asset management systems to identify the most critical transportation infrastructure assets that are also the most vulnerable to potential climate change impacts,
3. Apply this methodology to case study agencies at the local, metropolitan and statewide level, and
4. Demonstrate the value of this methodology to stakeholders by strategically identifying transportation infrastructure assets that should be targeted for investment.” (p. 4)

<table>
<thead>
<tr>
<th>Context</th>
<th>MARTA is in an urban area with a large system. Specific climate change identified to impact MARTA is heat, decrease in freezing days, extreme temperatures, increase in intense precipitation events and drought.</th>
</tr>
</thead>
</table>
| Tools   | The paper outlines several step-by-step approaches or key recommendations to various topics such as planning, risk incorporation, etc. from other sources. Some examples are as follows: Steps to develop climate change preparedness plan per source referenced in this document (Snover et al. 2007) (p. 27 & 28)  
- Scope the climate change impacts to your major sectors  
- Build and maintain support among stakeholders to prepare for climate change  
- Build your climate change preparedness team  
- Identify planning areas relevant to climate change impacts  
- Conduct a vulnerability assessment  
- Conduct a risk assessment  
- Establish a vision and guiding principles for a climate-resilient community  
- Set preparedness goals in each priority planning area based on the aforementioned guiding principles  
- Develop, select, and prioritize potential preparedness actions  
- Identify a list of important implementation tools  
- Develop an understanding of how to manage risk and uncertainty  
- Develop measures of resilience to allow tracking of actions over time  
- Review assumptions to ensure relevance of plan  
- Update plan frequently  
The paper goes specifically into using “Multiple Decision Making Criteria (MCDM)” principles for scoring infrastructure assets on criticality. The method outlined under this tool allows weighting of attributes. Section 5.3 focuses primarily on the tool which can be used for highways or bridges. Both have similar organization. For bridges, factors include inventory rating, weight posting, scour criticality, facture criticality, bypass length, and condition. A bridge criticality score is calculated as the some of the attributes weighted score. |
| Noteworthy Aspects | - The literature review provides background on asset management systems.  
- Table (p. 23) outlining climate impacts and adaptation strategies is modified from another resource. (Meyer_2010)  
- Identifies need to incorporate risk at the enterprise level.  
- In considering risk assessment as part of the integration process, the International Organization for Standards has outlined a process (p. 54) |
Figure 6. ISO 31000 Risk management process (ISO 2009)

- The paper outlines types of risk applications to the asset management systems agencies may use.
  - Performance-based
    - Step 1: “gather all relevant stakeholders so they can determine a definition for infrastructure performance that is based on societal, cultural, and technical values.” (p. 56)
    - Step 2: “Determine the geographic and organizational boundaries of the infrastructure assets in a system that is interconnected and interdependent.” (p. 56)
    - Step 3: “Performance requirements should then be established” (p. 56)
    - Step 4: “Infrastructure should next be identified and documented (e.g. using geographic information system, or GIS tools) at least at the regional level.” (p. 57)
    - Step 5: “the system should be tested in a way that allows for the identification of the most critical factors that affect system-wide performance.” (p. 57)
    - Step 6 “resources can be strategically targeted at the identified critical factors.” (p. 57)
    - Step 7: “The final step involves considering the effects of the failure of one infrastructure asset on another, or the interdependencies among infrastructure assets (Aktan and Moon 2010).” (p. 57)
- The paper outlines several tools such as scenario analysis, sensitivity analysis and more.
It provides a good outline of the benefits and considerations of using the tools outlined within the literature researched for the paper. The considerations include those tools and models used for prioritization and project management.

- The paper outlines some examples where risk application is utilized with the asset management system through identifying trademark products as well as other studies conducted. Specific examples mentioned in this section of the paper are Edmonton, Canada and England’s Department for Transportation in which a scoring criterion was used to assign risk to assets. An example of the criteria for England DfT is outlined in Table 5 on Page 74.

- The paper provides some details about MARTAs criticality assessment.

### Captivating Value

The paper provides a methodology for incorporating climate change considerations into the asset management system.

“After assessing the maturity of the asset management systems, this methodology involves four primary steps. First, a criticality assessment determines what transportation infrastructure assets are most critical to a given transportation network. Secondly, potential climate change impacts for a particular geographic region assist in the identification of climate stressors. Given the uncertainty of climate projections, climate projections identify plausible future trends, and temperature and precipitation scenarios. Third, using GIS, critical transportation infrastructure is spatially superimposed over various climate stressors and scenarios. Lastly, the most vulnerable, i.e. critical and susceptible to potential climate change impacts, transportation infrastructure assets are identified. These assets can be strategically targeted for additional analysis and potential adaptation activities.” (p. 108)

From page 152 to 157, the paper outlines a series of adaptation strategies MARTA could consider by department as part of a single Table.

Table 13 (p. 162) shows how MARTAs exiting system can incorporate climate change.

<table>
<thead>
<tr>
<th>Organizational Element</th>
<th>Climate-Sensitive Activities</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy, Goals and Objectives</td>
<td>Develop climate change policy with supporting goals and objectives</td>
<td>The process of developing a formal climate change policy will assist agencies in developing their knowledge on the real risks of climate change to their operations and assets.</td>
</tr>
<tr>
<td>Staffing</td>
<td>Assess the value of staff time to address climate change issues on a periodic/consistent basis</td>
<td>Agencies that address climate issues proactively will be better informed to develop climate risk management capabilities proactively.</td>
</tr>
<tr>
<td>Asset Management System Database (Data Collection)</td>
<td>Expand organizational capabilities to include expert of staff time for climate assessment and action plan with respect to agency assets and services.</td>
<td>E.g. Condition assessment can be conducted in collaboration with expert to integrate climate forecasts for climate assessment and action plan with respect to agency assets and services.</td>
</tr>
<tr>
<td>Enterprise Asset Management (EAM) System (Analysis of Alternatives including Tradeoffs)</td>
<td>Develop a code for climate sensitivity of assets and assess information first for mission-critical assets and then for other assets. While several transit agencies consider the age of an asset for repair and replacement decisions, MARTA considers asset condition and criticality (i.e., life safety, criticality, operation criticality, etc.) as well. A climate sensitivity code can be developed with respect to the level of severity, extent of impact and probability of climate-related failure of an asset.</td>
<td>The EAM system comes with the capability for adding fields that can designate particular asset groups, types or components as being vulnerable to different climate stressors, to different degrees.</td>
</tr>
<tr>
<td>Expert Choice Decision-Making Software (Resource Allocation Decision Making)</td>
<td>The Expert Choice decision-making tool will assist the CIP committee in making decisions based on a set of agency goals and objectives that can be accorded different levels of importance based on the agency’s changing priorities. A climate-related goal can be included in the current goals capturing MARTA’s desire to make assets and operations more resilient to the effects of climate change. The relative importance of climate considerations can be managed by the weight given to climate factors in the model.</td>
<td>Infrastructure resilience to climate hazards and disasters is a desirable attribute for a transit agency in this modern climate era. However, the relatively high levels of uncertainty associated with predicting climate change makes an adaptive management framework desirable, one that can respond to changes and new information revealed with better data over time. The weighting approach used in the decision-making software is a good platform on which to implement such an adaptive approach.</td>
</tr>
<tr>
<td>Design Standards</td>
<td>Engineering design standards may be developed to address extreme climate, e.g., higher frequency and intensity of storms.</td>
<td></td>
</tr>
</tbody>
</table>

From page 152 to 157, the paper outlines a series of adaptation strategies MARTA could consider by department as part of a single Table.
<table>
<thead>
<tr>
<th>Decision Question</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision maker</td>
<td>N/A</td>
</tr>
<tr>
<td>Relevance</td>
<td>The paper outlines significant literature which much has been considered under this effort. It provides a good outline for the potential useful resources as well as possible case studies. It primarily focuses on asset management and relates closely to the MARTA FTA pilot study. It also briefly touches on other areas of interest.</td>
</tr>
<tr>
<td>Status</td>
<td>N/A</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The literature review addresses or capture much of the information the project is working to complete. The author is guide by Dr. Amekudzi, the author of the MARTA pilot project. Though some additional information is included with more detail, the overall paper has a close relationship to the asset management aspects of the MARTA final report.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Essential Vocabulary

- Risk: Effect of uncertainty on objectives
- Uncertainty: Inherent component of the decision-making process when choices are made based on incomplete knowledge
- Criticality: Relative importance of transportation infrastructure assets based upon user-defined criteria
- Vulnerability: Those transportation infrastructure assets that are identified as both highly-critical and susceptible to higher-risk climate change impacts

### Potential Keywords

- “UK’s National Health Service released a Heatwave Plan for England that specifically discusses impacts on transportation infrastructure and railway infrastructure in particular (Department of Health 2011)” (p. 26)
- National Cooperative Highway Research Program (NCHRP) Project 20-83(S) entitled “Climate Change and the Highway System: Impacts and Adaptation Approaches” (p. 28)
- New York City Adaptation Report/Plan
- Federal Highway Administration recognizes the importance of incorporating risk into the TAM process and released a series of five reports on this topic (Proctor and Varma 2012a; b, 2013; Varma and Proctor 2012, 2013) 2 of 5 are:
  - Managing Asset Risks at Multiple Levels in a Transportation Agency (Varma and Proctor 2012), high lights the fact that risk management is required at agencies in Australia and New Zealand. FHWA sponsored an international scan tour that examined best practices in risk management in Australia, New Zealand, the Netherlands, Germany, Scotland, and England (Curtis et al. 2012) (p.39)
  - “Managing External Threats Through Risk-based Asset Management” (p. 42)
- Edmonton, Alberta, Canada incorporates risk analysis in the transportation decision-making process (p. 72)
### Citation

### Website/Source

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Research document

### Intended Audience
*TCRP Report 172* and accompanying TAPT spreadsheet are intended for use by:
- Transit agencies of all sizes and with all types of assets

### Abstract
"*TCRP Report 172: Guidance for Developing a Transit Asset Management Plan* provides a process for developing a transit asset management plan to be used by transit agencies seeking to achieve a state of good repair (SGR). The report is accompanied by a Transit Asset Prioritization Tool (TAPT), which is composed of four spreadsheet models designed to assist transit agencies in predicting the future conditions of their assets, and in prioritizing asset rehabilitation and replacement. *TCRP Report 172* together with the TAPT models are valuable resources for transit agencies and will be of interest to regional, state, and federal agencies that oversee, plan, or finance public transportation." (Foreword)

### Populations Referenced
*TCRP Report 172* together with the TAPT models are valuable resources for transit agencies and will be of interest to regional, state, and federal agencies that oversee, plan, or finance public transportation.

### Topics Covered
The report provides a process for developing a transit asset management plan to allow a transit agency to make investment decisions to achieve a state of good repair (SGR). The document provides:
- a five step approach to develop a transit asset management plan, which entails:
  1. Developing an inventory of assets and data
  2. Analyzing asset conditions and performance
  3. Defining asset investment scenarios
  4. Finalizing asset lifecycle policy, funding and prioritization assumptions
  5. Developing the transit asset management plan
- step-by-step instructions for using the Transit Asset Prioritization Tool (TAPT)
- step-by-step tutorials illustrating the use of TAPT

### Type of Sponsoring Agency or Organization
This Transit Cooperative Research Program was sponsored by the Federal Transit Administration

### Geographic Distribution
All of the United States

### Type of Transit Mode(s)
The document describes the process of developing a transit asset management plan and is intended for use by transit agencies of all sizes with all types of assets.

### Type of Vulnerability
The document does not speak to a specific vulnerability, rather the focus of the document is assessing asset condition to achieve a desired State of Good Repair (SGR) and provide a consistent level of service to passengers.

### Goals and
The goal of the research document was to describe a process for developing a Transit Asset

A-118

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Motivations</th>
<th>Management Plan (TAMP) that can be used by transit agencies seeking to achieve SGR, to comply with the requirements of MAP-21 and provide a consistent level of service to passengers. Although resiliency is not addressed specifically in the document, the goal to provide a consistent level of service by reducing interruptions resulting from asset failure is consistent with the objectives for improving the overall resiliency of a system.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
<td>See Goals and Motivations</td>
</tr>
<tr>
<td>Tools</td>
<td>The document introduces and provides step-by-step instructions on the use of the Transit Asset Prioritization Tool (TAPT). “TAPT is used to model rehabilitation and replacement needs for transit capital assets. The tool supports definition of a range of different asset types. For a transit agency’s asset inventory, the tool predicts future conditions and performance, helping to prioritize asset rehabilitation and replacement. The tool includes three basic models: • A model for vehicle assets • A model for non-vehicle assets that can be modeled based on age • A model for non-vehicle assets that can be modeled based on condition” (p. 30) “For each of these models, the user describes its existing asset inventory and the model predicts how the condition and performance of the inventory will vary over time, as well as when to rehabilitate or replace assets.” (p. 30)</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>The TAPT is scalable and robust enough to be used by transit agencies of all sizes and variability of assets.</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>To comply with “FTA’s rulemaking, transit agencies will be required to prepare transit asset management plans that describe the inventory and condition of their capital assets and how they prioritize their SGR investments. Section 20028 of MAP-21, which amends U.S.C. Title 49, Section 5337, further stipulates that any projects funded through the SGR grants defined in this section should be listed in the transit agency’s asset management plan.” (p. 3)</td>
</tr>
<tr>
<td>Decision Question</td>
<td>The research document provides guidance to transit providers in the development of policies to be taken to best achieve the transit agency’s objectives. “With respect to an asset, typically the transit agency’s objective is to minimize the lifecycle cost of purchasing and maintaining the asset. Ideally, the level of maintenance should also maintain or improve service levels and meet the public’s expectations.” (p. 5) “However, a transit agency may consider other factors that are difficult to incorporate in a lifecycle cost calculation, such as aesthetics, compliance with legal requirements, environmental concerns and other factors. Strictly speaking, the policy for an asset should address when all maintenance, repair, rehabilitation, and replacement actions should be taken and how these will, at least conceptually, relate to the quality of the transit agency’s services.” (p. 5) This document focuses on rehabilitation and replacement actions which may be included in a transit agency’s capital program.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Transit agency leadership</td>
</tr>
</tbody>
</table>
| Relevance | Asset management is an approach to help transit agencies manage their physical asset and achieve SGR. An asset management plan utilizes data related to lifecycle cost and asset life to support decisions regarding the maintenance, rehabilitation and replacement of existing asset to reduce the impact of asset failure. “Asset failure occurs when an asset unexpectedly ceases to provide its intended service.” (p. 5) “For revenue vehicles... a failure includes cases where the failure of a mechanical element of the
vehicle prevents the vehicle from completing a scheduled revenue trip or starting the next scheduled revenue trip. For other assets, the term refers to the catastrophic failure of the asset requiring its replacement.” (p. 5)

“However, a transit agency may consider other factors that are difficult to incorporate in a lifecycle cost calculation, including environmental concerns such as severe weather events. Since the primary goal of most transit agencies is to provide a consistent level of service by reducing interruptions, improving the resiliency of its assets through asset management planning support the mission of the agency.” (p. 5)

<table>
<thead>
<tr>
<th>Status</th>
<th>Research project completed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The document’s purpose was to develop guidance and a tool consistent with best asset management practice to allow transit agencies to fulfill the requirements of MAP-21. Those requirements include the preparation of transit asset management plans, setting performance targets that incorporate consideration of SGR and reporting on their performance. The document accomplished that desired purpose well. The report’s focus on SGR, asset condition, lifecycle cost and asset life is specific to retaining the mechanical and physical attributes of an asset with respect to fatigue and deterioration, is very specific to meet its purpose. In order to infuse a culture of resiliency into a transit agency, it will be necessary to clearly demonstrate how resiliency can be used to fulfill federal reporting requirements and where resiliency can be incorporated into the asset management process.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Essential Vocabulary | The report contained the following definitions and terms:  
  - “Asset Management—The term ‘asset management’ means a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.” (p. 3)  
  - “Transit Asset Management System—The term ‘transit asset management system’ means a strategic and systematic process of operating, maintaining, and improving public transportation capital assets effectively throughout the lifecycle of such assets.” (p. 3)  
  - “Transit Asset Management Plan—The term ‘transit asset management plan’ means a plan developed by a recipient of funding under that (A) includes, at a minimum, capital asset inventories and condition assessments, decision-support tools, and investment prioritization; and (B) the recipient certifies complies with the rule issued under this section.” (p. 3)  
  - “Capital Assets—The term ‘capital asset’ includes equipment, rolling stock, infrastructure, and facilities for use in public transportation and owned or leased by a recipient or sub recipient of Federal Financial assistance under this chapter.” (p.8) |
| Potential Keywords | Transit Asset Management Plan (TAMP) Framework  
State of good repair (SGR)  
Asset prioritization  
Funding  
Capital investment |
### Citation

### Website/Source
[http://people.ce.gatech.edu/aa103/Asset%20Management-10-2734.pdf](http://people.ce.gatech.edu/aa103/Asset%20Management-10-2734.pdf)

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

### Document Type
Research Document

### Intended Audience
Transportation Agencies

### Abstract
The purpose of this paper is to provide information on how to utilize asset management systems to address climate change through its incorporation into the system. To support the research, the paper outlines international examples where climate change has already been incorporated into transportation agencies.

### Populations Referenced

### Topics Covered
- Climate Change Impacts to Infrastructure & Adaptive Strategies;
- Asset Management Process;
- International Examples/Case Studies; and
- Recommendations towards adoption.

### Type of Sponsoring Agency or Organization
N/A

### Geographic Distribution
Reviewed progress by state and city agencies as well as looked at the UK and New Zealand as example for incorporating climate change into asset management systems.

### Type of Transit Mode(s)
Transportation

### Type of Vulnerability
Precipitation, sea-level rise, heat/cold, flooding

### Goals and Motivations
"This paper examines the role that asset management systems can play in providing a decision-making platform for making investment decisions that consider the uncertainty associated with climate-related changes. By incorporating the consideration of anticipated effects of climate change into an agency’s infrastructure preservation and asset management process, and by doing this systematically over time, transportation officials could end up with the most cost-effective approach towards system adaptation to changing environmental conditions." (p. 3)

### Context
N/A

### Tools
The paper also outlines an example simple risk scoring scheme pulled form one of its referenced sources.

### Noteworthy Aspects
Adaptation Strategies (Page 5 & 6)
The document outlines a generic asset management system describing seven elements: Goals and policies, Asset Inventory, Condition assessment/performance monitoring (modeling), Alternatives analysis/program optimization, Short/long range plans, Program implementation, and Performance monitoring.

- The paper identifies that condition assessment and performance modeling as the most important piece to fully incorporating climate change into the asset management system. As part of this element, risk to climate change should be incorporated into the evaluation. The results would provide a trigger in the performance modeling which would result in
consideration of alternative approaches given an assets vulnerability.

- Alternatives analysis and program optimization should utilize scenarios and include the understanding of uncertainty surrounding climate change data.
- Short and long-range plans would outline the strategies to address climate change while being flexible to change as planning horizons increase.
- Program implementation addresses the actual changes being made (e.g. retrofit, rehab, etc.).

Captivating Value

The document identifies that several state agencies that have begun to process, including 8 which have made progress in completing adaptation plans. Additionally, the document identifies New York City as one of the cities moving forward on a more local level. Internationally, the UK (specifically, Transport for London & London Underground) and New Zealand (specifically, Transit New Zealand) have incorporated climate change considerations into their asset management system.

The document also provides a table of how climate change can be incorporated into the generic asset management system outlined within the paper. (Page 10)

<table>
<thead>
<tr>
<th>Asset Management System Component</th>
<th>Monitoring Technique(s)/Adaptation Strategy(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals and policies</td>
<td>Incorporate climate change considerations into asset management goals and policies, these could be general statements concerning adequate attention of potential issues, or targeted statements at specific types of vulnerabilities (e.g., sea level rise)</td>
</tr>
<tr>
<td>Asset inventory</td>
<td>Mapping, potentially using GIS, of infrastructure assets in vulnerable areas; inventory critical assets that are susceptible to climate change impacts</td>
</tr>
<tr>
<td>Condition assessment and performance modeling</td>
<td>Monitor asset condition in conjunction with environmental conditions (e.g., temperature, precipitation, winds) to determine if climate change affects performance, incorporating risk appraisal into performance modeling and assessment; Identification of high risk areas and highly vulnerable assets; Use of &quot;smart&quot; technologies to monitor the health of infrastructure assets</td>
</tr>
<tr>
<td>Alternatives evaluation and program optimization</td>
<td>Include alternatives that use probabilistic design procedures to account for the uncertainties of climate change; Possible application of climate change-related evaluation criteria, smart materials, mitigation strategies, and hazard avoidance approaches</td>
</tr>
<tr>
<td>Short and long range plans</td>
<td>Incorporate climate change considerations into activities outlined in short and long range plans; Incorporate climate change into design guidelines; Establish appropriate mitigation strategies and agency responsibilities</td>
</tr>
<tr>
<td>Program implementation</td>
<td>Include appropriate climate change strategies into program implementation; Determine if agency is actually achieving its climate change adaptation/monitoring goals</td>
</tr>
<tr>
<td>Performance monitoring</td>
<td>Monitor asset management system to ensure that it is effectively responding to climate change. Possible use of climate change-related performance measures; &quot;Triggering&quot; measures used to identify when an asset or asset category have reached some critical level.</td>
</tr>
</tbody>
</table>

Decision Question  N/A

Decision Maker  N/A

Relevance  The paper provides a distinct outline of where climate adaptation fits into asset management systems. It further provides international examples and case studies.

Status  N/A

Critical Assessment  The paper provides a high-level but succinct description of how and where to incorporate climate change considerations into an agency’s asset management system. In general, it's a great resource for agencies beginning to look into doing this and it provides some resources for
additional consideration.

<table>
<thead>
<tr>
<th>Additional Comments</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>N/A</td>
</tr>
</tbody>
</table>
**Citation**  

**Website/Source**  

**Focus Area(s)**
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Research Document</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended Audience</td>
<td>Transportation agencies</td>
</tr>
</tbody>
</table>

**Abstract**
An examination of the design standards in the face of climate change. With a focus on the engineering process, the paper looks at the implications of heat, precipitation, water, wind, storm surge and waves in the short and long term. Overall, the authors determined there is a need for more inclusive perspectives during the engineering and design process to include considerations of potential climate impacts.

“The purpose of this paper as defined by the organizing committee was to ‘provide a broad conceptual framework for the possible role and objectives of standards and guidelines for the planning, design and construction of the transportation infrastructure under the assumption that climate change is occurring and will impact U.S. transportation.’” (p. 2)

**Populations Referenced**
- Civil engineers
- Road engineers

**Topics Covered**
- Typical infrastructure outline which require design standard considerations
- Design Standards general overview
- Climate change impacts on design

**Type of Sponsoring Agency or Organization**
Unknown

**Geographic Distribution**
Nationally

**Type of Transit Mode(s)**
The paper addressing all modes of transportation as it relates to infrastructure such as pavement, bridges, rail lines, runways, transit facilities, etc.

**Type of Vulnerability**
“temperature change, precipitation and water levels, wind loads, and storm surges and wave heights” (Page 1)

**Goals and Motivations**
Examine the implications of climate change on design standards.

**Context**
N/A

**Tools**
Outlines the characteristics of a risk assessment approach to long lifetime structures. Those are outline on page 23 and are listed as follows:
1. “Focus on infrastructure that has long lives (greater than 40 to 50 years); infrastructure designed for a shorter life has flexibility incorporated into the facility replacement schedule to account for significant changes in environmental conditions and thus do not need to be included in this approach.
2. Identify geographic areas in a jurisdiction that have particular sensitivity to changes in climate, such as coastal or low-lying areas.

3. Assign a likely occurrence probability for environmental changes occurring in these sensitive areas that reflect the likelihood that such changes will occur over the useful life of the facility.

4. Undertake different designs for the facility with varying degrees of design standards applied to account (or not) for changing environmental conditions. Estimate the cost (both replacement and economic cost due to facility disruption) of each design.

5. Apply the hazard occurrence probability to the different cost components of the design that will be affected by changing environmental conditions. Estimate the likely costs in present dollars of each design. The design with the lowest net present value cost would be the desired alternative.” (p. 23)

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>The paper outlines the general components of design standards. Those are:</td>
</tr>
<tr>
<td>• Subsurface Conditions – Engineers must consider the saturation and soil movement under such conditions. Seismic codes provide an example of how changes in design standard can mitigation impacts.</td>
</tr>
<tr>
<td>• Materials – Materials will need to hold up to different conditions such as increased moisture, and violent surge and wave action in coastal communities.</td>
</tr>
<tr>
<td>• Cross Sections and Standard Dimensions – Example of changes in the design standards in the Gulf Coast include reconstructed bridges over waterways at higher elevations to reduce the chance of surge carrying decks off of its supports.</td>
</tr>
<tr>
<td>• Drainage and Erosion – An example of changing the design would be to increase the culvert size to allow surge to flow through it.</td>
</tr>
<tr>
<td>• Structure (refers to bridges here) – Addressing the structure through utilization of AASHTO’s LFRD Bridge Design Specifications supports climate considerations through consideration for flooding, water elevations, and other hazards.</td>
</tr>
<tr>
<td>• Location Engineering – Moving built infrastructure out of flood zones.</td>
</tr>
</tbody>
</table>

Some are applying risk-based approaches to decision making within the design process, though no agency is identified by author. The paper concludes that designs need to be flexible for extreme events like a Hurricane Katrina.

Table 1 from Page 21 outlining climate impacts on design.
The paper also outlined other options outside of design standards to address climate change.

1. Addressing land use in general to avoid risk altogether.
2. Retrofitting where applicable can provide some mitigation.
3. Planning for redundant networks can support recovery efforts and timelines.
4. Utilize sensors to determine where a failure may occur before it happens.
5. Changes in insurance policies.

### Captivating Value

"Transportation infrastructures have different design lives, that is, they are expected to last under normal loads for a specific number of years... We need to be thinking today of the potential impacts of climate change on infrastructure that will be still serving society 100 years in the future." (p. 3 & 4)

The paper identifies 11 agencies which are recognized as sources of information for design standards. It further outlines how long it takes for some design standards to become widely adopted. The example outlined, "Superpave", was a 14 year effort.

"The time it takes to change design standards is also influenced by current design practice and the degree to which the particular design factor is accepted by the professional community... However, something more traumatic to engineering practice, say, for example, adopting a risk-based design approach to all infrastructure components could be debated and discussed for a long time. Thus, it seems likely that the lead time needed for making changes to design
standards that reflect potential climate change-induced environmental conditions could be very long. This further suggests that the research needed to lay the ground work for such changes needs to be done even earlier than this.” (p. 14)

One way to think about the problem of designing bridges with a long lifecycle but to build infrastructure with a shorter design life. For example, instead of building a bridge to last 100 years, build it to last 50 years. However, the tradeoff is the realization of climate change. If environmental conditions do not change, then there is a cost incurred.

| Decision Question | The author poses several questions and then digs in with some descriptions of how one may address the question. One question posed by the author was how to consider climate change impacts in structures with decades to more than a century lifetime. Another includes how to account for interdependent systems. |
| Decision Maker | Transportation Agencies |
| Relevance | This research paper is relevant to the design standard area of focus and provides a good foundation for considerations necessary to address climate change. |
| Status | N/A |
| Critical Assessment | The paper provides a good connection for those with knowledge about design standards but not about climate change but also vice versa. It’s a great introductory piece but it lacks some agency level actionable items to begin the process for considering climate change. It outlines that it needs to be considered as part of the design process and why but what are the concrete steps for that to occur? However, given the focus on all transportation infrastructures at all levels of government, this type of question should not be expected to be answered here. |
| Additional Comments | N/A |
| Essential Vocabulary | For purposes of this paper, the term “structure” and “infrastructure” will be used interchangeably in a generic way to represent the facility or infrastructure being designed for. Technically, “structure” in civil engineering refers to such things as buildings and bridges, but would not be used, for example, in describing a road. |
| Potential Keywords | Design Standards Environment Engineering |
| **Citation** | Metropolitan Transportation Authority. 2007. August 8, 2007 Storm Report. Appendix 3: Benchmarking Study: Discussion of Storm Impacts, Summary of Findings prepared by Region II, University Transportation Research Center. Metropolitan Transportation Authority. New York City, NY |

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

| **Document Type** | Agency Report |
| **Intended Audience** | City of New York government, MTA |
| **Abstract** | The objective was “To consider MTA operations during the unanticipated storm of August 8, 2007 and whether they were within the bounds of Good Practice.” (PDF p. 113 – p. 1 of Appendix 3). |
| **Populations Referenced** | MTA, BART, Tokyo RR, Transport for London, MARTA, WMATA, Toronto, NYCDOT, NYSDOT, NJTransit, PATHNYNJ, customers |
| **Topics Covered** | • Study Findings  
• MTA Storm Response |
| **Type of Sponsoring Agency or Organization** | Governor of New York – State funded |
| **Geographic Distribution** | What geographic area does this document address? Please consider:  
• Regional  
• Large Urban  
• NY (NYC, Long Island, CT) |
| **Type of Transit Mode(s)** | Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, Demand Response, Ferry Stations |
| **Type of Vulnerability** | Precipitation/Storm |
| **Goals and Motivations** | See Abstract. |
| **Context** | MTA ad the region in general has several critical intersections of infrastructure and services including all modes. IN addition to MTAs services, Amtrak, NJ Transit, PANYNJ and other service providers including various ferryboat agencies all cross serve customers and interact accordingly. |
| **Tools** | N/A |
| **Noteworthy Aspects** | The information outlined below are part of a summary findings document.  
Transport for London, based on the survey, found similar experiences with flooding as stations and the subways close, customers look to buses which become overburdened to be effective.  
Mitigation efforts agencies are looking into include water management (e.g. pumps, drainage and other techniques). Toronto is looking to separate the combined sewer system while Tokyo tripled its pump capacity to deal with flooding. In general, all systems surveyed have pumping standards |
but they do not follow a single national or international standard to address floods. Some are designed for 50 year storms while others 100 year storms.

Several systems have SOPs for flood events.

Most use pumps as its initial line of defense although Transport for London and Tokyo have flood gates.

MTAs response was:
- Consistent with peer agencies;
- Followed accepted protocols;
- Did not communicate the response to the community well; and
- Did not have an adequate plan for using bus bridges;

MTA protocols should ensure:
- “All primary pumps and redundant and backup pumps must be in full working order, and routinely tested to insure full capacity can be met.
- All drainage paths must be kept clear.
- Redundancy must be assured in the most critical stations and points along the ROW.
Based upon the recent storm and predictions of strong storms with greater frequency, MTA must develop a new list of critical points and develop a pumping strategy for those.
- In fact, MTA might take this opportunity to develop a modern—system-wide – storm plan for a new level of storm severity and frequency. To carry out such a plan effectively, there MUST BE regional agreement (NYCDOT, NYSDOT, NJT, PATH, and others) on what the new design criteria will be, areas of greatest susceptibility, and ways to maximize availability of system-wide resources during these emergencies.
- MTA must integrate current State of Practice design for new station construction (SAS), minimizing the probability of intrusion of water from street level.
- MTA should play a leadership role in assessing – together with all appropriate regional agencies – the impacts of global warming.” (PDF p. 115, p. 3 of Appendix 3)

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>The document provides some initial leads on international practices which follow similarly to US agency experiences.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>MTA</td>
</tr>
<tr>
<td>Decision Question</td>
<td>Upgrading flood response protocols.</td>
</tr>
<tr>
<td>Relevance</td>
<td>The document provides summary of impacts to a precipitation event and the summary findings of a transit agency survey on their efforts to mitigate flood impacts.</td>
</tr>
<tr>
<td>Status</td>
<td>The post storm study is included as part of a MTA report which has been used to begin addressing climate adaptation.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Although short and specific to pumping and MTAs response, the document provides some good insight into which agencies internationally may provide some bets practices and information to support climate adaptation in the U.S.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>The storm seemed to have prepared the agency well for future incidents as some elements such as public communications and adequate bus bridges which were identified as poor or lacking were well received after Sandy.</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Flood Response</td>
</tr>
<tr>
<td></td>
<td>Pumping Water Communication</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------</td>
</tr>
</tbody>
</table>

A-131

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Dawson, S. Incorporating Disaster Response Management into Asset Management. Transit State of Good Repair Conference. March 11, 2015, Washington D.C. Port Authority of NY &amp; NJ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus Area(s)</td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>Conference Presentation</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Transit Agencies</td>
</tr>
<tr>
<td>Abstract</td>
<td>The PANYNJ strategy to address resiliency through asset management and emergency management.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Businesses, customers, airports, marine terminals, and regional transportation partners.</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>• Asset Management</td>
</tr>
<tr>
<td></td>
<td>• Emergency Preparedness, Response and Recovery</td>
</tr>
<tr>
<td></td>
<td>• Design Standards</td>
</tr>
<tr>
<td></td>
<td>• Implemented Adaptation Strategies</td>
</tr>
<tr>
<td>Type of Sponsoring</td>
<td>Port Authority of New York and New Jersey</td>
</tr>
<tr>
<td>Agency or Organization</td>
<td></td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>The PANYNJ is a bi-state agency with various assets and connections to other transit agencies including MTA and NJTransit in the New York City region.</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Heavy Rail, Bus Terminals,</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Floods, Sea-Level Rise, and Coastal Storm</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>Meeting needs of customers. Under asset management, the PANYNJ works to make financial decisions based on risk ensure staff is prepared to support strategies, maximize asset life and to “enable maximum availability of... assets.” (Slide 4) Under emergency management, the PANYNJ mission is to effectively manage assets/resources during disasters, implement “preparedness, response and recovery plans” (Slide 4) and to reduce vulnerability through the implementation of response and recovery strategies.</td>
</tr>
<tr>
<td>Context</td>
<td>The PANYNJ is a bi-state agency connecting customers through various agencies and modes. This includes NJDOT, NJ Turnpike Authority, NYSDOT, NYCMTA (including the Long Island Railroad), and NJTransit. The PANYNJ responded to Sandy with some plans in place. This included the ability to pre-purchase mitigation supplies such as generators, sandbags, and flood barriers.</td>
</tr>
<tr>
<td>Tools</td>
<td>N/A</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>The PANYNJ identifies 3 critical elements in asset management. Those are maintaining a complete asset inventory, conducting a condition assessment and recording and implementing a maintenance program/policy.</td>
</tr>
</tbody>
</table>
In preparing for a disaster, the PANYNJ have developed emergency plans for coastal storms and continuity of operations plans. The agency regularly participates in training and exercises and specifically in response to Sandy, pre-purchased resources such as power generators, sand bags and barriers to reduce risk and minimize effects of the storm on its system.

The presentation outlines mitigation planning steps to include focus on most critical assets, expediting projects which incorporate resiliency, and strengthen relationships with stakeholders.

The agency updated its design standards to address climate events. Guidelines include: complying with resiliency codes, identification of critical infrastructure, consideration of local, state and federal recommendations, and considerations for climate change. The guidelines include a “clear definition of flood risk to an asset.” (Slide 17). Additionally, mitigation strategies have been developed in consultation with the agencies OEM. Strategies will have a cost-benefit analysis performed when considering project and the final prelim design will “establish appropriate flood protection levels.” (Slide 17)

Some mitigation strategies implemented include raising infrastructure onto pilings and constructing flood barriers,

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>The agency updated standard design guidelines. The agency created a storm mitigation office after Sandy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Question</td>
<td>When to move forward with mitigation and resiliency projects</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>The PANYNJ utilizing the new guidance.</td>
</tr>
<tr>
<td>Relevance</td>
<td>The PANYNJ outlines critical elements of the asset management and emergency preparedness missions as they relate to climate change. It further identifies that the agency has progressed in addressing design standards.</td>
</tr>
<tr>
<td>Status</td>
<td>The Storm Mitigation Office is still active and efforts are ongoing per the presentation timeline.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The source is a presentation and as expected lacks some detail which may have been addressed upon presenting at the conference. Overall, the agency identifies some critical steps many other agencies have not yet done and provides leads on potential bets practices in the area of design standards, asset management and emergency preparedness.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>It would be of interest to see detailed process using the new design guidelines including the “clear definition of flood risk to an asset.” (Slide 17)</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Design Standards State of Good Repair Flood Mitigation Resilience</td>
</tr>
<tr>
<td>Website/Source</td>
<td><a href="https://www.whitehouse.gov/sites/default/files/microsites/ceq/20100218-nepa-consideration-effects-ghg-draft-guidance.pdf">https://www.whitehouse.gov/sites/default/files/microsites/ceq/20100218-nepa-consideration-effects-ghg-draft-guidance.pdf</a></td>
</tr>
<tr>
<td>Document Type</td>
<td>Government Memorandum</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Federal Agencies, Public</td>
</tr>
<tr>
<td>Abstract</td>
<td>Draft guidance for federal agency head regarding the considerations of GHG and climate change in their evaluation for proposals. “This draft guidance is intended to help explain how agencies of the Federal government should analyze the environmental effects of GHG emissions and climate change when they describe the environmental effects of a proposed agency action in accordance with Section 102 of NEPA and the CEQ Regulations for Implementing the Procedural Provisions of NEPA, 40 C.F.R. parts 1500-1508. This draft guidance affirms the requirements of the statute and regulations and their applicability to GHGs and climate change impacts.” (p. 1)</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Agency Heads</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>Purposes of guidance, Consideration of agency action on GHG emissions, Current/project effects of climate change on agencies; and NEPA background.</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>Council on Environmental Quality</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>Nationally</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Not specified.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>floods, storm surges, or higher temperatures</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>“CEQ proposes to advise Federal agencies that they should consider opportunities to reduce GHG emissions caused by proposed Federal actions and adapt their actions to climate change impacts throughout the NEPA process and to address these issues in their agency NEPA procedures.” (p. 1) CEQ is seeking comment on the way to assess GHG emissions affected by federal land and decisions among other issues.</td>
</tr>
<tr>
<td>Context</td>
<td>N/A</td>
</tr>
<tr>
<td>Tools</td>
<td>Specific tools are not identified but resources for reviewing climate data are identified.</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>The document focuses on guidance for GHG and climate change considerations and outlines that within an EA and EIS may be a great opportunity for such considerations.</td>
</tr>
</tbody>
</table>
The document identifies land-use policy as lacking federal control which plays a critical part in land and resource management. But at the same time can be applied to support GHG reduction and reduce risk to climate change.

The document has a GHG focus.

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>“In some cases, discussion of climate change effects in an EA or EIS may warrant a separate section, while in others such discussion may be integrated into the broader discussion of the affected environment.” (p. 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>“Climate change effects should be considered in the analysis of projects that are designed for long-term utility and located in areas that are considered vulnerable to specific effects of climate change (such as increasing sea level or ecological change) within the project’s timeframe. For example, a proposal for long-term development of transportation infrastructure on a coastal barrier island will likely need to consider whether environmental effects or design parameters may be changed by the projected increase in the rate of sea-level rise.” (p. 7)</td>
</tr>
<tr>
<td></td>
<td>Additionally, the document points to resources on where agencies can go to get climate change data and explanations of their limitations. (See p. 8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Question</th>
<th>A list of 7 total questions under the conclusion section is outlined for public review as well. How to consider GHG and climate change into agency action decisions?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>Federal agencies to the second question listed above.</td>
</tr>
<tr>
<td>Relevance</td>
<td>Although not a specific transportation document, the document highlights the need for all federal agencies to begin considering climate change in their own actions. Additionally, it points to transportation examples such as constructing infrastructure along coastal areas and highlight the needs for design to consider sea-level rise.</td>
</tr>
</tbody>
</table>

| Status         | N/A |
| Critical Assessment | No assessment developed |
| Additional Comments | N/A |
| Essential Vocabulary | N/A |
| Potential Keywords | N/A |
### Citation

### Website/Source

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Management handbook on principles and practices of resiliency with extensive case studies and organizational self-assessment checklists

### Intended Audience
Practitioners and managers in many different fields, particularly those involving operations and maintenance, and where safety and reliability are important.

### Abstract
Managing the Unexpected is a guide for learning the hard-won lessons of high reliability organizations (HROs) (e.g., flight operations on aircraft carriers, hospital emergency rooms, nuclear power plants and wildfire firefighting operations) that are able to manage unexpected threats and bounce back in a stronger position to tackle future challenges. Through discussion of the principles of mindfulness and the practices that can be used to apply it, it shows how to anticipate and respond to threats with flexibility rather than rigidity.

### Populations Referenced
Emphasis on importance of operations and maintenance personnel as generally closest to small, emerging signs of problems and solutions; need for entire organization to engage in the principles, with full support and direction from top management.

### Topics Covered
- Managing the unexpected: What businesses can learn from HROs
- Expectations and mindfulness – expectations can act as blinders to what is actually occurring
- Three principles of anticipation:
  - Preoccupation with failure
  - Reluctance to simplify
  - Sensitivity to operations
- Two principles of containment:
  - Commitment to resilience
  - Deference to expertise
- Assessing your agency’s capabilities for resilient performance
- Organizational culture: institutionalizing mindfulness
- How to manage mindfully

### Type of Sponsoring Agency or Organization
Other: general management guide not specific to transit, but with applicable lessons

### Geographic Distribution
Not applicable- case studies include U.S. and international organizations. Case studies include positive examples as well as evaluations of disasters such as Challenger, Columbia and more.

### Type of Transit Mode(s)
Not applicable; does include a short case study of a disaster on a ferry (bay doors left open- door operator fell asleep, ferry sinks, many deaths)- lesson on basic reporting orders – assume everything is done and ready unless officer hears otherwise (as was the case on the ferry) versus
<table>
<thead>
<tr>
<th><strong>Type of Vulnerability</strong></th>
<th>Specifically addresses wildfire firefighting operations as case studies; principles and practices pertain to all types of vulnerabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goals and Motivations</strong></td>
<td>HROs operate in complex environments with high consequences for failure – comparable to most transit agencies. The goal was to identify principles and practices that HROs follow that could be emulated by other organizations to improve their safety and resilience.</td>
</tr>
<tr>
<td><strong>Context</strong></td>
<td>HROs practice resilience and preparedness as an everyday mindfulness cultural context- constantly alert to small problems that could be indicators of larger problems; therefore are prepared for basically any scale of disaster. Safety is the highest priority for cited HROs, within the context of performing their demanding jobs.</td>
</tr>
</tbody>
</table>
| **Tools**                 | Chapter 5 includes a series of self-audits to ascertain the organization’s resilience, as follows:  
  - Audit 1: A starting point for assessing your firm’s mindfulness  
  - Audit 2: Assessing your firm’s vulnerability to mindlessness  
  - Audit 3: Assessing where mindfulness is most required  
  - Audit 4: Assessing your firm’s preoccupation with failure  
  - Audit 5: Assessing your firm’s reluctance to simplify  
  - Audit 6: Assessing your firm’s sensitivity to operations  
  - Audit 7: Assessing your firm’s commitment to resilience  
  - Audit 8: Assessing the deference to expertise in your firm  
  - Audit 9: The Mindfulness Organizing Scale  
Chapter 7 includes questions for After Action Reports as well as “Small Wins” – specific suggestions with elaborations- on topics including:  
  - the basics of mindfulness (e.g., balance centralization with decentralization);  
  - development of a preoccupation with failure (e.g., create awareness of vulnerability, define the near miss);  
  - development of resistance to simplification (e.g., encourage alternative frames of reference, treat all unexpected events as information);  
  - development of sensitivity to operations (e.g., reward contact with the front line, spend time on the front end of operations; briefing protocol STICC- situation, task, intent, concern, calibrate);  
  - development of a commitment to resilience (e.g., don’t overdo lean, mean ideals; accelerate feedback; treat your past experience with ambivalence); and  
  - development of deference to expertise (e.g., encourage imagination as a tool for managing the unexpected. |
| **Noteworthy Aspects**    | Basic precept: “It is impossible to manage any organization solely by means of mindless control systems that depend on rules, plans, routines, stable categories, and fixed criteria for correct performance. No one knows enough to design such a system so that it can cope with a dynamic environment. Instead, designers who want to hold dynamic systems together have to organize in ways that evoke mindful work. People have to adopt a style of mental functioning that enables continuous learning as well as ongoing refinement of expectations.” (p. 39)  
Novel idea: planning can be detrimental to resilience. Three problems posed by anticipation and planning:  
1) “Since plans are built from assumptions and beliefs about the world, they embody expectations. Strong expectations influence what people see, what they choose to take for granted, what they choose to ignore, and the length of time it takes to recognize small problems that are growing” (p. 66).  
2) “Plans can undercut organizational functioning because they specify contingent actions that are designed to cope with the future….contingency plans preclude improvisation,” (p. 67). |
### Captivating Value

1) “It takes more than a shrewd expert to forestall the unexpected in most situations. It takes mindful practices that encourage imagination, foster enriched expectations, raise doubts about all expectations, increase the ability to make novel sense of small interruptions in expectations, and facilitate learning that intensifies and deepens alertness.” (p. 30-31)

2) HROs continually alter their actions and interactions to deal with the unexpected, but they do not alter their mindful processes of understanding, evidence collection, detection, evaluation and revising. Non-HROs tend to keep their activities constant under the influence of routines and expectations, and vary their processes of mindfulness.

3) “The authority hierarchy does not correspond reliably with the knowledge hierarchy...Engineering separates itself from the hands-on work of operations, which separates itself from maintenance in a downward spiral from ‘mind’ to ‘hand’ to dirty overalls and greasy hands. HROs make an effort to see what people with greasy hands know.” (p. 77)

### Decision Question

What are the foundational principles and strategies for developing and sustaining a culture of resilience within an organization?

### Decision Maker

Applies to any organization; specifies the importance of executive leadership as well bottom-up and top-down responsibility for resilience—“migrating” to expertise as needed

### Relevance

- The book links safety culture with resilience culture, using examples outside the transit realm

Basic Five Principles:

1. Preoccupation with failure-1) detect small failures that may be early signs of bigger problems or failures elsewhere; 2) anticipate and specify significant mistakes they don’t
<table>
<thead>
<tr>
<th>Basics for modifying an organizational culture to institutionalize mindfulness (highlights):</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Culture is how we do things around here and what we expect around here. (p. 115)</td>
</tr>
<tr>
<td>• “A culture of mindfulness, held together by norms of appropriate behavior, will not persist unless:”</td>
</tr>
<tr>
<td>o Top management conveys a clear preference for mindfulness in its beliefs, values and actions</td>
</tr>
<tr>
<td>o Those top management actions and words are communicated credibly and consistently and remain salient for everyone</td>
</tr>
<tr>
<td>o Those communicated values are seen to consistent rather than hypocritical and are felt strongly by the majority of people</td>
</tr>
<tr>
<td>o Bonuses, raises, promotions, and approval flow towards those who act mindfully and away from those who don’t. (p. 117)</td>
</tr>
<tr>
<td>• People need to feel strongly that it’s good to speak up when they make a mistake, good to spot flawed assumptions, good to focus on a persistent operational anomaly. They need to expect support when they do them, and they need to offer support when someone else does them. Likewise, people need to agree that it’s bad to refrain from asking for help, bad to let success go to one’s head, bad to ignore lower ranking experts. (p. 110-111)</td>
</tr>
<tr>
<td>• “While HROs make an effort to develop an integrated culture based on safe operations, they rely heavily on the distinctive subcultures associated with operators, engineers and executives to detect a broader range of weak signals. (p. 113)</td>
</tr>
<tr>
<td>• “If you want to cope successfully with a wide variety of inputs (from a complex environment) you need a wide variety of responses (in your systems). (p. 113)</td>
</tr>
<tr>
<td>• “If changes need to be made in how the organization is run, try to build on existing cultural strengths rather than attempting to change those elements that may be weaknesses.” (p. 120)</td>
</tr>
<tr>
<td>• “The common content thread in cultures that strive to be mindful, informed and safe is that they all focus on wariness….The best way to maintain these states of wariness is to collect and disseminate information about incidents, near misses, and the state of the system’s vital signs- all elements of an informed culture.” (p. 125)</td>
</tr>
<tr>
<td>• An informed culture requires four subcultures:</td>
</tr>
<tr>
<td>o “Reporting culture- what gets reported when people make errors or experience near misses.” (p. 125)</td>
</tr>
<tr>
<td>o “Just culture: how people apportion blame when something goes wrong” (p. 125)</td>
</tr>
</tbody>
</table>
| “An organization is defined by how it handles blame and punishment, and that, in turn, can affect what gets reported in the first place. A just culture is described as “an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information- but in which they are clear about where the line must be drawn between acceptable and unacceptable
human tendency to actively seek evidence that confirms our expectations and avoid evidence that disconfirms them. (p. 26)

- “The primary threat to operations (in nuclear plants) is the engineering culture, which places a higher value on knowledge that is quantitative, measurable, hard, objective, and formal and a lower value on the more experiential knowledge needed by operators... Doubt, discovery and on-the-spot interpretation are hallmarks of sensitivity.” (p. 60)

- “A second threat to sustained sensitivity (to operations) is the tendency of routines to become mindless. The word mindless are not routine, and the better HROs are clear about the difference.” (p. 61)

- “A final threat to operations is an overestimation of their soundness. This happens most often when people learn the wrong lessons from close calls. Close calls sharpen the meaning of failure in relation to success. The most effective HROs regard close calls- for example, a near-collision in aviation- as a kind of failure that reveals potential danger. In contrast, less effective HROs do just the opposite: they look at a near miss and interpret it as evidence of safety and their ability to avoid disaster.” (p. 61)

**Summary actions supporting resiliency**

- Pay as much attention to building capabilities to cope with errors or events that have occurred as to improving capabilities to plan and anticipate events before they occur.

- Develop capabilities for mindfulness, swift learning, flexible role structures, and quick size-ups.

- Adopt an organizational mindset of cure as well as prevention. This means that people are attentive to knowledge and resources that relieve, lighten, moderate, reduce and decrease surprises.

- Encourage people to make knowledge about the system transparent and widely known.

- Establish pockets of resilience through uncommitted resources such as informal networks of people who come together on an as-needed basis to solve sticky problems.

- Create a set of operating dynamics that shifts leadership to the people who currently seem more likely to have an answer to the problem at hand.
### Essential Vocabulary

- Culture is how we do things around here and what we expect around here. (p. 115)
- Conceptual slack: “refers to a divergence in organizational members’ analytical perspectives about the organization’s technology or production processes, a willingness to question what is happening rather than feign understanding, and greater usage of respectful interaction to accelerate and enrich the exchange of information.” (p. 73)
- “Resilience is a combination of keeping errors small and of improvising workarounds that allow the system to keep functioning.” (p. 14)
- “Resilience involves three abilities:
  1) the ability to absorb strain and preserve functioning despite the presence of adversity (both internal adversity, such as rapid change, lousy leadership, and performance and production pressures, and external adversity, such as increasing competition and demands from stakeholders);
  2) an ability to recover or bounce back from untoward events- as the system becomes better able to absorb a surprise and stretch rather than collapse, the “brutality” of an audit decreases; and
  3) an ability to learn and grow from previous episodes of resilient action.” (p. 71)
- Unexpected events can take one of three forms:
  1) an event that was expected to happen fails to occur;
  2) an event that was not expected to happen does happen; and
  3) an event that was simply unthought-of happens.

### Potential Keywords

- Resilience
- Safety culture
- Mindfulness
- Highly reliable organizations (HROs)
- Brutal audit
<p>| Focus Area(s) | | | |
| | X | X | | | | |
| Document Type | National guidance report |
| Intended Audience | Public transportation agencies or entities seeking to improve their safety culture |
| Abstract | The report: |
| | 1) Provides a working definition of safety culture and identifies its key components for use by the public transportation industry |
| | 2) Presents methods and tools for assessing safety culture |
| | 3) Identifies performance indicators and reporting practices to support improved safety culture |
| | 4) Presents best practices in use by public transit and other organizations as tried-and-true strategies for improving safety culture |
| | 5) Provides guidelines that can be used to initiate and build a program for improving safety culture by public transportation agencies |
| | This report presents considerable research on the definition and elements that make up and influence safety culture within public transportation and in other industries. The research included a review of available literature, stakeholder interviews, surveys of transit industry leaders and experts, interviews on safety culture with leaders in other industries, and case studies. Drawing on the successes of organizations both within and outside the transit industry, the report presents specific strategies for improving safety culture and guidelines for public transportation agencies. |
| Populations Referenced | All actors involved in public transportation: upper management (including Boards and Commissioners as well as the General Manager / CEO and his key staff), mid-management, union leadership as well as line-haul managers, operators, maintenance personnel and other personnel. Users of public transport systems are also included in the report. |
| Topics Covered | Subject areas included Public Transportation as well as Safety and Human Factors. The research team prepared a definition of safety culture for public transportation drawing on the literature review, the stakeholder survey, case studies, and interviews from outside the transit industry. Chapters covered include: |
| | 1. Literature Review Highlights |
| | 2. Safety Culture Within Public Transportation |
| | 3. Safety Culture Outside Public Transportation |
| | 4. Definition and Key Components of Safety Culture for Public Transportation |</p>
<table>
<thead>
<tr>
<th></th>
<th>6. Key Performance Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Guidelines for Improving Safety Culture and Recommendations for Additional Research</td>
<td></td>
</tr>
</tbody>
</table>

**Appendices Include:**
- Appendix A Literature Review
- Appendix B Transit Agency Mini–Case Study Detail
- Appendix C Company Mini–Case Study Detail
- Appendix D Draft Transit Safety Culture Survey
- Appendix E References

**Type of Sponsoring Agency or Organization**
- Transportation Research Board

**Geographic Distribution**
- Public Transport Agencies at all sizes in all geographic areas within the United States

**Type of Transit Mode(s)**
- Mass transit (heavy rail, light rail, bus & streetcar), paratransit, and demand response systems

**Type of Vulnerability**
- The absence of a safety culture within a public transport agency or entity, poses significant risk to all impacted by or providing services as well as, the general public who are not using the system but can be affected by unsafe operations. Establishing and maintaining an ongoing safety culture is an ongoing and incremental process that should incorporate key performance indicators, open communications, an ongoing assessment of safety measures and an overarching philosophy within the public transport provider.

**Goals and Motivations**
- To provide a useful definition of a safety culture for public transport providers and users and to then describe various methods to attain this goal.

**Context**
- Applicable to any organization, either public or private, that is engaged in public transport.

**Tools**
- Case studies and lessons learned both within the public transportation and other industries including aviation, nuclear operations and offshore petroleum operations.

**Noteworthy Aspects**
- TRB’s TCRP Report 174 (Improving Safety Culture in Public Transportation) presents research on the definition of safety culture within public transportation, presents methods and tools for assessing safety culture, and provides strategies and guidelines that public transportation agencies may apply to initiate and build a program for improving their safety culture.

**Captivating Value**
- The report may be the first where TCRP researchers studied the role of safety culture in public transportation with a foundation in existing literature on the theory of safety culture. Basically there are two fields of safety climate culture research and safety culture research. Safety climate research flows from the concept of organizational climate, which is grounded in psychology. Safety culture research, on the other hand, is based on organizational culture whose roots are found in anthropology and sociology.

**Decision Question**
- How do create a safety culture within a public transport entity, how do you measure it, and how do you assess your existing safety culture?

**Decision Maker**
- Leaders and their staff at all levels of government (international, national, state, regional, local)

**Relevance**
- This report establishes useful definitions of safety culture as opposed to safety climate.
### Status
As is noted in the report, efforts at resiliency are ongoing and are incremental across all modes.

### Critical Assessment
This report is well written and could serve as good example for our report, especially given the way they summarized key findings within chapters and used appendices to provide further details.

### Additional Comments
N/A

### Essential Vocabulary
The authors wrote in a generally approachable manner.

### Potential Keywords
Disaster preparedness
Post-disaster recovery
Transport resiliency
Disaster planning
Citation | Excalibur Associates, Inc. Unknown. “Security and Emergency Management: An Information Briefing for Executives and Senior Leaders of State Department of Transportation.”
---|---
---|---|---|---|---|---|---
Document Type | Presentation for educational/informative purposes
Intended Audience | State DOT senior officials/executives.
Abstract | The presentation was developed to provide an overview of emergency management concepts and policies to senior leaders at state DOTs to provide highlights of transportation responsibilities in the field of emergency preparedness and security. The intent was to address perceptions at DOTs that they have no responsibilities and to provide information with those who have limited knowledge about the roles of DOTs in emergency management and security.
Populations Referenced | Executives and Senior Leaders
Topics Covered | • “Emergency Management; • Emergency Operations Plans; • National Response Framework; • Emergency Support Function 1, Transportation; • National Incident Management System; • Incident Command System; • Operations Centers; • Obtaining Resources; • Organizing a State Emergency Management Program; • Leadership; and, • Resource Materials.” (p. 2)
Type of Sponsoring Agency or Organization | Federal Highway Administration Transportation Pooled Fund Study 5 (161), Transportation Security and Emergency Preparedness Professional Capacity Building (PCB)
Geographic Distribution | The application is to be applied nationally but the specific state DOT agencies who contributed to the pool fund include: California, Florida, Georgia, Kansas, Mississippi, Montana, New York, Texas, and Wisconsin. Additionally, the U.S. Transportation Security Administration supported the effort as well.
Type of Transit Mode(s) | Although intended for DOT audiences, the presentation provides information applicable for all transportation stakeholders.
Type of Vulnerability | All hazards
Goals and Objectives | The motivation was to ensure state DOTs understand they play a critical role in security and...
<table>
<thead>
<tr>
<th>Motivations</th>
<th>emergency management and to outline some of those responsibilities defined by the federal government.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
<td>Provides applicable practices and information transit agencies should be aware of to address emergency management.</td>
</tr>
<tr>
<td>Tools</td>
<td>No tools were outlined, but ICS and NIMS are policies agencies should review.</td>
</tr>
</tbody>
</table>
| Noteworthy Aspects| • The presentation outlines the phases of emergency management (Mitigation, Preparedness, Response, and Recovery) which each in its own right plays into climate adaptation planning and activities for transit agencies.  
  o Mitigation: “action taken to prevent hazards from developing into disasters, or to reduce the effects or mitigate the consequences of disasters when they occur.” (p. 4) As part of mitigation, conducting assessments to understand vulnerabilities and interdependencies with non-transformational infrastructure (e.g. communications, power).  
  o Preparedness: “develop plans of action for implementation when a disaster strikes. Common preparedness measures include:  
    ▪ Conducting risk assessment to focus efforts towards the greatest hazards/threats;  
    ▪ Taking action to reduce vulnerability and mitigate consequences;  
    ▪ Developing emergency response plans describing how an entity will organize to conduct and manage response operations;  
    ▪ Training individuals and teams to conduct response operations;  
    ▪ Conducting exercises to test response plans and validate training; and,  
    ▪ Incorporating lessons learned from exercises and actual events to improve the level of preparedness.” (p. 4)

The first step is the identification of potential hazards including Earthquakes, Floods, Fire, etc. |
| Captivating Value | ICS is the most critical element of NIMS and has become the standard used in developing response plans across all stakeholders, including transportation. Used from start to finish of any incident of any size, it also provides a foundation of guiding planning activities. ICS supports managing span of control, establishment of facilities and locations to operate from, resource management, integrated communications, information sharing, accountability, command and control, unified command elements, and chain of command. |

“Agencies and organizations that are successful at responding to emergencies and disasters – and meeting expectations – have several traits in common. They all have a solid understanding of the need for being prepared to execute their emergency responsibilities. They all have at some level:  
- Established a formal emergency management program;  
- Identified critical tasks to perform during a response;  
- Developed comprehensive emergency response and continuity plans;  
- Established training programs and requirements for all personnel;
<table>
<thead>
<tr>
<th><strong>Decision Question</strong></th>
<th>Process for incorporating emergency management into an agency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decision Maker</strong></td>
<td>All stakeholders with a role in supporting emergency incidents.</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>The document really shows the needs for transit agencies to be proactive, in coordination with stakeholders, in planning for future events, including the impacts of extreme weather. It is particularly of relevance in outlining the phases of emergency management which correlate closely to the climate adaptation planning. In addition, establishment of successful plans itself is an adaptation strategy in itself to increase resilience and the ability to recover faster from an event.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>The presentation meets its purpose and provides a great overview of emergency management for those less familiar with the field of study; in particular, the phases of emergency management, organization and the Incident Command System. It further highlights the involvement expected of transportation agencies under the NRF. However, some solutions for incorporating emergency management into agency organization may be applicable to DOTs only.</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>N/A</td>
</tr>
</tbody>
</table>
| **Essential Vocabulary** | • Incidents: “An incident is an occurrence, regardless of cause, that requires response actions to prevent or minimize loss of life, or damage to property and/or the environment.” (p. 35)  
• Mitigation: “action taken to prevent hazards from developing into disasters, or to reduce the effects or mitigate the consequences of disasters when they occur.” (p. 4)  
ICS has its own list of vocabulary words useful to those with emergency management roles within their agency. (See p. 43) |
| **Potential Keywords** | National Response Framework  
National Incident Management System  
Incident Command System  
Emergency Management  
Incident Response  
Mitigation  
Preparedness |
#### Citation

#### Website/Source

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

#### Document Type
Resource Document

#### Intended Audience
Transit agencies

#### Abstract
Prepared by the Federal Transit Administration’s (FTA) Office of Safety and Security, Response and Recovery for Declared Emergencies and Disasters: A Resource Document for Transit Agencies is part of FTA’s technical assistance to transit agencies. It addresses response and recovery actions that transit agencies can take, including securing funding and reimbursement for restoring services following a declared emergency or disaster. It is written specifically for transit agencies that are either affected by a declared emergency or disaster or that offer services to an affected community or region. It applies to all modes of transit and to all types of declared emergencies and disasters.

#### Populations Referenced
Transit agencies affected by a declared emergency or disaster.

#### Topics Covered
- Plans and Frameworks for Response and Recovery
  - Federal Roles and Authorities
  - State, Regional, and Local Planning
  - FTA Recommendations for Transit Agencies
- Resources and Funding for Response and Recovery
  - Federal Transit Administration
  - Federal Emergency Management Agency
  - State, Regional, and Local Resources
  - Nongovernmental and Nonprofit Agencies

#### Type of Sponsoring Agency or Organization
The Federal Transit Agency's (FTA) mission is to assist in developing improved mass transportation, encourage the planning and establishment of area-wide mass transportation systems, and provide financial assistance to state and local governments to finance mass transportation systems and carry out national transit goals and policy.

#### Geographic Distribution
United States

#### Type of Transit Mode(s)
All types of transit

#### Type of Vulnerability
Storm, Flooding, Winter, Other

#### Goals and Motivations
This document is written specifically for transit agencies that either are affected by a declared emergency or disaster or provide assistance to others who are affected by a declared emergency or disaster. It addresses response and recovery actions that transit agencies can take, including...
securing waivers of regulation, funding, and reimbursement for restoring services and rebuilding their systems, following a declared emergency or disaster. It applies to all modes of transit and to all types of declared emergencies and disasters (p. 1-3)

This resource document does not address emergency preparedness or emergency management for transit agencies, nor does it provide information for developing or executing emergency response plans or procedures (p. 1-3)

<table>
<thead>
<tr>
<th>Context</th>
<th>To provide a resource for transit agencies.</th>
</tr>
</thead>
</table>
| Tools | • Section 1 provides background for and defines the terms “declared emergency” and “declared disaster,” and explains the purpose and scope of this resource.  
• Section 2 explains the roles and authorities of federal, state, regional, and local government agencies in planning for response and recovery from declared emergencies and disasters.  
• Section 3 discusses resources, funding, and reimbursements available to transit agencies that are either directly impacted by a declared emergency or disaster, or are providing services to affected communities or regions.  
• Section 4 lists other documents that transit agencies may find useful in understanding and planning for disaster response and recovery actions. |
| Noteworthy Aspects | This document provides a resource transit agencies to turn to in the aftermath of an emergency or disaster. |
| Captivating Value | A resource document for transit agencies in the aftermath of an emergency or disaster. |
| Decision Question | N/A |
| Decision Maker | N/A |
| Relevance | Providing a plan of action to handle the aftermath of a natural disaster in the transportation sector is important in the case that resiliency measures fail. Approaches to involve local and federal governments, clarifies their role in planning for response and recovery during an emergency. Furthermore, the piece discusses available resources, funding, and reimbursements that can help facilitate recovery. Overall, planning for disaster response and anticipating the worst case scenario can reveal areas within transit that could use resiliency plans to mitigate the amount of recovery needed in the case of a natural disaster. |
| Status | N/A |
| Critical Assessment | No Assessment Developed |
| Additional Comments | N/A |
| Essential Vocabulary | See Appendix D  
• All hazards:  
  1) Integrated planning and capability building for safety, security, and emergency management to optimize and continuously improve the use of resources and the management of risks from hazards, threats, vulnerabilities, and adverse events or incidents  
  2) Describing an incident, natural or man-made, that warrants action to protect life, property, environment, and public health or safety, and to minimize disruptions of government, social, or economic activities...  
• Emergency. A natural disaster affecting a wide area (such as a flood, hurricane, tidal wave, earthquake, severe storm, or landslide) or a catastrophic failure from any external cause, as a result of which: |
1) The Governor of a state has declared an emergency and the Secretary of Transportation has concurred; or
2) The President has declared a major disaster under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. 5170).

- **Evacuation:**
  1) A condition requiring all passengers and employees to depart a transit vehicle and enter onto the transit right-of-way or roadway under emergency circumstances
  2) Organized, phased, and supervised withdrawal, dispersal, or removal of civilians from dangerous or potentially dangerous areas, and their reception and care in safe areas.
  3) Incident. An occurrence, natural or man-made, that requires a response to protect life or property. Incidents can, for example, include major disasters, emergencies, terrorist attacks, terrorist threats, civil unrest, wild-land and urban fires, floods, hazardous materials spills, nuclear accidents, aircraft accidents, earthquakes, hurricanes, tornadoes, tropical storms, tsunamis, war related disasters, public health and medical emergencies, and other occurrences requiring an emergency response.

- **Incident/Attack:**
  1) Occurrence, caused by either human action or natural phenomena, which may cause harm and may require action.
  2) Occurrence, caused by either human action or natural phenomena, that may cause harm and that may require action.

- **Incident command system:** A standardized on-scene emergency management construct specifically designed to provide an integrated organizational structure that reflects the complexity and demands of single or multiple incidents, without being hindered by jurisdictional boundaries. ICS is the combination of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure, designed to aid in the management of resources during incidents.

- **Major disaster:** Any natural catastrophe (including any hurricane, tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought), or, regardless of cause, any fire, flood, or explosion, in any part of the United States, which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance under the Stafford Act to supplement the efforts and available resources of states, local governments, and disaster relief organizations in alleviating the damage, loss, hardship, or suffering caused thereby.

- **National Incident Management System.** A set of principles that provides a systematic, proactive approach guiding government agencies at all levels, nongovernmental organizations, and the private sector to work seamlessly to prevent, protect against, respond to, recover from, and mitigate the effects of incidents, regardless of cause, size, location, or complexity, in order to reduce the loss of life or property and harm to the environment.

- **National Response Framework.** A guide to how the United States conducts all-hazards response.

- **Recovery:**
  1) The development, coordination, and execution of service- and site-restoration plans; the reconstitution of government operations and services; individual, private sector, nongovernmental, and public assistance programs to provide housing and to promote restoration; long-term care and treatment of affected persons; additional measures for social, political, environmental, and economic recovery.
restoration; evaluation of the incident to identify lessons learned; post-incident reporting; and development of initiatives to mitigate the effects of future incidents.

2) Those capabilities necessary to assist communities affected by an incident to recover effectively, including but not limited to, rebuilding infrastructure systems; providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources.

- Reimbursement: A mechanism to recoup funds expended for incident-specific activities.
- Resources: Personnel and major items of equipment, supplies, and facilities available or potentially available for assignment to incident operations and for which status is maintained. In NIMS (2008), resources are further “described by kind and type and may be used in operational support or supervisory capacities at an incident or at an Emergency Operations Center.”

Response:

1) Activities that address the short term, direct effects of an incident. Response includes immediate actions to save lives, protect property, and meet basic human needs. Response also includes the execution of emergency operations plans and of mitigation activities designed to limit the loss of life, personal injury, property damage, and other unfavorable outcomes. As indicated by the situation, response activities include applying intelligence and other information to lessen the effects or consequences of an incident; increased security operations; continuing investigations into nature and source of the threat; ongoing public health and agricultural surveillance and testing processes; immunizations, isolation, or quarantine; and specific law enforcement operations aimed at preemption, interdicting, or disrupting illegal activity, and apprehending actual perpetrators and bringing them to justice.

2) Immediate actions to save lives, protect property and the environment, and meet basic human needs. Response also includes the execution of emergency plans and actions to support short-term recovery.

3) Those capabilities necessary to save lives, protect property and the environment, and meet basic human needs after an incident has occurred. Special needs population. A population whose embers may have additional needs before, during, and after an incident in functional areas, including but not limited to: maintaining independence, communication, transportation, supervision, and medical care. Individuals in need of additional response assistance may include those who have disabilities; who live in institutionalized settings; who are elderly; who are children; who are from diverse cultures; who have limited English proficiency or are non-English-speaking; or who are transportation disadvantaged.

- Terrorism. As defined in the Homeland Security Act of 2002, activity that involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources; is a violation of the criminal laws of the United States or of any state or other subdivision of the United States; and appears to be intended to intimidate or coerce a civilian population, to influence the policy of a government by intimidation or coercion, or to affect the conduct of a government by mass destruction, assassination, or kidnapping.

- Terrorist activity/attack: Intentional act of violence with the intent to inflict significant damage to property, inflict casualties, and produce panic and fear.

Check sources for additional information.
<table>
<thead>
<tr>
<th>Potential Keywords</th>
<th>Federal Transit Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Office of Safety and Security</td>
</tr>
<tr>
<td></td>
<td>Emergency response and recovery</td>
</tr>
<tr>
<td></td>
<td>Disaster response and recovery</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source
https://www.cite7.org/WaterlooRegion2014/documents/7A_01_ManJenessa.pdf

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

<table>
<thead>
<tr>
<th>Place an “X” by all that apply</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Conference presentation with three case studies.

### Intended Audience
This paper is aimed at and was presented to traffic engineers.

### Abstract
This study explores transit resilience through a holistic lens in an attempt to capture broader, trickle-down effects of disruption on transit systems. It focuses on the impact of disruptions which are more severe in impact and less frequent in occurrence. It includes three case studies on the prevention and mitigation strategies employed by transit operators, transit service planners, and city planners in the periods preceding, during and following a severe disruption. These include: Hurricane Sandy on the New York metropolitan area and the Metropolitan Transportation Authority (MTA) operations; transit resilience implications of the 7 July 2005 London bombings; and the impact of the 8 July 2013 storm in Toronto and specifically on Toronto Transit Commission (TTC) and GO Transit services. It examines parallels in the prevention and mitigation strategies employed in New York, London and Toronto. All three case studies highlight the overall vulnerability of transit infrastructure to suffer severely, post-disruption, being in a state of reduced mobility and limited accessibility.

### Populations Referenced
This focuses primarily on transit riders and the operators of transit systems.

### Topics Covered
Establishing resilience in the response and recovery systems for major urban mass transit systems in the face of both natural and terrorist disasters. Case studies cover one hurricane (Sandy); one terrorist attack (London); and a major storm and flood scenario (Toronto).

### Type of Sponsoring Agency or Organization
Conference presentation for Canadian Institute of Transportation Engineers. The paper does not specifically mention any research sponsors.

### Geographic Distribution
- New York City Metro area; London; Toronto

### Type of Transit Mode(s)
Commuter rail in all three case studies

### Type of Vulnerability
Hurricane, flood, storm surge, terrorist attack, severe storm; climate change impacts are an underlying consideration.

### Goals and Motivations
Potential improvements in system resilience for major urban commuter rail systems, with the aim of applying lessons from three case studies to improvements in Toronto.

### Context
- Each case study focuses exclusively on commuter rail but in a large metropolitan area where multiple modes of mass transit exist in each case.
- Each commuter rail system is part of a larger network of transit assets including bus, longer-distance rail systems, highways, etc., all of which can be directly or indirectly impacted by...
temporary or prolonged disabling of the subway system due to the various hazards studied.

- **What are the transit agencies? What is its organizational structure and size? Are there any interdependencies?**
- Each is different. In NYC, clearly vulnerability to coastal storms is higher, as demonstrated by the impacts of Hurricane Sandy. All three are no doubt vulnerable to terror attacks, as has happened not only in London but NYC. The Toronto case study, however, focuses on a severe summer storm in July 2013 that flooded tracks for both regional trains (GO Train) and the city subway system, forcing service suspension.
- Repeated theme was a transit agency’s relationship with its customers, and the role of human capital in influencing the outcome as a result. Passengers can identify alternate modes in an emergency, but much depends on the quality of communication from the agency.

<table>
<thead>
<tr>
<th>Tools</th>
<th>Mostly narrative case studies comparing the experiences of the three cities and their systems.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Noteworthy Aspects</strong></td>
<td>Key point made was that “perception of resilience can influence actual resilience,” thus the behavioral response of transit users is a key consideration that demands effective communication and dissemination of information to influence user response.</td>
</tr>
<tr>
<td><strong>Captivating Value</strong></td>
<td>“Transit resilience can be enhanced through leveraging the resourcefulness of a system’s users, as in the case of the MTA’s ridership.”</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
<td>Not clear.</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>Regional commuter transit agencies (MTA, London Underground, GO Train, TTC)</td>
</tr>
</tbody>
</table>
| **Relevance** | As noted above, this paper compares the experiences of three major urban transit systems under impacts of varying hazards, both human and natural. The primary comparison point is how they handled the stress on the system in crisis.  
Briefly identify and summarize:  
- Accepted practice: paper cites pre-emptive shutdown and relocation of rolling stock from low-lying areas as one precaution, based on anticipation of disruption, but this obviously has less relevance to terrorist attacks.  
- Guidelines: Not particularly clear in this respect.  
- No particularly noteworthy data sources or approaches.  
- Barriers: not specifically discussed. |
| **Status** | All are case studies of recent past impacts, does not discuss ongoing status as such. |
| **Critical Assessment** | This has very limited quantitative value since it is largely a narrative-based case study comparison of three varying situations involving major metropolitan transit systems responding to threats. |
| **Additional Comments** | None. |
| **Essential Vocabulary** | None. |
| **Potential Keywords** | Transit, user behavior, subway, storm, severe disruption |
| **Follow-up Comments** | None. |

---

*Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies*

Copyright National Academy of Sciences. All rights reserved.
### Citation

### Website/Source
ISSN 0097-8515

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

### Document Type
Research

### Intended Audience
Practitioners, MPOs, State DOTs

### Abstract
The paper outlines the impacts of incorporating climate change on systems management, operations and emergency response. In following up to a series of recommendations by a variety of entities to incorporate climate change into long-term planning and near-term operational decisions, the paper supports the anticipated efforts MPOs and DOTs will be undertaking.

### Populations Referenced
Customers

### Topics Covered
- Operations and the impacts of climate change including travel for customers.
- Monitoring for climate change and impacts.

### Type of Sponsoring Agency or Organization
N/A

### Geographic Distribution
National

### Type of Transit Mode(s)
Roadway impacts specifically, but much of the information crosses modes.

### Type of Vulnerability
Coastal Storm, Sea-level rise, heat, intense precipitation and drought.

### Goals and Motivations
N/A

### Context
N/A

### Tools
N/A

### Noteworthy Aspects
Description of Operational impacts climate change has based on climate indicator:
As part of operations, the paper highlights the importance of customer communications. Identification of monitoring needs.

<table>
<thead>
<tr>
<th>Climate Change</th>
<th>Impacts on Transportation</th>
<th>Operations Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increases in very hot days</td>
<td>• Softening and buckling of pavements</td>
<td>• Reduced (and variable) speed limits</td>
</tr>
<tr>
<td></td>
<td>• Thermal expansion of bridge expansion joints</td>
<td>• Truck restrictions</td>
</tr>
<tr>
<td></td>
<td>• Rail–track deformities</td>
<td>• Road and transit diversions</td>
</tr>
<tr>
<td></td>
<td>• Limitations on periods of construction activity due to health and safety concerns</td>
<td>• Work zone management (accommodate additional lane closures)</td>
</tr>
<tr>
<td></td>
<td>• Vehicle overheating (resulting in roadway incidents)</td>
<td>• Increase in incident management activities</td>
</tr>
<tr>
<td>Rising sea levels</td>
<td>• Flooding of coastal roads, tunnels, and rail lines</td>
<td>• Road and lane closures</td>
</tr>
<tr>
<td></td>
<td>• Erosion of road base and bridge supports (scouring)</td>
<td>• Disruption of transit service</td>
</tr>
<tr>
<td>Increases in intense</td>
<td>• Increases in weather-related delays and traffic disruptions</td>
<td>• Road and transit diversions</td>
</tr>
<tr>
<td>precipitation events</td>
<td>• Increased incidents</td>
<td>• Diversions</td>
</tr>
<tr>
<td></td>
<td>• Erosion of road base and bridge supports (scouring)</td>
<td>• Increase in incident management activities</td>
</tr>
<tr>
<td>Increases in drought</td>
<td>• Increased susceptibility to wildfires and reduced visibility</td>
<td>• Reduced (and variable) speed limits</td>
</tr>
<tr>
<td>conditions for some regions</td>
<td></td>
<td>• Road closures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Diversions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increase in incident management activities</td>
</tr>
<tr>
<td>Increases in hurricane</td>
<td>• More frequent and potentially more extensive emergency evacuations</td>
<td>• Contraflow lane operations</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td>• Ramp management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Corridor Management (along evacuation routes)</td>
</tr>
</tbody>
</table>

(p. 49)

(p. 50)
As part of emergency planning, the paper identifies the need for evacuation planning through establishing evacuation routes and contraflow plans and rethinking proper life-safety messages to the public.

The paper identifies the need for operational elements and planners of an agency coordinate to be sure investments reflect full considerations including climate change.

Boston MPO provides a good example of infrastructure planning where climate change was considered. The first objective in this example identifies projects that “include adaptation measures to protect against climate change impacts.” The second objective focuses on the “protection (sic) transportation infrastructure from natural hazards and climate change impacts.”

<table>
<thead>
<tr>
<th>Decision Question</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Maker</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Relevance         | - Paper addresses operational impacts, emergency planning and monitoring assets and climate data.  
- It addresses the importance of communicating to the public as well. |
| Status            | N/A |
| Critical Assessment | The paper provides most knowledge in terms of operational impacts from climate change. These impacts may support educational outreach to those in charge of operations. Additionally, the emergency planning information provided has some additional concepts other documents reviewed have not touched on including contraflow plans and addressing proper actions and direction to the public. |
| Additional Comments | N/A |
| Essential Vocabulary | N/A |
| Potential Keywords | Adaptation  
Adaptation Strategies  
Climate Data  
Risk |
**Citation**


**Website/Source**

N/A

**Focus Area(s)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Document Type**

Book chapter

**Intended Audience**

- Researchers
- Emergency managers
- Transportation professionals

**Abstract**

This book chapter examines evacuation planning for carless and vulnerable populations across the United States and examines federal policy. It provides a case study of the New Orleans City Assisted Evacuation Plan and then summarizes lessons for the inclusion of carless and vulnerable populations during disaster planning.

**Populations Referenced**

Vulnerable and carless populations

**Topics Covered**

- Evacuation planning for carless and vulnerable populations
- Federal policy on emergency preparedness and evacuation planning
- Case study of New Orleans City Assisted Evacuation Plan (CAEP)
- Lessons for the Inclusion of Carless and Vulnerable Populations during Disaster Planning

**Type of Sponsoring Agency or Organization**

Nonprofit published book (Brookings Institution Press). Federal Transit Administration provided funding for the study.

**Geographic Distribution**

United States / International

**Type of Transit Mode(s)**

All

**Type of Vulnerability**

Hurricane

**Goals and Motivations**

To identify a national problem of the need for planning for carless and vulnerable populations; to summarize a successful case study of the New Orleans CAEP; and to make recommendations

**Context**

This is a book chapter published by a nonprofit press recognized as a leading think tank.

**Tools**

This chapter highlights the case study of the New Orleans CAEP, which was successful deployed during Hurricane Gustav in 2008.

**Noteworthy Aspects**

CAEP successfully evacuated 18,000 during the Gustav evacuation. The CAEP includes partnerships with local, city, state and other stakeholders. The city of New Orleans works with the state of Louisiana’s *Emergency Operations Plan*, developed by the Governor’s Office of...
<table>
<thead>
<tr>
<th><strong>Homeland Security and Emergency Preparedness (GOHSEP)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Captivating Value</strong></td>
</tr>
<tr>
<td>CAEP is one of the only public transit emergency evacuation plans that have been tested during a real storm. The chapter focuses on how this could be a model for other communities across the nation.</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
</tr>
<tr>
<td>This chapter allows for identifying how carless and vulnerable populations can be accommodated during a mass evacuation.</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
</tr>
<tr>
<td>Transportation agencies</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
</tr>
<tr>
<td>Evacuation of vulnerable populations, as shown in New Orleans City, advocates a city assisted evacuation plan. This plan could be implemented as part of an overall transportation resiliency effort to ensure population safety in the case of emergency. Furthermore, these carless individuals need to be taken into consideration and found a reliable mode of transportation during a weather hazard to evacuate.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
</tr>
<tr>
<td>No assessment developed</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
</tr>
<tr>
<td>Carless evacuation</td>
</tr>
<tr>
<td>City assisted evacuation plan</td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
</tr>
<tr>
<td>Carless evacuation</td>
</tr>
<tr>
<td>City assisted evacuation plan</td>
</tr>
</tbody>
</table>
REFERENCE DOCUMENTS NOT CITED IN SYNTHESIS REPORT
(ALPHABETICAL BY AUTHOR)
**Citation**

**Website/Source**
(http://scholarworks.uno.edu/cgi/viewcontent.cgi?article=1005&context=unoti_pubs)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Document Type**
Research document

**Intended Audience**
This document addresses all interested parties who reside or work within regions that are susceptible to natural or man-made disasters.

**Abstract**
Transportation systems play a crucial role in responding to a region’s pre-disaster evacuation and post-disaster recovery. The ability of these systems to perform under adverse circumstances (i.e. when disaster impacts a city or region) depends upon their fixed and movable assets as well as their operational procedures before, during and after the disaster. In addition, planning and coordination between the various state and federal agencies is now recognized as a critical factor during all phases of a disaster. So is the post-disaster realization that “communications is the Achilles Heel” during all phases of a disaster as stated by the General Manager of the New Orleans Public Belt Railroad, a publicly owned and operated terminal switching railroad serving the Port of New Orleans and local industry along the City’s East Bank riverfront.

What is unique about this report is both authors were personally affected by the wrath of Katrina and participated in literally hundreds of meetings from neighborhood associations to several Community Congress’ that included participants from all neighborhoods in all income categories and all races. This gave the authors a unique perspective which will be valuable to any and all researchers undertaking disaster preparation or recovery efforts post-disaster projects.

**Populations Referenced**
Users and providers of transportation systems (all modes) in both the public and private sector.

**Topics Covered**
This document reports on both the opportunities realized and missed in Greater New Orleans Region during all phases of disaster preparedness as well as recovery from Hurricane Katrina.

**Type of Sponsoring Agency or Organization**
This report was sponsored with funds provided by the United States Department of Transportation Research and Innovative Technology Administration (RITA).

**Geographic Distribution**
The Greater New Orleans Region (Orleans, Jefferson, Plaquemines, St. Bernard, St. Tammany and Tangipahoa Parishes).

**Type of Transit Mode(s)**
Mass transit (bus & streetcar), paratransit, and demand response systems throughout the 5 parish region (Orleans, Jefferson, Plaquemines, St. Bernard, St. Tammany, Tangipahoa,.

**Type of Vulnerability**
Natural and man-made disasters with an emphasis on lessons learned from Hurricane Katrina.

**Goals and Motivations**
Utilize the Greater New Orleans Region’s experience in all phases of preparation, evacuation, repopulation and recovery from Hurricane Katrina (2005-2006).

**Context**
Applicable to any region, within the U.S. and internationally, that is susceptible to natural or man-
<p>| <strong>made disasters.</strong> |  |
| <strong>Tools</strong> | Case studies and lessons learned. |
| <strong>Noteworthy Aspects</strong> | See relevance section. |
| <strong>Captivating Value</strong> | The report documents how the Greater New Orleans Region has bolstered its resiliency in all modes of transport in both disaster evacuation and response post-Katrina. This is of extreme importance to all regions subject to disasters in any form or fashion. |
| <strong>Decision Question</strong> | Disaster preparation and recovery are documented for the Greater New Orleans Region in the context of Hurricane Katrina. The report documents the importance of the Metropolitan Planning Organization as a key resource and facilitator to all levels of government |
| <strong>Decision Maker</strong> | At all levels of government (federal state, regional, local). |
| <strong>Relevance</strong> | Documents both opportunities realized and missed prior to, during and after Hurricane Katrina struck the Greater New Orleans Region which devastated all modes of transportation. This event is especially relevant to disaster prone regions at the local, regional, national and international scale given this particular disaster was the costliest in history. |
| <strong>Status</strong> | As is noted in the report, efforts at resiliency are ongoing and incremental across all modes. |
| <strong>Critical Assessment</strong> | This documents both qualitative and quantitative measures to achieve resiliency at all scales in a post-Katrina environment (80% of the City of New Orleans flooded when the flood protection system failed). |
| <strong>Additional Comments</strong> | N/A |
| <strong>Essential Vocabulary</strong> | No specialized vocabulary. |
| <strong>Potential Keywords</strong> | Disaster preparedness Post-disaster recovery Transport resiliency Disaster planning |</p>
<table>
<thead>
<tr>
<th>Citation</th>
<th>Document, American Public Transportation Association, 2013. Standards Development Program.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Type</td>
<td>This document describes the standards development program of the American Public Transportation Association (APTA) and provides an inventory of the standards, by category, that were in place as of 2013.</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>This document is intended for public transportation stakeholders who are either affected by, or who wish to pursue the development or modification of a standard that regulates the operation, construction, or management of some aspect of public transportation.</td>
</tr>
<tr>
<td>Abstract</td>
<td>This document describes APTA’s role in developing standards for the public transportation industry and provides a brief description of the myriad standards administered by APTA.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>The providers and consumers of public transportation services.</td>
</tr>
</tbody>
</table>
| Topics Covered | • A Program of the American Public Transportation Association,  
• Standards Development at APTA,  
• What are APTA Standards,  
• Benefits of Standards,  
• How Can I Become Involved or Obtain Existing APTA Standards,  
• Bus Transit Systems,  
• Information Technology for Transit Systems,  
• Universal Transit Fare Systems (UTFS),  
• Universal Transit Fare System Specifications & Reports,  
• Rail Passenger Equipment Safety Standards (PRESS),  
• Procurement Standards,  
• Rail Transit Systems,  
• Rail Maintenance Training,  
• Security for Transit Systems,  
• Sustainability & Urban Design Standards for Transit Systems,  
• Technical Specifications for Transit Systems. |
| Type of Sponsoring Agency or Organization | APTA has been developing standards since 1995, releasing hundreds to date. Development of standards is guided by the Standards Development and Oversight Council (SDOC) and various Standards Policy and Planning Committees, following universally accepted policies of the American National Standards Institute (ANSI). APTA is recognized as a SDOC by the U.S. Department of Transportation (DOT), U.S. Department of Homeland Security (DHS), Transport Canada, Canadian Urban Transport Association (CUTA) and other SDOs such as IEEE, SAE, ITE and ASSHTO. Standards development at APTA is supported by U.S. Federal Transit Administration (FTA), U.S. Transportation Security Administration (TSA), members of APTA and many others. The SDOC was created to promote the use of standards in the public transportation industry and guide the standards development program. |

The Council, working in concert with existing APTA standards development policy and planning
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

<table>
<thead>
<tr>
<th>Geographic Distribution</th>
<th>APTA’s standards program is primarily oriented towards the needs of the American public transportation market. APTA’s membership includes both very large and very small transportation agencies from across the United States.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Seemingly all modes of surface passenger transportation are addressed by APTA.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>The APTA standards development program addresses a wide range of public transportation issues brought to it by a wide range of interests; from persons seeking from congestion to interests seeking a competitive advantage.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>This document communicates the role and purpose of the APTA standards development program, provides an inventory of the various standards that have been approved through the APTA standards program since its inception in 1995, and invites interested parties to participate and/or to offer suggestions for revisions to current standards or proposals for new standards. At the present time there are no APTA standards that address state of good repair, asset management, or resilience.</td>
</tr>
<tr>
<td>Context</td>
<td>Current APTA standards do not address resilience.</td>
</tr>
<tr>
<td>Tools</td>
<td>There are currently no tools in the APTA standards program that address resilience.</td>
</tr>
</tbody>
</table>

members, provides top-level technical coordination and funding oversight. The council’s specific charge is to:

- Establish priorities for standards programs at APTA,
- Coordinate the standards development activities of APTA’s modal groups such as rail, bus, safety, ADA, procurement, etc., and;
- Develop and manage the standards annual work plan and budget.

Members of the SDOC are drawn from the chairs of APTA standing committees and augmented by representatives of the Federal Transit Authority (FTA) as ex-officio members.

The Policy and Planning Committees establish specific technical direction within modal groups through development of needs assessments, technical guidance of standards development, and overall management of standards development process and promulgation. The Policy and Planning Committees retain official release authority for APTA standards.

APTA standards are documents developed and adopted by a consensus process that contain criteria, design requirements, measures of comparison, and best practices and/or processes. There are four types of documents: standards, recommended practices, guidelines and white papers. These documents and other supportive reports are required for safety or system interoperability issues.

Standards use collective wisdom to provide a path or paths to a desired outcome such as:

- the design of a simple component
- the design of an entire complex system
- the definition of a process or operation
- the steps to follow to perform a task
- guidance or recommendations based on industry best practices or operation

APTA promotes its standards development program by noting that its widely accepted consensus transit standards benefit public transportation by minimizing the need for federal regulations and in several other important ways:

- improve safety of operations and services
- reduce operating and maintenance costs


<table>
<thead>
<tr>
<th><strong>Noteworthy Aspects</strong></th>
<th>There may be noteworthy aspects of future standards with regard to resilience, but none exist at the present time.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Captivating Value</strong></td>
<td>This document describes the means and methods by which standards addressing resilience may be developed in the future.</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
<td>What decision, if any, is being made? As noted above, APTA standards use the collective wisdom of the participants in a consensus process to provide a path or paths to a desired outcome.</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>Development of standards is guided by the Standards Development and Oversight Council (SDOC) and various Standards Policy and Planning Committees, following universally accepted policies of the American National Standards Institute (ANSI). APTA is recognized as a SDOC by the U.S. Department of Transportation (DOT), U.S. Department of Homeland Security (DHS), Transport Canada, Canadian Urban Transport Association (CUTA) and other SDOs such as IEEE, SAE, ITE and ASSHTO. Standards development at APTA is supported by U.S. Federal Transit Administration (FTA), U.S. Transportation Security Administration (TSA), members of APTA and many others. The SDOC was created to promote the use of standards in the public transportation industry and guide the standards development program. The Council, working in concert with existing APTA standards development policy and planning committees, provides top-level technical coordination and funding oversight. The council’s specific charge is to: Establish priorities for standards programs at APTA Coordinate the standards development activities of APTA’s modal groups such as rail, bus, safety, ADA, procurement, etc. Develop and manage the standards annual work plan and budget Members of the SDOC are drawn from the chairs of APTA standing committees and augmented by representatives of the Federal Transit Authority (FTA) as ex-officio members. The Policy and Planning Committees establish specific technical direction within modal groups through development of needs assessments, technical guidance of standards development, and overall management of standards development process and promulgation. The Policy and Planning Committees retain official release authority for APTA standards.</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>This document was reviewed in order to accurately portray the standards process through which it is hoped that recommendations stemming from this study will be considered, and standards that address resilience within the context of state of good repair will be developed.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Efforts to develop resilience standards may be encouraged by the publication of this project.</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>The APTA standards development process requires significant discussion and negotiation among stakeholders. The case for creating a standard for resilience will require sensitivity to the wide range of resources and capabilities reflected in the diversity of America’s transit agencies and the</td>
</tr>
</tbody>
</table>
locations and conditions in which they operate.

### Additional Comments

- N/A

### Essential Vocabulary

- **Consensus standards** – standards developed through an iterative process that requires the concurrence of all participating stakeholders.
- **Resilience** – is not defined in this document.
- **Standards Development and Oversight Council (SDOC)** – the APTA organization that leads and sets priorities for APTA’s standards development program.
- **Standards Policy and Planning Committees** – Sub-units of the SDOC.

### Potential Keywords

- Consensus standards
- Guidelines
- Recommended practices
- Standards
- Standards development
- White paper
<table>
<thead>
<tr>
<th>Citation</th>
<th>Document: APTA, 2013. “Capital Asset Inventory and Condition Assessment – APTA SGR-TAM_RP_003_13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website/Source</td>
<td><a href="http://www.apta.com/gap/fedreg/Documents/Capital_Asset_Inventory_Assessment.pdf">http://www.apta.com/gap/fedreg/Documents/Capital_Asset_Inventory_Assessment.pdf</a></td>
</tr>
<tr>
<td>Focus Area(s)</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>This is a guidance document for managers of transit agencies of any size. It is most pertinent for agencies that have not already undertaken Asset Management initiatives.</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>All transit agency managers, but especially those who have not started either an asset management initiative, or a state of good repair program.</td>
</tr>
<tr>
<td>Abstract</td>
<td>This document outlines the initial steps needed to create and/or improve asset management within a transit agency, regardless of transit agency size. It outlines how to manage capital assets from procurement to disposal (i.e., over the life cycle).</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>All transit agencies.</td>
</tr>
<tr>
<td>Topics Covered</td>
<td></td>
</tr>
<tr>
<td>• Defining and organizing your assets,</td>
<td>• Developing an asset inventory,</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>The American Public Transportation Association (APTA) in support of its standards development committee produced this document. The committee is the facilitator for the Federal Transit Administration’s standards development initiative.</td>
</tr>
<tr>
<td>APTA is the national association representing transit agencies, industry vendors and consultants, local, state and federal transportation representatives, and academicians.</td>
<td></td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>This document is relevant to transit agencies of all sizes and in all locations.</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>This document is generic in nature, addressing all modes broadly in the context of capital asset inventory and condition assessment.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>This document does not address climate vulnerability. It is focused on strategies for developing an inventory of a transit agencies inventory of assets and ascertaining their condition.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The goals and motivation of this document is to assist transit agency managers in their efforts to establish an accurate inventory of their capital assets, and to discern the condition of those assets.</td>
</tr>
<tr>
<td>Context</td>
<td>There is no context in this document related to the current condition of transit agencies and their resilient capabilities.</td>
</tr>
</tbody>
</table>
Resilience is not in the vocabulary of this strategy.

<table>
<thead>
<tr>
<th>Tools</th>
<th>This text reflects the matrix and process for establishing a capital asset inventory and determining its condition:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Inventory assessment methodology --</strong> (Developed by Chicago Regional Transportation Authority [RTA])</td>
</tr>
<tr>
<td></td>
<td>The following recommended steps are herewith offered in order to follow a relatively easy, seamless, affordable and understandable procedure in developing an asset inventory and asset condition assessment.</td>
</tr>
<tr>
<td></td>
<td>1. Based on the agreed upon condition assessment strategy and agency may assemble an inventory assessment team composed of in-house asset stewards and contracted asset type experts to form a project team to collect and assemble the data into the inventory/assessment (I/A). The in-house staff may be asked to work part time on the I/A or to take it on as a temporary full time project.</td>
</tr>
<tr>
<td></td>
<td>2. Review sample inventory / assessments within this report, and select one or more to use as a guide for your I/A. Guidance and templates for this process will be forthcoming.</td>
</tr>
<tr>
<td></td>
<td>3. Define, tally, categorize and construct a living listing of every asset type, to form the basis of your agencies I/A. This is meant to be a large exhaustive list of every asset type within the agencies properties. For example a large transit system may include as many as 100 asset types broken into as many as 10 categories. These may include facilities, structures, rolling stock, track, yards etc. When assembling an inventory for the first time, asset data will most likely need to be obtained from a variety of sources. Potential asset data sources include:</td>
</tr>
<tr>
<td></td>
<td>• Prior I/A efforts</td>
</tr>
<tr>
<td></td>
<td>• Maintenance Management Systems (MMS, e.g., Maximo, Ellipse etc.).</td>
</tr>
<tr>
<td></td>
<td>• Fleet roster (for vehicles)</td>
</tr>
<tr>
<td></td>
<td>• Department level / asset manager records which may exist in spreadsheet format</td>
</tr>
<tr>
<td></td>
<td>• Fixed Asset Ledger (accounting system): Generally not a preferred source for larger assets but useful for small value items such as radios, shelters, and non-revenue vehicles</td>
</tr>
<tr>
<td></td>
<td>• Primary data collection</td>
</tr>
<tr>
<td></td>
<td>4. Create a recording template for each asset type (using the guide documents noted above). The templates should be designed to provide enough data to document each asset’s type, date built or acquired (to assess age), quantity, unit cost and condition.</td>
</tr>
<tr>
<td></td>
<td>5. Determine estimated useful life for each asset. These may be copied from the provided guide document samples or determined by the I/A team.</td>
</tr>
<tr>
<td></td>
<td>6. Establish age for each asset. Should the actual purchase or installation date be unavailable, proxies (estimates) must be used to determine these quantities.</td>
</tr>
<tr>
<td></td>
<td>7. The ratio of age to useful life can be used to group assets into age quintiles and these quintiles can then be used as simple measures of asset condition as follows:</td>
</tr>
<tr>
<td></td>
<td>• 5 = 25% of useful life consumed</td>
</tr>
<tr>
<td></td>
<td>• 4 = 26% to 50% of useful life consumed</td>
</tr>
<tr>
<td></td>
<td>• 3 = 51% to 75% of useful life consumed</td>
</tr>
<tr>
<td></td>
<td>• 2= 76% to 100% of useful life consumed</td>
</tr>
<tr>
<td></td>
<td>• 1 = &gt; 100% of useful life consumed</td>
</tr>
<tr>
<td></td>
<td>8. Populate the asset type templates with available data. Proxies (educated estimates) must be used for any unavailable data in order for the I/A to be as complete as possible.</td>
</tr>
</tbody>
</table>
|       | 9. Perform an inspection of a sampling segment of each asset type in order to verify the consistency of the calculated conditions above with the observed conditions. This activity
may necessitate changes to some of the condition ratings of the I/A.

10. Determine replacement costs (Cost to replace with new asset) for each asset. Knowledge of the original cost is helpful in this task. If unavailable; a proxy must be used to estimate such. This quantity represents the System Replacement Value. How do we handle betterment of an asset?

11. Calculate the replacement cost for all assets that exceed their useful life (i.e., rated 1 using the condition measure suggested above). This quantity represents the Backlog.

12. Determine the time period for the asset condition assessment. For consistency it is recommended that a 10-year period be utilized by all agencies. Create a 10-year matrix using Excel or other to record the following.

13. Determine any anticipated asset replacements (example bus fleet replacements) and any anticipated large capital investments (example locomotive half life overhaul) over the 10-year period. This quantity represents the Normal Reinvestment. Plot these on the 10-year matrix.

14. Add the quantities Backlog and Normal Reinvestment. This quantity represents the SOGR Need for the ten-year period.

15. In order to visualize the size of the SOGR Need, it is helpful to compare it to the System Replacement Value. This can be done by simply dividing the SOGR need for the ten-year period by 10 to get an Annual average SOGR need. This quantity can be compared to the agency’s System Replacement Value. For example, one large older agency’s SOGR need for the ten-year period is $26.4B. This amounts to an annual average SOGR need of $2.6B. Its System Replacement Value is $140B. By dividing the $2.6B by $140B we can see that the annual average SOGR need for this agency amounts to 1.8% of its System Replacement Value.

In order for different agencies’ quantities to be comparable, a level of consistency is important. As mentioned in item 12, it is recommended that all agencies utilize a consistent 10-year I/A period. In that same spirit, it is also recommended that the quantities used throughout the assessment period remain in starting dollar quantities, without addition of yearly inflationary adjustments.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>This is another in a series of documents produced under the auspices of the APTA standards development committee responding to congressional requirements to establish matrix to measure the efficacy of public investment in public transportation. This document does not address external consideration that may affect the cost of climate activities, or the conditions of the population served by the transit agency.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captivating Value</td>
<td>This document outlines the initial steps needed to create and/or improve asset management within a transit agency, regardless of transit agency size. It outlines how to manage capital assets from procurement to disposal (i.e., over the life cycle).</td>
</tr>
<tr>
<td>Decision Question</td>
<td>This document is intended to help transit agency managers to understand how to assess the condition of their agency’s capital asset inventory. It is a tool to be used in reaching decisions about where and how to utilize resources.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Transit agency managers, transportation policy decision makers, and other stakeholders who may have a voice in the deployment of resources to support the transit agency.</td>
</tr>
<tr>
<td>Relevance</td>
<td>This document is relevant in terms of establishing a foundation for allocating resources that may eventually be directed towards establishing a resilience capability once such capabilities are pursued by transit agencies. It does not address issues of climate change, severe natural events, or resilience.</td>
</tr>
<tr>
<td>Status</td>
<td>This document is another building block in the process of developing measures of performance for transit agencies.</td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
This document is another building block in the process that may eventually support inclusion of resilience standards as part of a transit industry state of good repair regime.

<table>
<thead>
<tr>
<th>Critical Assessment</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Essential Vocabulary
- **Asset dynamics**: Data that help predict the costs to maintain or improve an asset’s condition over its life cycle.
- **Asset management control**: (undefined)
- **Capital assets**: fixed, long-term items that will require preservation to add value and utility to an organization.
- **Resilience** is not addressed in this document.

### Potential Keywords
- Asset inventory,
- Condition assessment,
- Transit asset management,
- State of good repair,
- Performance management,
- MAP-21
| Focus Area(s) | X | X | X | X | X | X |
| Document Type | This is a guidance document for use primarily by transit agency managers. |
| Intended Audience | Transit agency managers and unit leaders. It may have additional interest for transportation policy decision makers, academics, and other industry observers. |
| Abstract | This document, “Recommended Practice,” introduces asset management in the context of the U.S. transit industry and provides basic steps and resources for an agency to begin an asset management program. |
| Populations Referenced | This document is intended for transit agency managers and their personnel. |
| Topics Covered | • Why improve transit asset management.  
• Drivers for Improving Asset Management.  
• Asset Management in Context.  
• Transit Asset Management Benefits.  
• Getting started.  
• Considerations for small agencies.  
• Resources.  
• References.  
• Definitions.  
• Abbreviations and acronyms. |
| Type of Sponsoring Agency or Organization | The sponsor of this document is the American Public Transportation Association (APTA), the trade association for transit agencies throughout the United States. APTA membership includes transit agency leadership and personnel, local and state transportation officials, transportation equipment manufacturers, and academics. |
| Geographic Distribution | This document is primarily directed at transit agency management, but it is of interest to transportation planners, operational personnel, local, state and federal transportation policy makers and advisors. Its focus, while primarily directed to individual transit agencies is applicable nationally. |
| Type of Transit Mode(s) | Transportation agencies of all sizes with equipment of all types. |
| Type of Vulnerability | This document does not address vulnerabilities. Its focus is on the establishing a management system to monitor the condition and content of a transportation agency’s fleet and facilities. |
| Goals and Motivations | The FTA’s State of Good Repair grants and the recent enactment of Moving Ahead for Progress in the 21st Century (MAP-21) has put considerable focus on improving the U.S. transit industry’s asset management activities. This document introduces asset management in the context of the U.S. transit industry and provides basic steps and resources for an agency to begin an asset management program.  
This document does not reference “Resilience,” but does offer recommendations for creating a... |
transit asset management program into which resilience could be addressed.

**Context**

There is no reference to resilience planning in this document.

This document addresses asset management as a core strategic management process, along with risk management and performance management. APTA posits that these are agency-wide management processes that together support the accomplishment of the entire agency’s goals and objectives.

An agency’s strategic plan is the starting point for developing asset management policy, strategy and business plans because the strategic plan provides the vision, mission and values of the organization, along with organizational goals, policies and strategies. To be most effective, transit asset management activities should be integrated into existing strategic, business and operational management processes.

**Tools**

The document offers two metrics to encourage the use of asset management. The first presents the transit agency business benefits and the approach to manage agency assets.

<table>
<thead>
<tr>
<th>Transit Asset Management Benefits</th>
<th>Business Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Agency</td>
<td>Asset Management Approach</td>
</tr>
<tr>
<td>Improved customer service</td>
<td>Improves on-time performance and service operations.</td>
</tr>
<tr>
<td></td>
<td>Improves vehicle and facility cleanliness.</td>
</tr>
<tr>
<td></td>
<td>Reduces missed trips, slow orders and station shutdowns.</td>
</tr>
<tr>
<td></td>
<td>Focuses investments around customer-centered goals and metrics.</td>
</tr>
<tr>
<td>Improved productivity and reduced costs</td>
<td>Maintains assets more effectively, using condition-based approaches and using predictive and preventive maintenance strategies (where these can be employed) to reduce costs while improving service delivery.</td>
</tr>
<tr>
<td>Optimized resource allocation</td>
<td>Better aligns spending with the agency’s goals and objectives to obtain the greatest return on investment (ROI) from limited funds.</td>
</tr>
<tr>
<td>Improved stakeholder Communications</td>
<td>Incorporates lifecycle cost, risk analysis and performance trade-offs into capital programming and operations maintenance budgeting.</td>
</tr>
</tbody>
</table>

Provides stakeholders with more accurate and timely customer-centered performance indicators.

Provides tools to communicate forecasted performance metrics (including level of service).
The steps for implementing a transit asset management program include the following:

1. Prepare for implementation:
   The starting point for developing a transit asset management program requires identifying the level of awareness and understanding of asset management within the agency. The agency can establish a foundation for the TAM improvement program by establishing a leadership and accountability framework and considering enablers. Enablers are supportive processes and activities that form the foundation of a successful TAM program. They include leadership and accountability, training, communications, values and culture, project management, and continuous improvement. Good, accurate data on assets will establish a solid foundation for the program, which in turn will generate sound and timely investment decisions, prioritization and planning. The resulting effect is a state of good repair (SGR), improved reliability and predictable operation.

2. Assess agency maturity:
   An important next step is completing an appraisal of an agency’s current asset management maturity. This can help to establish the agency’s baseline and target. The FTA Transit Asset Management Manual, PAS 55 and the AASHTO Asset Management Guide all include self-assessment tools (see References).

3. Develop a plan:
   An asset management plan specifies the implementing actions for increasing asset management maturity. It outlines exactly how the agency will meet its target in the context of the agency’s awareness of asset management, readiness for change and ambitions for the asset management improvement program.

4. Implement the improvement program:
   With all foundational items in place, the TAM improvement program can be implemented. Key steps involved in the implementation include developing and implementing the communications and information systems strategies.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>This document present the initial efforts of the public transportation industry to respond the legislated requirements to develop performance measures to demonstrate the effective use of assets that are purchased or subsidized by government grants or other taxpayer resources. At this stage in the program’s development, there is very little discussion about resilience, and no measurements for demonstrating resilience.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captivating Value</td>
<td>The FTA’s State of Good Repair grants and the recent enactment of Moving Ahead for Progress in the 21st Century (MAP-21) has put considerable focus on improving the U.S. transit industry’s asset management activities.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>This document encourages transit agencies to adopt asset management strategies within the context of their state of good repair initiatives.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Transit agency leadership, local, state and federal transit policy decision makers</td>
</tr>
<tr>
<td>Relevance</td>
<td>This document was selected because it is a building block for implementing a state of good repair program within which this project is intended to promote the development of standards for transit resilience.</td>
</tr>
<tr>
<td>Status</td>
<td>Transit agencies are in the early stages of establishing both state of good repair and asset management initiatives. The Federal Transit Administration is still formulating regulations and guidance for implementing these initiatives.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The approach outlined in this document was developed through a deliberative/iterate process and will change as the experience of transit agencies, and local, state, and federal transportation agencies dictate. There are no specific standards for performance at this juncture, only guidance, and there is no</td>
</tr>
</tbody>
</table>
The concept of resilience is just beginning to surface within the context of transit state of good repair and asset management.

<table>
<thead>
<tr>
<th>Additional Comments</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Vocabulary</td>
<td>Transit asset management: A strategic and systematic process through which an organization procures, operates, maintains, rehabilitates and replaces transit assets to manage their performance, risks and costs over their lifecycles to provide safe, cost-effective and reliable service to current and future customers.</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Performance management transit asset management MAP-21</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

**Document Type**: This document is a set of recommended practice meant to document the experience of agencies that have found measures that work in a real-world setting. Keeping in mind that asset management is a journey, not a destination, these experiences may assist other agencies that are beginning their own efforts to establish transit asset management programs.

**Intended Audience**: Transit agency managers

**Abstract**: This publication is intended as an introduction to the high-level requirements for building a transit asset management framework to achieve a state of good repair, including definitional issues and resources for further study.

**Populations Referenced**: The management, employees, and policy leadership of transit agencies.

**Topics Covered**
- Keys to building an asset management plan,
- Standards
- Definitions
- Asset management plan (AMP)
- Asset inventory
- Asset management systems
- Business practices
- Organizational change
- Performance measures
- Agency efforts:
  - Corpus Christi Regional Transportation Authority (CCRTA)
  - Massachusetts Bay Transportation Authority (MBTA)
  - Metropolitan Atlanta Rapid Transit Authority (MARTA)
  - Metropolitan Transportation Authority, New York (MTA)
  - Regional Transportation Authority of Northeast Illinois (RTA)
  - Utah Transit Authority (UTA)
  - Washington Metropolitan Area Transit Authority (WMATA)
- Summary / Conclusion
- References
- Abbreviations and acronyms

**Type of Sponsoring Agency or Organization**: The American Public Transportation Association (APTA) is the sponsor of this document. Its Standards Development Committee is the primary author. APTA is the national trade association for the U.S. public transit industry. Its membership includes transit agencies, local, state and federal transportation policy administrators, industry equipment providers, consultants and academics. APTA is the primary facilitator for FTA standards development.

**Geographic**: This document contains case studies that include:
### Distribution
- Corpus Christi Regional Transportation Authority (CCRTA),
- Massachusetts Bay Transportation Authority (MBTA),
- Metropolitan Atlanta Rapid Transit Authority (MARTA),
- Metropolitan Transportation Authority, New York (MTA),
- Regional Transportation Authority of Northeast Illinois (RTA),
- Utah Transit Authority (UTA), and
- Washington Metropolitan Area Transit Authority (WMATA).

<table>
<thead>
<tr>
<th>Type of Transit Mode(s)</th>
<th>All modes of surface public transportation are addressed in this document, e.g. Commuter Rail, Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, and Demand Response.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Vulnerability</td>
<td>The document does not address vulnerabilities per se. The document offers strategies for managing a transit agency's total inventory of assets, their condition, cost, cost of replacement, maintenance, agency revenue, and agency cost of financing among other factors. Weather conditions and vulnerability to climate conditions are not addressed unless the agency is aware of a risk for which the agency knows the repair or replacement is likely.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>To encourage transit agencies to establish asset management frameworks in order to maintain a state of good repair at a controllable and sustainable level.</td>
</tr>
<tr>
<td>Context</td>
<td>The document recognizes that transit agencies are not all the same in their ability to maintain a state of good repair, which is defined as a condition in which assets are fit for the purpose for which they were intended. The document defines a transit asset management framework as a means to achieve a state of good repair for transit assets such as rolling stock, right-of-way, stations, facilities, systems and equipment. It defines “asset category” as a primary grouping of asset classes such as “vehicles” that includes both rail and rubber-wheeled vehicles. Under this definition, the term “asset” does not refer to financial assets typically documented in accounting statements, nor does it refer to non-physical assets such as trademarks and intellectual property. The document refers agencies to the FTA’s Asset Management Guide that for defines transit asset management as a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates and replaces transit assets to manage their performance, risks and costs over their lifecycle to provide safe, cost-effective, reliable service to current and future customers. Additionally, the FTA’s Asset Management Guide defines transit asset management as a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates and replaces transit assets to manage their performance, risks and costs over their lifecycle to provide safe, cost-effective, reliable service to current and future customers. It defines an asset management business plan as a document that outlines the implementing activities, roles, responsibilities, resources and timelines needed to address an agency’s asset management policy and strategy. It defines an asset management business plan as a document that outlines the implementing activities, roles, responsibilities, resources and timelines needed to address an agency’s asset management policy and strategy. Resilience planning is not addressed in either the APTA document or the FTA definitions referred to in the APTA document.</td>
</tr>
<tr>
<td>Tools</td>
<td>The document contains an asset inventory that is the structured foundation from which an agency documents baseline data and conditions and develops its performance plan. It is important that the inventory be accurate and have identifying attributes tailored to the system from which all data is collected and manipulated. The inventory hierarchy common to most all transit organizations is comprised of five major</td>
</tr>
</tbody>
</table>

---

A-176
Elements: vehicles, facilities, stations, guide ways, and systems. These groups are the building blocks from which a solid asset inventory is derived. Agencies will add their own organization’s assets under each major category. For example, the vehicles category can be broken into rail vehicles and buses. From there, the agency can decide how to break it down further until every vehicle is classified (The document refers to Chapter 3 of the FTA’s Asset Management Guide).

The document suggests that the asset inventory should constantly be maintained and added to as the agency completes major asset purchases and projects. The inventory should be maintained by the specific work groups responsible for the maintenance of the assets. This inventory will assist the financial and capital planning staffs in making accurate decisions and projections for keeping the asset inventory in a state of good repair.

**Noteworthy Aspects**

The document recommends the following:
- The plan must have a champion at the executive level;
- Concepts need to be taught, shared and internalized by employees at all levels;
- The transit development plan (TDP) should have a section allocated to maintaining SGR;
- Maintenance efforts should become more proactive and planned as opposed to reactionary in nature;
- Balances and compromises must be found between new construction versus rehabilitation and replacement efforts;
- Barriers between different departments need to be broken down in order for information to be shared; and,
- Department expertise needs to be recognized and valued for the contributions it can provide.

**Captivating Value**

Provided a detailed asset management plan to achieve an up to date state of good repair which could contribute to evaluating transit agencies for the implementation of resiliency provisions.

**Decision Question**

N/A

**Decision Maker**

N/A

**Relevance**

This document was selected because it is one of the foundational elements of the effort between industry and the government to ensure that resources — both private and public — are being used to provide the best, most reliable, and efficient public transportation service available.

The document focuses on several transit agencies that have attempted to establish transit asset management initiatives to determine the effectiveness of their implementation.

**Status**

This document was published in 2013, based on the experience to that time. Since then, the FTA has published additional guidance and notices. The evolution of “state of good repair and transit asset management continues. Only recently has the concept of resilience been introduced into the discussion.

**Critical Assessment**

No assessment developed

**Additional Comments**

N/A

**Essential Vocabulary**

Asset classification – previously defined
Asset inventory
Asset management plan – previously defined
Basic inventory categories – vehicles, stations, facilities, guide way elements and systems
State of good repair – previously defined

**Potential Keywords**

Asset management guide
Business practices
Performance measures
<table>
<thead>
<tr>
<th>Transit asset management</th>
</tr>
</thead>
<tbody>
<tr>
<td>State of good repair</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Website/Source</td>
</tr>
<tr>
<td>Document Type</td>
</tr>
<tr>
<td>Intended Audience</td>
</tr>
</tbody>
</table>
| Abstract | “System resiliency of transportation infrastructure is a growing concern of transportation professionals for both longer term risks associated with climate change and in response to extreme weather events. This paper presents a prioritization framework and case study addressing climate change adaptation for transportation infrastructure. This framework is based on:  
1) Outcomes of a series of engineering assessments to identify implications of incorporating climate variability in projects already completed/underway;  
2) Development of policies for including risk as part of decision making in planning and engineering;  
3) Development of methods by which to prioritize improvements to reduce / eliminate risks to the existing network; and  
4) Development of methods by which to incorporate climate change / extreme weather into decision making for planning and engineering projects.  
Based on temporal distribution of expected climate change and observed issues, potentially at-risk facilities are identified. This framework also includes design life of transportation facilities, replacement cost values and an assignment of loss scores for damage/loss value – all of which are utilized in a benefit/cost framework. This general framework can be customized by various agencies by redefining their priorities and addressing risks.” |
| Populations Referenced | The makes no mention of any specific populations, but relevant stakeholders that would benefit from this information include high-level planners, engineers, and administrators from state and local DOTs as well as Metropolitan Planning Organizations (MPOs). |
| Topics Covered | The purpose of this paper is to describe a decision-making framework for adaptation planning for individual assets that could also be used to determine priorities among assets at a subarea level. To accomplish this a ten step approach was proposed that includes:  
1. Identify the physical limits of the asset and what is to be analyzed.  
2. Clearly identify the climate variables to be examined and the mechanisms by which the climate variable can damage the asset (e.g. wave action on bridge decks, roadway embankment failure due to high velocities associated with weir overtopping flow, softening/rutting of asphaltic pavements due to vehicle loading combined with extended high temperatures, etc.) |
3. Identify design criteria and standards currently used to design the asset.
4. Determine whether the asset meets current design criteria/standards. What is required to bring the asset to meet current standards?
5. Identify relevant climate data applicable to engineering analysis. If exact data required for design cannot be obtained from climate modeling, how can the readily obtainable data be used in the analysis? Is there an alternative design method that can be substituted or a data surrogate that could be used? Also include discussion of uncertainty and appropriate level of risk based on traffic, criticality, current development, and examination of check floods.
6. Develop a reasonable range of climate scenarios to analyze.
7. Identify design thresholds and perform a sensitivity analysis of which design standards are violated by which climate variables.
8. Perform an economic analysis that includes present worth of the capital cost, maintenance, failure replacement cost, damage cost, and economic loss of each design option.
9. Consider practicality of each option, obstacles to implementation.
10. Make a final judgment based on sound scientific principles and peer acceptance.

<table>
<thead>
<tr>
<th>Type of Sponsoring Agency or Organization</th>
<th>The sponsor of the work described in this paper is not explicitly named. It appears that it carry on of initial work completed by the authors under support from the Transportation Research Board.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>Although, there is nothing to suggest that the information contained in the paper would not be generally applicable to any transportation agency, the level of the analyses and the scope/scale of the infrastructure it refers to, suggest that it is targeted primarily towards major metropolitan areas or state-level applications.</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>The tools and methods discussed in this paper were targeted broadly at transportation infrastructure and, in particular, the large-scale economic and investment strategies to maintain accessibility and limiting damage/vulnerability of these systems. Modes were named as “asset types” and included roadways, bridges, ports, waterways, airports, rail, and transit assets. A notable application to transit was the example discussing the flooding vulnerability of the New York subway system from storm surge. From a roadway perspective could be vulnerable bus routes that could be lost due to flooding.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>The vulnerabilities that were focused on in this work were climate change and sea-level rise related and focused on natural hazards. Although other weather extremes like rising temperatures, extreme cold, high precipitation (snow/rain), erosion, landslides etc. were not mentioned, the techniques and frameworks here could be applicable to them as well. It is also likely that these techniques could apply to a range of other mad-made hazards, both accidental and intentional.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The authors state that “transportation infrastructure is designed to “fit” into a local environment and to withstand a defined level of forces and climate impacts that have the potential to destabilize infrastructure integrity. The design criteria to which this infrastructure has been designed to meet is based upon historical climate data. However, as climate conditions continue to change, these criteria may no longer provide a sufficient level of protection or utilization. In the paper a step-by-step process for considering adaptation considerations in facility/asset design, and an approach for establishing priorities was proposed. Given recent experiences with extreme weather events, e.g. Superstorm Sandy, Hurricane Katrina, Midwest floods, and wildfires in the U.S. west, transportation officials cannot ignore the mounting evidence that critical transportation infrastructure needs to be designed differently than what has been done in the past.”</td>
</tr>
<tr>
<td>Context</td>
<td>The context of this work is quite broad, but would include transportation agencies (including planners, engineers, and administrators from state and local DOTs and MPOs) in areas of...</td>
</tr>
</tbody>
</table>
substantial size that also house major transportation infrastructure systems. The level of applicability would depend upon the specifics of the type and level of threat and corresponding vulnerability.

| Tools | Although no specific “tools” were developed in this work per se, the paper presents a “prioritization framework to facilitate climate change adaptation for transportation infrastructure. This framework is based on four step process that includes:

1) Outcomes of a series of engineering assessments to identify implications of incorporating climate variability in projects already completed/underway;
2) Development of policies for including risk as part of decision making in planning and engineering;
3) Development of methods by which to prioritize improvements to reduce / eliminate risks to the existing network; and
4) Development of methods by which to incorporate climate change / extreme weather into decision making for planning and engineering projects.” |

| Noteworthy Aspects | This work is noteworthy in that it provides a “comprehensive, high-level framework on which to assess vulnerability conditions and use it to predict expected potential damage, losses, and outcomes. It can also be applied to perform economic analyses that include present worth of the capital cost, maintenance, failure replacement cost, damage cost, and economic loss of design options. Although it has similarities to other existing tools and techniques that are based on subjective assessments, this framework has potential to be useful to support or provide quantitative support/rational for financial investments and other decision making.” |

| Captivating Value | Research presented in this paper could be expanded further to develop tools to mitigate the effects of extreme weather on transportation structures. Furthermore, it provides a framework connecting policy to the implementation of these policies which transit agencies. |

| Decision Question | Should transit organizations adopt climate mitigation provisions in their designs and practices as a precautionary measure in the case of an extreme weather event? If so, how would this be implemented? |

| Decision Maker | The source does not discuss applicable/relevant decision makers explicitly. However, it is clear that this guidance is geared towards very high-level planners and administrators from state and local DOTs as well as Metropolitan Planning Organizations (MPOs) in major metropolitan areas. |

| Relevance | The direct relevance of this information specifically to transit system agencies would be at the very highest levels. As the tools and techniques are focused primarily at the administrative planning level. However, if used by related transportation agencies it would have potential to inform transit resilience planning in which, for example, agencies would be more aware of systems and routes that are susceptible to flooding and pavement degradation. |

| Status | As a conceptual document, it does not appear that anything that was presented in this source has been used in any actual applications. |

| Critical Assessment | No results or assessments of them or the framework were reported on in this source. |

| Additional Comments | N/A |

| Essential Vocabulary | Adaptation planning - “Adaptation planning involves responding to the impacts of climate change, both proactively and reactively. Adaptation planning can include preventative measures to slow down the progression of climate change and mitigation measures to reduce the effects.” Definition from: http://climate.dot.gov/impacts-adaptations/planning.html |

| Potential Keywords | Transportation  
Resilience  
Climate change  
Adaptation planning |
### Citation

### Website/Source

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

### Document Type
Report

### Intended Audience
All

### Abstract
This report summarizes key findings from the Transportation System Resilience, Extreme Weather and Climate Change thought leadership series held at Volpe, the National Transportation Systems Center from fall 2013 to spring 2014.

### Populations Referenced
Transportation Infrastructure systems, Stakeholders

### Topics Covered
- Transportation System Resilience, Extreme Weather and Climate Change: Driving Forces
  - Assessment of Climate Change Risks and Vulnerabilities
    - Indicators of a Warming World
    - Changes in Sea Levels
    - Changes in Average Temperature and Rainfall
    - What’s Causing Climate Change?
    - Impacts of Climate Change on Transportation Infrastructure
  - Climate Change Adaptation Strategies
    - Adaptation Benefits, Co-Benefits, and Challenges
    - Adaptation Success Metrics
    - Climate Change Adaptation in New York City
    - Pre-Super Storm Sandy NYC Task Force Climate Risk Assessment
    - Post-Sandy Damage Assessment and Lessons Learned
    - Perspective on Federal Response to Super Storm Sandy
  - Mitigation of Climate Change Consequences
    - Beneficial Effects of CAFE Standards as a Mitigation Measure
    - Adverse Impacts of Fossil Fuels on Rates of CO₂ Concentration
- Resilience in the Face of Climate Change Impacts and the Importance of Planning
  - Importance of Planning

### Type of Sponsoring Agency or Organization
U.S. Department of Transportation, John A Volpe National Transportation Systems Center

### Geographic Distribution
National, NYC area

### Type of Transit
All
<table>
<thead>
<tr>
<th>Mode(s)</th>
<th>Climate change (air and water temperatures, sea levels and precipitation rates)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Vulnerability</strong></td>
<td>A framework for tackling transportation challenges arising from the escalating threats of our changing climate. This report summarizes the strategies and realities within this framework.</td>
</tr>
<tr>
<td><strong>Context</strong></td>
<td>The region contains a serious of complex transportation networks run by the US DOT, however size and funding continue to pose limitations. Prior to seeing the extreme weather change, the region did have some adaptation strategies in place – adaptation through re-zoning and ecosystem restoration.</td>
</tr>
<tr>
<td><strong>Tools</strong></td>
<td>The NPCC Task Force recommended adaptation actions that ranged from incremental to large-scale strategies, with planning horizons that ranged from short-term projects of less than 5 years to long-term projects of over 15 years. Closely following the 5 facets of adaptation, the NPCC recommended an 8-step adaptation process: 1. Identify current and future climate hazards; 2. Conduct risk assessment and develop an inventory of built assets to identify vulnerabilities; 3. Characterize risks of climate change on built areas; 4. Develop an initial list of adaptation strategies; 5. Prioritize strategies and identify opportunities for coordination; 6. Link strategies to development cycles and prepare adaptation plans; 7. Implement adaptation plans; and 8. Monitor progress and reassess strategies.</td>
</tr>
<tr>
<td><strong>Noteworthy Aspects</strong></td>
<td>Planning for climate change-resilient infrastructure requires a coordinated process of assessing risks, formulating adaptation and mitigation strategies, and coordinating implementation. The process of planning for climate change is closely associated with resilience planning in general, and adapting to and mitigating adverse consequences of climate change.</td>
</tr>
<tr>
<td><strong>Captivating Value</strong></td>
<td>Infrastructure resilience (see Figure 13) depicts resilience as an overarching concept linking infrastructure fault-tolerance and event-monitoring capabilities with elements of adaptation and mitigation of adverse consequences to ensure functional continuity.</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
<td>No decisions have been made.</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>Federal, US DOT</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>Resilient practices were promoted throughout the report. The piece mentioned the following relevant practices:  • Make risk-based benefit-cost assessments at the right time using updated flood maps and flood vulnerabilities as a function of sea-level rise, while also accounting for changing physical and social asset configuration and vulnerabilities and optimal resiliency pathway is reached;  • Develop sea-level rise adaptation policies with public-private stakeholders and create land-use plans that balance the merits of temporary protection and medium-term protection, accommodating for sea-level rise, with long-term, sustainable retreat to safer neighborhoods;  • Incorporate climate change data and risk estimates for various time horizons into all strategic planning and capital decisions;  • Use each climate change and sea-level rise challenge as an opportunity for improvement and renewal of urban infrastructure. The costs for the NYC metro region will be upward of $100 billion—some $30 billion of which for the transportation sector alone—but not investing in these resilience measures would be more expensive by factors of 4 to 10 in post-disaster costs;  • Ensure robust planning for interim operational emergency and business continuity of</td>
</tr>
</tbody>
</table>
The following guidelines were also provided:
- Short-term actions include updating flood maps, installing gates at subway entrances, and draining flooded subways;
- Medium- and long-term actions include carbon pricing as well as new zoning and building codes, floodplain buyouts, analyzing hazard-related data to determine where it is safe to build or locate temporary facilities, or developing technologies that could be used to support mitigation strategies.

<table>
<thead>
<tr>
<th>Status</th>
<th>Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The approaches presented herein are widely known and used, particularly in the NYC Metro region since Superstorm Sandy. A clear path forward and the next step form the planning process should be more clearly defined.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>Resiliency was not defined.</td>
</tr>
</tbody>
</table>
| Potential Keywords | Climate Change  
Resilience  
Mitigation  
Adaptation  
Transportation Planning  
National Climate Assessment |
| Citation | Adapting to Climate Change Through Asset Management Planning, APTA 2013 Sustainability and Public Transportation Workshop |
| Document Type | Conference PowerPoint Presentation |
| Intended Audience | Transit agency political leadership, executives, management, and operational staff |
| Abstract | This presentation examines the relationship between potential climate change factors and transit assets and operations, with particular focus on how a transit agency’s asset management system can be used in support of strategic adaptation investment decision making. It offers a framework for integrating climate adaptation in transit asset management. |
| Populations Referenced | Asset managers, operational personnel and customers. |
| Topics Covered | Asset management and lifecycle management component and opportunities to integrate climate adaptation. |
| Type of Sponsoring Agency or Organization | Transit agency (MARTA), academic institution (Georgia Tech), and industry contracting and engineering firm (Parsons Brinkerhoff). |
| Geographic Distribution | Mass transportation service for the Atlanta, Georgia metropolitan area. |
| Type of Transit Mode(s) | • 48 miles of rail service (120 miles of track); • 338 rail vehicles; • 3 rail yards; • 38 rail stations; • 590 buses; • three (3)3 bus maintenance facilities; • 175 paratransit vehicles; • 450 non-revenue vehicles; • 1 (one) non-revenue vehicle maintenance facility; and, • Over 100 ancillary buildings. |
| Type of Vulnerability | More intense precipitation (and thus flooding), higher maximum temperatures and wider range of temperature, higher-strength winds related to more intense storms, and drought. |
| Goals and Motivations | • Adopt an agency-wide policy on climate change and climate adaptation and mitigation. • Conduct climate vulnerability and risk assessment for assets and operations. • Develop and implement a climate change adaptation and mitigation plan. • Utilize existing agency processes and standard operating procedures to implement adaptation/mitigation strategies. • Install sufficient generator capacity to entirely power bus maintenance facilities and their... |
equipment during power outages.
- Review and update standard operating procedures for extreme weather conditions to incorporate emergency evacuation and restart plans for maintenance facilities and alternative communication Plan.
- Develop a system accessibility plan which should establish what level of service will be provided during or after extreme weather events (ice storm, floods, etc.), as well as how access to that service will be maintained (e.g. snow/ice removal).
- Coordinate with local weather services to identify extreme weather events within the service area in real time.
- Allow system users (passengers) to crowd source updates via social media (like Twitter) (e.g. flooded routes, broken A/C in train cars and buses) to key agency personnel.

**Context**
Applying the FTA Asset Management Guide to address climate adaptation opportunities identified at the enterprise and asset levels. No discussion of resilience.

**Tools**
N/A

**Noteworthy Aspects**
Asset lifecycle management planning addresses the following:
- Business units,
- Asset or asset classes,
- Location of assets,
- Climate risks to assets,
- Climate Risk Mitigation Strategies,
- Lifecycle steps impacted,
- Preventive or reactive/corrective activities,
- Timing of implementation, and
- Cost of implementation.

**Captivating Value**
The objective of this presentation was to examine the relationship between potential climate change factors and transit assets and operations, with particular focus on how a transit agency’s asset management system can be used in support of strategic adaptation investment decision making.

**Decision Question**
As noted under “Goals and Motivations,” above, the presentation presented a series of initial integrated adaptation strategies for bus maintenance and operation, rail vehicle maintenance and operation, track structures, civil engineering and design, capital facilities, architecture, and general management in a series of tables that offered long-term and short-term decision points and actions to be taken depending on the nature of the “Climate Stressor.”

**Decision Maker**
This presentation is intended to communicate to transit agency decision makers and state and federal department of transportation policy personnel the experience of Atlanta, Georgia’s MARTA system in preparing for and dealing with climate events.

**Relevance**
This presentation was selected to demonstrate how one major urban transit agency, MARTA, is preparing to deal with climate events. The presentation offers an integrated strategy for all of MARTA’s enterprises and the management of each unit’s assets.

The presentation identifies a particular software program that MARTA has selected to help managers understand the potential condition of their system, and the options and decision points that need to be considered in the initial stages of its climate adaptation management process.

Many of these decision points and suggested options have been “costed” and actions already taken.

While this presentation does not address resilience per se, it does reflect key actions and considerations that transit agencies may wish to consider should they decide to pursue an asset management strategy that will ultimately incorporate resilience.
### Status

This presentation was made 2013. There is no follow-up presentation or information to suggest that MARTA has not, or is not pursuing the full implementation of the strategy outlined in this presentation.

### Critical Assessment

This presentation offers the experience of one transit agency, MARTA, in taking the initial steps in its efforts to adapt to climate change. The strategy outlined in this presentation appears to be comprehensive. The presentation offers no perspective on the success or impact of the strategy outlined. It may be worthwhile to do follow-up interviews with MARTA officials to ascertain their perspective on the value and impact of implementing this strategy.

### Additional Comments

N/A

### Essential Vocabulary

- Adaptation strategies – decision points and steps transit agencies could take to cope with change.
- Climate stressors – the intensity of climate events on various transit agency assets and functions.

### Potential Keywords

- Adaptation strategies
- Climate stressors
- Asset management
- Transit agency enterprises
- Climate hazards
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Type</td>
<td>Best practices</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Practitioners in transit organizations and jurisdictions that oversee them</td>
</tr>
<tr>
<td>Abstract</td>
<td>This guide provides a transit-specific framework for use of current best practices in asset management.</td>
</tr>
<tr>
<td>Populations Referred</td>
<td>Governing jurisdictions, transit agencies, transit engineering, planning, and maintenance organizations</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>• Transit Asset Management Framework</td>
</tr>
<tr>
<td></td>
<td>o Management vision and direct [including purpose and value]</td>
</tr>
<tr>
<td></td>
<td>o Policy, strategy and planning</td>
</tr>
<tr>
<td></td>
<td>o Lifecycle management</td>
</tr>
<tr>
<td></td>
<td>o Capital planning</td>
</tr>
<tr>
<td></td>
<td>o Operations and maintenance budgeting</td>
</tr>
<tr>
<td></td>
<td>o Performance modeling</td>
</tr>
<tr>
<td></td>
<td>• Information technology</td>
</tr>
<tr>
<td></td>
<td>o Asset management information systems</td>
</tr>
<tr>
<td></td>
<td>▪ Importance of accuracy of data</td>
</tr>
<tr>
<td></td>
<td>▪ Asset inventory</td>
</tr>
<tr>
<td></td>
<td>▪ Asset condition</td>
</tr>
<tr>
<td></td>
<td>▪ Active condition monitoring, detection, and tracking</td>
</tr>
<tr>
<td></td>
<td>▪ Maintenance management</td>
</tr>
<tr>
<td></td>
<td>▪ Fleet management</td>
</tr>
<tr>
<td></td>
<td>▪ Parts management and inventory control</td>
</tr>
<tr>
<td></td>
<td>▪ Facilities management</td>
</tr>
<tr>
<td></td>
<td>▪ Scenario analysis and decision making [key aspect for resilience]</td>
</tr>
<tr>
<td></td>
<td>▪ Financial, accounting engineering and other systems</td>
</tr>
<tr>
<td></td>
<td>• Implementation guidance</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>Federal agency</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>• National</td>
</tr>
<tr>
<td></td>
<td>• All regions, sizes, and types</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>All</td>
</tr>
<tr>
<td>Type of Vulnerabilities</td>
<td>Vulnerabilities are not studied.</td>
</tr>
</tbody>
</table>
### Vulnerability

<table>
<thead>
<tr>
<th>Goals and Motivations</th>
<th>Goals were to enable transit agencies to enhance safety and customer satisfaction while controlling costs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
<td>Resiliency planning is not mentioned. One basic message of advocates of asset management cited in the guide is: Transit assets exceeding their useful life can result in asset failures, which can increase the risk of catastrophic accidents, disrupt service, and strain maintenance departments. One can view natural disasters as catastrophic threats to the useful life of assets. Avoiding or mitigating the threats through resiliency processes reduces the probability of catastrophic accidents, disruption of service (or deterrence of recovery) and prolonged strain of maintenance departments.</td>
</tr>
<tr>
<td>Tools</td>
<td>N/A</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>The authors were supported by several transit agencies with a broad range of services:</td>
</tr>
<tr>
<td></td>
<td>- New York Metropolitan Transportation Authority</td>
</tr>
<tr>
<td></td>
<td>- Long Beach Transit</td>
</tr>
<tr>
<td></td>
<td>- Utah Transit Authority</td>
</tr>
<tr>
<td></td>
<td>- TriMet (Portland, OR)</td>
</tr>
<tr>
<td></td>
<td>- Sound Transit (Puget Sound)</td>
</tr>
<tr>
<td></td>
<td>- Bay Area Rapid Transit</td>
</tr>
<tr>
<td></td>
<td>- King County Transit (Seattle)</td>
</tr>
<tr>
<td></td>
<td>- Metropolitan Atlanta Transit Authority</td>
</tr>
<tr>
<td></td>
<td>- Southeastern Pennsylvania Transportation Authority</td>
</tr>
<tr>
<td></td>
<td>- Long Island Railroad</td>
</tr>
<tr>
<td></td>
<td>- Los Angeles County Metropolitan Transportation Authority</td>
</tr>
<tr>
<td></td>
<td>- Chicago Regional Transit Authority</td>
</tr>
<tr>
<td></td>
<td>- London Underground</td>
</tr>
<tr>
<td></td>
<td>- Massachusetts Bay Transportation Authority</td>
</tr>
<tr>
<td></td>
<td>- Victoria Department of Transportation (Australia)</td>
</tr>
<tr>
<td></td>
<td>- Metropolitan Transportation Commission (San Francisco Bay Area)</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>This report integrates concepts of asset management with case studies of the experience of many practitioners. It provides a clear vision of the leverage provided by asset management and significant evidence to support those who seek decisions that will enhance asset management practices and systems in their transit organizations. The framework for systematic asset management, although not claiming so, supports scenarios for resiliency planning and execution.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>No decision is made. The recommendations are for investing in asset management.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Federal agencies might decide to sponsor improved asset management. Most decision concerning adoption, implementation, and ongoing improvement will be made by transit agencies and the local jurisdiction(s) that support them.</td>
</tr>
<tr>
<td>Relevance</td>
<td>Management can make credible estimates of the severity of losses that might be caused by natural disasters if they have the data about assets produced by asset management. Without such data, quantification of the costs of disasters, scenario by scenario, slides into the realm of guesswork. With such data, managers can generate more reliable estimates of both the cost and benefits of resiliency.</td>
</tr>
<tr>
<td>Status</td>
<td>Descriptions of concepts and practices already in place.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Authors use a typical consultants’ approach to discussion of concepts and reporting of case studies. Report is simple and clear. Authors did not discuss resilience considerations as a factor in asset management. Authors fail to include enhanced safety as a benefit of systematic asset management.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>Cross-asset planning and management – this concept means that planning and management must consider the possibilities that changes in one asset may necessitate changes in processes or in inventories of other assets. Resiliency is not mentioned.</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Potential Keywords   | Lifecycle management  
Total cost of ownership  
Risk management,  
Enterprise asset management  
Cross-asset planning |
<table>
<thead>
<tr>
<th>Citation</th>
<th>Brown, Richard. 2014. Transport Resilience Review: A review of the resilience of the transport network to extreme weather events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Type</td>
<td>Government report presented to UK Parliament</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Legislators and policy makers</td>
</tr>
<tr>
<td>Abstract</td>
<td>This is a very broad, overarching review of the impact of extreme weather events in the UK on various transport modes, primarily road and rail, but very little of it pertains directly to urban mass transit.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Rail operators, drivers, highway maintenance managers, ports operators</td>
</tr>
</tbody>
</table>
| Topics Covered | This report covers:  
- Basic descriptions of extreme weather and of specific events in 2013 and 2014 in UK  
- Common issues across transport modes including single points of failure, flood defenses, recovery planning, resilience, forecasts, communication, and crisis response  
- Impacts on specific sectors, specifically, Strategic Road Network, local roads, railways, and ports |
| Type of Sponsoring Agency or Organization | UK Parliament |
| Geographic Distribution | National level (UK)  
Regional  
Local |
| Type of Transit Mode(s) | Railways, road networks, local roads, and ports |
| Type of Vulnerability | Flooding (inland and coastal), extreme rain events, extreme heat |
| Goals and Motivations | Goals are to determine avenues for creating greater resilience in various elements of the national transport system. Motivation was damage to and resilience of the existing network as a result of severe storms in 2013-2014. |
| Context | Modes of transportation in the region include: Railways, Road Networks, Ports, and Airports. Agencies operating in the area include: Network Rail, Strategic Road Network (SRN) managed by the Highways Agency (HA), Local highway authorities, and Department for Transport (DfT) working with Highways Maintenance Efficiency Programme (HMEP) on local roads. There exists financial limitations and the challenge of dealing with historically old structures already in place. Most modes of transit have little to no resiliency measures implemented presenting several risks in the case of a natural disaster. |
| Tools | N/A |
Although the report does not mention any tools used to mitigate effects of extreme weather events, it does give a list of long and short-term recommendations that would allow for an appropriate response to these events.

SHORT-TERM SOLUTIONS:
It is recommended that all transport operators have contingency plans for extreme weather, clear channels for receiving weather updates, and a dedicated passenger and communications plan for times of transport disruption. Specifically in the area of communication, ideas must be broadcasted in the everyday language utilizing pictures and airing on frequently used networks in order to fully inform the audience of the event. All operators, regardless of transportation sector, are encouraged to revisit their Climate Change Risk Assessments and Adaptation Plans in addition to attending workshops on how to handle natural disasters.

- Local roads - “identify a 'resilient network' to which they will give priority, in order to maintain economic activity and access to key services during extreme weather... The report also recommends that Government should consult Local Highway Authorities on a single set of criteria to be applied to emergency highway repair funding, to consume minimum administrative resource when applying for funds at times of crisis.” (15-16).
- Rail – “In response to the winter’s flooding it is recommended that Network Rail should:
  o develop plans to raise track heights and raise lineside equipment cabinets above track level on sections of track at risk of flooding, as part of its new Route Resilience Plans;
  o consider accelerating introduction of axle counters for areas at high risk of flooding;
  o deploy its new temporary automatic signaling system in the event of track flooding.

It is also recommended that, in the event of major disruption, coordination arrangements over adjacent geographical areas are enhanced.” (16)

- Ports and Airports – “All major ports and airports should review the location and flood protection of their power, communications and IT infrastructure. It recommends improved liaison between port operators, the HA and Network Rail to consider and develop resilient links to and from ports. In order to provide greater certainty to travelers and operators, the report proposes that airports and their principal airlines should adjust capacity on a pre-emptive basis when extreme weather is coming, rather than waiting for the weather to hit” (16).

LONG TERM SOLUTIONS
Maintenance activity to resiliency needs to be included in funding. The DfT and Treasury need to ensure that funding decisions include resiliency maintenance. The report also recommends that the DfT develops benchmark ratios for highway maintenance spending to make sure money is going where it is needed, identify a critical network prioritizing where the network should be maintained, as well “review current economic appraisal guidance and develop robust systems to ensure that the full costs of disruption and recovery are captured in industry appraisals.” (17) As flooding persists to be a serious issue in the region it is recommended to improve flood forecasting and “that the government considers [flooding] and the argument for funding to supplement the private and public sector resources currently available” (17).
Strategic Road Networks – “Given the importance of drainage to resilience, the HA should complete its drainage asset inventory. The Review also recommends that the HA should consult freight and other interests on the restriction of vulnerable vehicles on exposed sections of the Strategic Road Network during high winds, so that these locations can be kept open longer for all other users. It further recommends that the HA works with the Met Office to improve wind forecasts for the benefit of lorry fleet operators. The Review recommends that the HA and the DfT should review the range and wording of messages displayed on variable message signs at times of disruption, and improve and refine the content of the HA website. Driver behavior is an important factor in secondary disruption, and there is a recommendation that the DfT should review the content of the Driving Theory Test, to ensure adequate coverage of driving techniques for use in, and preparations for, adverse weather conditions. The DfT should ensure that the new HA Government Company has, in its top-level performance indicators, network availability and that this is supported by appropriate indicators of asset condition.” (17)

Local Roads – “Local Highway Authorities should develop, maintain and work to Asset Management Plans and these should incorporate drainage. The DfT should proceed with its plan to use a proportion of funding to encourage the development and adoption of these plans, allowing local authorities time to prepare and implement those plans.

Railways – “On engineering structures, the Review recommends that Network Rail:
  o amends its classification of embankments to take account of the economic importance of the traffic on the route;
  o continues to trial newly available condition monitoring and slope stabilization technologies.

Lineside trees were found to be a major factor in last winter’s disruption and it is recommended that Network Rail:
  o develops a ten-year strategy to significantly reduce the number of trees, particularly those posing a risk to the railway and its users, and the overall level of vegetation;
  o develops an active biodiversity strategy including off-setting any reduction through tree planting, generally away from the railway;
  o makes appropriate budget provision for vegetation management;
  o addresses at-risk embankment slopes, with trees confined to the bottom one third or so of the slope where they can help stabilize it;
  o prevent re-growth on embankments, cuttings and the lineside after vegetation clearance.

The Review also recommends that there should be a sharpening for the rail industry of the economic signals on tree falls, including the cost of rolling stock damage from trees and consequent overcrowding and poor performance. A review by the DfT is recommended relating to the 1842 legislation governing Network Rail’s ability to tackle potential threats to safe operation of the railway which are on neighboring land. We recommend that Network Rail should commission studies of the resilience of its sections of coastal railways in light of events at Dawlish. The rail industry should also keep its design standards under regular review in the light of evolving understanding of the impact of climate change on extreme weather. Network Rail should liaise with electricity suppliers to trace through power supplies and identify single points of failure to be made suitably resilient. In terms of managing in a crisis, it is recommended that the Rail Delivery Group continues to investigate more flexible techniques for producing contingency timetables. It is also recommended that the DfT, the Office of Rail Regulation, Passenger Focus and the Rail Delivery Group should collaborate on an
amended approach to performance and compensation regimes during periods of extreme weather disruption, which gives the right signals to the industry but is seen to be fair for passengers.” (18-19)

- Ports – “The Environment Agency and Met Office work together to improve the granularity and accuracy of coastal flooding forecasts, involving complex modeling of a variety of factors.

<table>
<thead>
<tr>
<th>Status</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>No Assessment developed</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>“Resilience in the context of this Review can be described as the ability of the transport network to withstand the impacts of extreme weather, to operate in the face of such weather and to recover promptly from its effects.” (8)</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Transport resilience, Railways, Extreme weather, Road network, Extreme heat, Flood</td>
</tr>
<tr>
<td>Website/Source</td>
<td><a href="http://dx.doi.org/10.3141/2459-15">http://dx.doi.org/10.3141/2459-15</a></td>
</tr>
<tr>
<td>Document Type</td>
<td>Paper</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Transportation practitioners, researchers, transit agencies, users of transit systems</td>
</tr>
<tr>
<td>Abstract</td>
<td>“Brisbane and New York both experienced catastrophic weather events in recent years. In January 2011 the Brisbane River flooded, inundating over 20,000 houses; in October 2012 super storm Hurricane Sandy hit New York producing a major storm surge that flooded much of the city. Ferry systems in both cities were badly impacted.” (Abstract)</td>
</tr>
<tr>
<td></td>
<td>“Comparative research is used to explore how each city’s ferry operators and managers dealt with the impacts prior to, during and after these events. A review of published materials relating to the two systems during and after the disasters was supplemented with interviews with key agency personnel in each city, conducted in mid-2013. The results suggest that how ferries are affected by floods and other disasters, and how they may be used to rapidly respond and provide for post-flood transport needs, is entirely context specific. The linear river ferry operations of Brisbane suffered much terminal damage and operations were unable to recommence due to the nature of the swollen river and debris for many weeks after the flood. By contrast, New York’s ferries were able to be reintroduced on key routes within two days, and introduced to new emergency locations, providing mobility for citizens otherwise cut-off by storm damage from using other transport modes.” (Abstract)</td>
</tr>
<tr>
<td></td>
<td>“The learnings made by the operators include essential steps that need to be taken by authorities prior to a disaster, including in the design and resilience of infrastructure, disaster planning, insurance and legal requirements, staff management, and coordination in reconstruction phases. The findings suggest that other authorities may significantly reduce damage and improve recovery times if they plan and prepare for such events well ahead of time.” (Abstract)</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>The case study presented in this paper will be a valuable resource for transit agencies and emergency management officials.</td>
</tr>
</tbody>
</table>
| Topics Covered | The report suggest that it is possible to significantly reduce damage and improve recovery times, if ferry operators plan and prepare of catastrophic events well ahead of time. To support that finding the report provides:  
  - an overview of the published research on ferries in disasters, highlighting issues for preparedness and response  
  - an introduction of the two ferry systems under analysis  
  - a discussion of the approach and method undertaken for the study  
  - the results of the interviews and reviews of the ferries before, during and after the flood/hurricane events |

A-195

Copyright National Academy of Sciences. All rights reserved.
| **Type of Sponsoring Agency or Organization** | Academia |
| **Geographic Distribution** | International and United States |
| **Type of Transit Mode(s)** | The focus of this paper is ferry systems |
| **Type of Vulnerability** | Flooding and storm surge are the vulnerabilities addressed |
| **Goals and Motivations** | The goal of this paper is to document the experiences of two ferry operators during and after major flooding events, “to obtain learnings from the operators and managers for the benefit of the wider ferry community.” (p. 1) |
| **Context** | “Brisbane is Australia’s third largest city by population with just over 2 million residents and greater New York is the most populous US city with almost 20 million residents. But one thing they feature in common are linear river ferries, which is the specific focus of this particular study. ...They are very similar; in size, vessel type, terminal type, and operations, but they had very different experiences after the flooding (and hurricane) events they suffered in 2011 and 2012.” (p. 2) |
|  | “The direct comparison of these two systems allows for a useful comparison of how the managers and operators planned for, reacted during and learned from the emergency events they experienced, and the contextual features that helped shape the outcomes in each city.” (p. 2) |
|  | “The two systems both operate seven days a week, all year. The vessels differ slightly, but both feature open-air standing and seating areas on board. Brisbane has more terminals and shorter average stop spacing than in New York. But both use so-called ‘spud barges’ (pontoons with long posts on each of their four corners that allow them to float up and down, but not horizontally) with attached ramps as terminals. Both systems provide a mixture of cross-river opportunity as well as linear line-haul transit on a ‘parallel system’ servicing commuters, students, tourists and other markets. Both are supplemented by their operators (and other operators in New York’s case) by a set of additional cross-river ferries in and around their corridor.” (p. 3) |
|  | “The linear river ferry operations of Brisbane suffered much terminal damage and operations were unable to recommence due to the nature of the swollen river and debris for many weeks after the flood. By contrast, New York’s ferries were able to be reintroduced on key routes within two days, and introduced to new emergency locations, providing mobility for citizens otherwise cut-off by storm damage from using other transport modes.” (p. 3) |
|  | “The study findings accord with previous research on disaster preparedness in the transport sector, highlighting the need for pre-preparations and emergency disaster planning. The study shows that temporary ferry services can be provided quickly if fleets are secured effectively, basic terminal infrastructure is resilient, and if navigation on the river is safe.” (p. 10) |
| **Tools** | The paper did not introduce any tools or metrics |
| **Noteworthy Aspects** | The report noted that as a result of the storm event, Brisbane is reconstructing several terminals with a spud barge and a new more flood resilient design. “The new terminals are being designed to be resilient for a 1-in-200 year flood. The ramps are not fully retractable, but include fifth wheel hinges that allow them to re-angle with the floodwaters (such hinges offer both up-down and left-right rotation, significantly reducing horizontal tension loadings) and the pontoon
deflection structures at the upstream end are streamlined. The intent is that these new designs will both reduce damage and cost, and improve recovery times.” (p. 6-7)

“In New York, the East River Ferry was the first public transport mode that enabled East River crossings between Manhattan and Queens/Brooklyn. After service resumed, ridership doubled and a fourth ferry was added to meet demand. Critical to this was effective human resources management and highly proactive steps taken by the operators to take and refuel the cars of the ferry staff while they were on the water. Given the gas crisis that engulfed the post-hurricane city, without this measure staff would otherwise not have been able to present to work and operations would have ceased. Also, extremely helpful in the re-commencement phase was a recently released Smart Phone App that the ferry company had launched, allowing direct fare payment. This fare system, highly popular with regular users, significantly reduced the load on staff handling the additional passenger numbers, especially as most ticket machines were destroyed.” (p. 8)

Another aspect is “the operators and managers have recognized the need for quick disconnect systems to speed up removing power from the terminals” (p. 8) and raising the spud heights of the barges to provide more resilience.

<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>Investing modest sums in more resilient ramps and pontoons will be cost-effective in the long-term where damage is avoided.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Question</td>
<td>The research paper was written to inform ferry operators elsewhere that they may avoid significant damage and improve their own recovery from a flood or storm surge, if they follow the lessons provided by Brisbane and New York.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Ferry operators, civil leaders and emergency management professionals</td>
</tr>
<tr>
<td>Relevance</td>
<td>The study findings agree “with previous research on disaster preparedness in the transport sector, highlighting the need for pre-preparations and emergency disaster planning. The study shows that temporary ferry services can be provided quickly if fleets are secured effectively, basic terminal infrastructure is resilient, and navigation on the river is safe.” (p. 10) “Ferries have particular potential to re-connect vulnerable or isolated populations, and to replace other modes where bridges, tunnels or key networks are severed. With minimal infrastructure requirements (no roadway, no rails, no tunnels) ferries can be reintroduced rapidly post-disaster.” (p. 10)</td>
</tr>
</tbody>
</table>

“The introduction of ferries during or after emergencies can also be aided by significant pre-planning, such as through identifying the locations ferries may safely berth, and scenario-testing to determine how best they may be deployed if other key transport links are severed. Cities that take these steps will optimize their emergency responses.” (p. 10)

“How ferry systems themselves cope with emergencies is entirely context specific. The steps being taken by Brisbane City to make those terminals more resilient suggest it will be a far less expensive and more rapid recovery after any future flood. Operators elsewhere may avoid significant damage and improve their own recovery from a flood or storm surge if they follow the learnings provided by Brisbane and New York. Investing modest sums in more resilient ramps and pontoons will be cost-effective in the long-term where damage is avoided.” (p. 10)

<table>
<thead>
<tr>
<th>Status</th>
<th>Research project is complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The paper provides a good comparative case study that validates previous research in the area of disaster preparedness regarding the benefits of the need for pre-preparations and emergency management planning. The value of resiliency is also demonstrated by the study.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Vocabulary

| Potential Keywords | Ferries  
|                   | Flooding  
|                   | Emergency management  
|                   | Resiliency  
|                   | Terminal design  
|                   | Pre-planning |
### Citation
Burks-Copes, Dr. Kelly A. 2014. “Quantifying Coastal Storm and Sea Level Rise Risks to Naval Station Norfolk.”

### Website/Source

|---------------|--------------------------------------|-----------------|-------------------------------------------------|-----------------|-----------------------------|---------------------------------------------|

### Document Type
Presentation, Case Studies

### Intended Audience
Practitioners

### Abstract
“Employ a SMART strategy that drills down using portfolio investments to manage regrets and make decisions based on return on investment with a focus on: RESILIENCE and SUSTAINABILITY” (Slide 6)

### Populations Referenced
Naval Station Norfolk

### Topics Covered
Slide 9 - Vulnerability & Risk Assessment 101: Basic Steps
1. Establish a team
2. Set the goals & objectives
3. Define the problem context
   - Study area
   - Define an actionable scale (temporal & spatial)
   - Mine for data
4. Define the threat (aka scenarios)
   - SLR scenarios
   - Coastal storm intervals
5. Characterize exposure
6. Decompose infrastructure network
   - Determine sensitivity (i.e., fragility)
   - Determine adaptive capacity
   - Focus on systems approach (assets, capabilities, services, mission)
7. Characterize Vulnerability & Risk
   - Establish heuristics to determine sustainability
   - Combination of exposure, sensitivity, adaptive capacity and consequences
8. Proactively manage adaptation
   - Establish triggers or response thresholds and monitor
   - Consider life cycles & costs with the intent of managing regrets!

### Type of Sponsoring Agency or Organization
Federal – USACE ERDC

### Geographic Distribution
National
<table>
<thead>
<tr>
<th>Type of Transit Mode(s)</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Vulnerability</td>
<td>Sea-level rise, Natural hazards</td>
</tr>
</tbody>
</table>
| Goals and Motivations  | • Characterize impacts  
                          • Decompose mission & infrastructure systems  
                          • Pinpoint vulnerabilities  
                          • Quantify performance sustainability risks  
                          • Identify adaptive capacity tipping points  
                          • Communicate results to field |
| Context                | • Devise and demonstrate a rigorous yet flexible systems-scale approach  
                          • Quantitatively evaluate natural hazard risks to critical military assets (i.e., infrastructure) and mission capabilities  
                          • Address a range of SLR, tidal fluctuation, and storm stage-frequencies |
| Tools                  | Storm Modeling, Risk Assessment Approach, Infrastructure Vulnerability Assessment |
| Noteworthy Aspects     | Tier 1: Coarse Level Assessment  
                          • High-level screening  
                          • Subject Matter Experts  
                          • Facilitated workshops  
                          • Develop & apply a vulnerability  
                          • Down Select  
                          Tier 2: Intensify Analysis of Vulnerable Sites  
                          • Coarse asset fragility analysis  
                          • Improve vulnerability indices  
                          • Refine Exposure assessment using analytical engineering models  
                          • Down Select  
                          Tier 3: Maximize Analysis of Most Vulnerable Sites  
                          • Detailed hydrological analysis  
                          • Advanced infrastructure analysis  
                          • Refine vulnerability assessment  
                          Tier 4+: Path Forward (Slide 36) |
| Captivating Value      | “Vulnerability Assessments can be run on a shoestring or with a plethora of time, money & resources . . . . the key again is regret management” (Slide 37) |
| Decision Question       | N/A |
| Decision Maker         | N/A |
| Relevance               | “Portable, Scalable Approach  
                          • Demo Project - NSN Master Planning, Adaptive Management (Retrofits), Contingency Planning  
                          • Assist with Informing Policy and Planning  
                          • Portfolio Risk Management  
                          • Navy’s Task Force Climate Change Worldwide Installation Vulnerability Assessment” (Slide 36) |
<p>| Status                  | N/A |
| Critical Assessment     | How can this be applied to transportation agencies and the tools necessary to sue, funding? |
| Additional              | N/A |</p>
<table>
<thead>
<tr>
<th>Comments</th>
<th>Resiliency is not defined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
<td>Storm Modeling, Risk Assessment Approach, Infrastructure Vulnerability Assessment, Regret Management, Adaptive Management</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Research Document

### Intended Audience
State agencies and sector stakeholders of New Jersey.

### Abstract
This New Jersey Climate Adaptation Alliance report is a compilation report of deliberate stakeholder engagement efforts across a variety of cross-cutting sectors including built infrastructure (transportation), agriculture, coastal communities, emergency management, environmental justice, natural resources, public health social services and water resources. The efforts were guided by the NJCAA advisory committee.

Building off an earlier report, this report serves as an overarching outline of key issues to be addressed as part of a statewide climate change adaptation discussion. The purpose is to initiate and inform discussion statewide for enhancing the state’s adaptation efforts in preparing for climate change.

### Populations Referenced
New Jersey residents

### Topics Covered
The document primarily provides context and detail on a number of recommendations identified by those conducting the study. The areas in which recommendations are made include:
- Climate Change Policy Recommendations;
- Implementation of standards, regulations & policies that apply to risk management;
- Reliance on existing governance structures;
- Development of funding strategies;
- Promoting education, training and outreach;
- Undertaking analyses and research.

### Type of Sponsoring Agency or Organization
The New Jersey Climate Adaptation Alliance, a nonprofit organization.

### Geographic Distribution
The report is centric to New Jersey and those entities which operate or conduct business within the borders of the state.

### Type of Transit Mode(s)
Transportation in general.

### Type of Vulnerability
All

### Goals and
“The mission of the Alliance is to identify, demonstrate, recommend and communicate policies
<table>
<thead>
<tr>
<th>Motivations</th>
<th>and activities that can prepare New Jersey’s vulnerable sectors to better meet the anticipated impacts of climate change.” (p. 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
<td>N/A</td>
</tr>
<tr>
<td>Tools</td>
<td>The report references a “climate impact assessment” (CIA) but does not provide further information of what that entails and how it compares to risk and vulnerability assessments.</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>The document outlines recommendations to enhance state-level climate adaptation by the various topics covered. Although it applies across multiple sectors, the report outlines which recommendations apply to which sectors including those which apply to the built infrastructure. A summary table is provided at the beginning for quick referencing. A summary of some of those recommendations for the built infrastructure sector are:</td>
</tr>
<tr>
<td></td>
<td>• Policy</td>
</tr>
<tr>
<td></td>
<td>o Encourage collaborative partnerships and state working groups to discuss and push climate change adaptation;</td>
</tr>
<tr>
<td></td>
<td>o Develop capabilities to develop climate impact assessments (CIA);</td>
</tr>
<tr>
<td></td>
<td>o Incorporate climate change into the various planning horizons;</td>
</tr>
<tr>
<td></td>
<td>o Incorporate climate change into capital planning efforts as well as decision-making processes;</td>
</tr>
<tr>
<td></td>
<td>o Evaluate policies which govern land use and revise land-use laws and master plans to address climate change;</td>
</tr>
<tr>
<td></td>
<td>o Incorporate the community where appropriate;</td>
</tr>
<tr>
<td></td>
<td>o Educate and train staff on climate change and risk assessment processes;</td>
</tr>
<tr>
<td></td>
<td>o Review and amend policies which may be a disincentive for proactive actions to address climate change.</td>
</tr>
<tr>
<td></td>
<td>• Systems Planning &amp; Design Standards</td>
</tr>
<tr>
<td></td>
<td>o Conduct vulnerability assessments of asset using the CIA;</td>
</tr>
<tr>
<td></td>
<td>o Utilize CIA to inform adaptation efforts;</td>
</tr>
<tr>
<td></td>
<td>o Establish a team to develop new design standards, codes and regulations which address climate change.</td>
</tr>
<tr>
<td></td>
<td>• Emergency Preparedness</td>
</tr>
<tr>
<td></td>
<td>o Conduct outreach to encourage participation from stakeholders beyond the transportation sector to include those responsible for responding to incident such as emergency managers;</td>
</tr>
<tr>
<td></td>
<td>o Develop long-term resilience plans.</td>
</tr>
<tr>
<td></td>
<td>• Finance</td>
</tr>
<tr>
<td></td>
<td>o Integrate climate change adaptation into budget processes for capital programming, operations and maintenance;</td>
</tr>
<tr>
<td></td>
<td>o Seek federal funds for climate adaptation projects and planning needs.</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>The report identifies a series of gaps that cross cut sectors and apply to transportation. Those gaps are:</td>
</tr>
<tr>
<td></td>
<td>• “Research, needs assessment and data development;</td>
</tr>
<tr>
<td></td>
<td>• Enhanced implementation of existing data, tools, and methods;</td>
</tr>
<tr>
<td></td>
<td>• Regulation, policy and governance support;</td>
</tr>
<tr>
<td></td>
<td>• Coordination of adaptation planning and preparedness actions;</td>
</tr>
<tr>
<td></td>
<td>• Ensure suitable funding;</td>
</tr>
<tr>
<td></td>
<td>• Education and outreach efforts.” (p. 5)</td>
</tr>
<tr>
<td>Decision Question</td>
<td>Actionable items to support both government and NGO efforts or incorporate climate change into planning and business processes.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Government and stakeholder agencies.</td>
</tr>
<tr>
<td>Relevance</td>
<td>A detailed list of recommendations by which generally fall within the subject headings. Identification of gaps which apply to transit agencies as well to include gaps in funding, coordination between stakeholders, outreach and other areas which are generally expressed throughout other documents.</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Status</td>
<td>N/A</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Great series of policy recommendations for agencies and governments alike. To be seen how these overall gaps are applied to agencies.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Potential Keywords                                                      | Climate Change
Climate Change Adaptation
Sector
Transportation
Policy                                                                                 |
<table>
<thead>
<tr>
<th>Citation</th>
<th>Cox, Andrew; Prager, Fynnwin; and Rose, Adam Z., “Transportation Security and the Role of Resilience: A Foundation for Operational Metrics” (2011). Published Articles &amp; Papers. Paper 207.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website/Source</td>
<td><a href="http://research.create.usc.edu/published_papers/207">http://research.create.usc.edu/published_papers/207</a></td>
</tr>
<tr>
<td>Document Type</td>
<td>framework for evaluating transportation risk</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Practitioners, Transit agencies, authorities</td>
</tr>
<tr>
<td>Abstract</td>
<td>“This paper presents operational metrics to determine a passenger transportation system’s resilience to terrorism. The paper also provides a framework for evaluating transportation risk, including the important role of perceptions in potentially amplifying these risks. The paper concludes with a set of proposed prospective resilience measures to evaluate the potential resilience of a transportation system. “ (p. 307)</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Commuters, Transit Riders, Operations Personnel, Manager, Coordinating Agencies, Authorities</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>• Transportation system risk from terrorist attacks  • Resilience and Transportation  • Resilience Metrics  • Measuring transportation system resilience  • Prospective resilience measures for decision makers  • Conclusions and further research</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>U.S. Department of Homeland Security through the Center for Risk and Economic Analysis of Terrorism Events (CREATE) and the National Science Foundation under grant numbers SES-072893</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>National, London as an example</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Commuter Rail, Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, Demand Response, Ferryboat, Aviation, all</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Terrorism risk</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>Provide operational metrics to estimate a transportation system’s resilience. These metrics aid government decision makers in rendering more informed judgments about resource allocation and how to design a portfolio of security and recovery.</td>
</tr>
</tbody>
</table>
| Context | • “A transportation system can be defined as “the assemblage of components associated with a specific means of transport” (Tolley and Turton, 1995, p. 42). And yet, “collectively, all the individual transport systems within a country are referred to as the national transport system” (Tolley and Turton, 1995, p. 42).” (p. 309)  • This study focuses on transportation systems that move people rather than freight.  • “Strategies that mute losses at the microeconomic level include:  o Conservation is maintaining service with fewer inputs (e.g., railroad cars, employees) on the supply side or doing with less transportation on the demand
side.
- Input substitution is shifting input combinations or transportation modes to achieve the same function or level of productivity.
- Inventories include both emergency stockpiles and ordinary working supplies of production inputs for both the transportation system and for economic activities dependent on transportation.
- Excess capacity refers to idle plant and equipment. A special case is redundancy that refers to backup systems that do not increase productive capacity, but rather compensate for damaged capital (e.g., multiple tracks).
- Relocation is changing the site of business activity in terms of travel routes or end-user sites.
- Resource unimportance refers to the portion of business operation that can continue without a critical input like transportation.
- Import substitution is importing resources from other regions. This might be imports for the transportation system itself or the employment of the transportation system in doing so.
- Export substitution refers to selling goods to other regions that cannot be sold otherwise to local customers.
- Technological change allows for easier manipulation to restore function, to increase production, change hours of operation, and to respond to altered service demands.
- Production recapture refers to working overtime or extra shifts to catch up on lost production or service.
- Logistics refinement refers to reducing impediments to the delivery of goods and services.” (p. 309)
- “Dynamic resilience strategies to speed recovery include:
  - Removing operating impediments involves debris removal and related complications, and streamlining paperwork for insurance claims and government assistance.
  - Management effectiveness refers to skills that promote restoration, repair and reconstruction.
  - Speeding restoration refers to a range of options such as alternative means of access to repair sites and incentive contracts.
  - Input substitution, import substitution, inventories, as above, also speed restoration, but pertain to materials and labor needed for repair activities rather than quantification of resilience has been possible: p. 309
- Through retrospective analysis of events than normal production operations.

<table>
<thead>
<tr>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude mathematical definitions of resilience. Adapting an established definition, direct static economic resilience (DSER) refers to the level of the individual firm or industry and corresponds to what economists refer to as “partial equilibrium” analysis, or the operation of a business or household entity itself (Rose, 2004, 2005). An operational measure of DSER is the extent to which the estimated direct output reduction deviates from the likely maximum potential reduction given an external shock, such as the curtailment of some or all of a critical input:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>- DSER%</td>
</tr>
<tr>
<td>- %DDYm</td>
</tr>
<tr>
<td>- %DDYm</td>
</tr>
<tr>
<td>- δIP</td>
</tr>
<tr>
<td>where, %DDYm is the maximum percent change in direct output, %DDY is the estimated percent change in direct output in essence DSER is the percentage avoidance of the maximum economic disruption that a particular shock could bring about. A major measurement issue is what should be used as the maximum potential disruption. For ordinary disasters, a good starting point is a</td>
</tr>
</tbody>
</table>
linear, or proportional, relationship between an input supply shortage and the direct disruption to the firm or industry. (p. 310)
Used on the London 2005 bombing as an example.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captivating Value</td>
<td>“Our study of transportation resilience is only a beginning because passenger journeys are not an end in themselves” (p. 315)</td>
</tr>
<tr>
<td>Decision Question</td>
<td>No decisions based on the document</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>No decisions based on the document</td>
</tr>
<tr>
<td>Relevance</td>
<td></td>
</tr>
</tbody>
</table>
  - What measures are available for security decision makers when they try to estimate the resilience of a system prospectively? How can decision makers craft strategies of resilience and have confidence that those strategies will work when a disaster strikes?  
  - Create a series of interrelated measures that can help predict transportation system resilience that complements prospective performance measures proposed by Lee (2010).  
  - Involve the explicit estimation of the role of transportation as a direct and indirect input to the economy and an evaluation of resilience in this broader context. This would ideally enable a dollar figure to be placed on transportation system resilience, so that the cost of implementing it can be compared with other loss reduction strategies in a risk management framework. |
| Status             | Stage of planning |
| Critical Assessment | No assessment developed |
| Additional Comments | N/A |
| Essential Vocabulary |  
  - Economic resilience - microeconomic level, it would include both supply and demand (i.e., both the provision of a good or service and its utilization). At the mesolevel, it would include the workings of individual markets and their interactions. At the macrolevel, it would not end at the boundaries of a specific product, service, supply chain or network, but rather extend as far as the indirect impacts of a terrorist attack or other disaster can go, which means the economy as a whole.  
  - Transportation resilience- consideration of resilient actions by providers of transportation services and then proceed to the resilience of its customers through the alternative modes, telecommuting, greater reliance on existing inventories (as opposed to newshipments), etc. |
| Potential Keywords  | Transportation security  
  Terrorism  
  Resilience  
  Risk perception  
  London bombings |
| Website/Source | http://ascelibrary.org/doi/abs/10.1061/9780784413586.062 |
| Document Type | Journal article |
| Intended Audience | Transportation authorities, engineers |
| Abstract | Paper describes proposed changes to the PANYNJ’s Design Guidelines to improve infrastructure resiliency. The proposed changes were developed based on a multidisciplinary review of the existing guidelines using the New York City Panel on Climate Change (NPCC) 2013 climate projections and Super Storm Sandy experience. Proposed guidelines include considering the probability of the event occurring during the design life of the asset. |
| Populations Referenced | Incorporating resilience into transportation infrastructure systems requires a team of experts including engineers, planners, emergency management personnel, security personnel, insurance professionals, operations personnel and maintenance personnel. |
| Topics Covered | - Designing for resiliency: Steps to establish resilience criteria for a project  
  o Identify threats and their potential to influence design  
  o Determine the influence of any area- or system-wide strategy  
  o Review current codes and standards  
  o Determine funding source influence  
  o Identify critical infrastructure  
  o Determine life expectancy and probability of occurrence  
  o Determine consequences and order of magnitude mitigation cost  
  o Establish resilience criteria  
- Super Storm Sandy Impacts to PANYNJ facilities  
- Projected climate changes with greatest potential impact of PANYNJ facilities  
- Design Guideline review  
  o Team of civil, mechanical, electrical engineers and architects  
- New Design Guidelines  
  o No one size fit all approach to standards  
    - Infrastructure criticality  
    - Risk of occurrence  
      - Facility-specific flood risk maps  
  o Future climate projections |
<p>| Type of Sponsoring Agency or Organization | Transportation authority |
| Geographic Distribution | Regional, Large (NY-NJ metro region) |
| Type of Transit | Rail (Infrastructure managed by PANYNJ also includes tunnels, bridges, airports and seaport) |</p>
<table>
<thead>
<tr>
<th><strong>Mode(s)</strong></th>
<th>Flooding, Severe Storm Events, Heat-high Days, Winter Storm (Heavy Snow/Ice)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Vulnerability</strong></td>
<td>In 2013, the Presidential Policy Directive (PPD-21) established a policy for the United States to strengthen the security and resilience of its critical infrastructure against both physical and cyber threats. Transportation systems were identified as a critical infrastructure sector. As critical components of the region’s transportation network, the PANYNJ’s facilities need to be resilient against natural and man-made threats.</td>
</tr>
<tr>
<td><strong>Goals and Motivations</strong></td>
<td>Goals and Motivations In 2013, the Presidential Policy Directive (PPD-21) established a policy for the United States to strengthen the security and resilience of its critical infrastructure against both physical and cyber threats. Transportation systems were identified as a critical infrastructure sector. As critical components of the region’s transportation network, the PANYNJ’s facilities need to be resilient against natural and man-made threats.</td>
</tr>
<tr>
<td><strong>Context</strong></td>
<td>Bi-state region; several large transit providers; multi modes</td>
</tr>
<tr>
<td><strong>Tools</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Noteworthy Aspects</strong></td>
<td>The proposed design guidelines include project specific assessment that takes into account the probability that the risk will occur during the design life of the asset</td>
</tr>
<tr>
<td><strong>Captivating Value</strong></td>
<td>PANYNJ made changes to its design standards to make the infrastructure they are responsible for more resilient</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
<td>How to revise infrastructure design guidelines to incorporate resiliency?</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>Transportation authority</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>Relevant topic of how to incorporate resiliency into infrastructure design guidelines. Step-by-step list on how to establish resiliency criteria for a project. Unfortunately, not much detail is provided about each of the steps, limiting the paper’s usefulness.</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>Paper does not provide a lot of detail about the process for determining the proposed guideline changes or about the changes proposed</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td>• “Resilience is the ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions” (Department of Homeland Security definition) (p. 650) • “Resiliency related to infrastructure has the following characteristics: spare capacity, limited or “safe” failure, rapid rebound, flexibility, constant learning” (Rodin, Rockefeller Foundation description) (p.652)</td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
<td>Resilience Criteria Probability of occurrence Climate Impacts Design guidelines</td>
</tr>
</tbody>
</table>
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

### Citation

### Website/Source

|---------------|--------------------------------------|------------------|--------------------------------------------------------------------------------|-----------------|---------------------------|-----------------------------------------------|

<table>
<thead>
<tr>
<th>Document Type</th>
<th>This is a module within a more extensive sourcebook of modules addressing sustainable transport needs for developing cities around the world.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended Audience</td>
<td>Policy makers and their advisors in developing cities. Modules are also intended as units for short course training events.</td>
</tr>
<tr>
<td>Abstract</td>
<td>Because current weather impacts on urban transport are becoming more pronounced as a result of climate change, stress on such systems will become more frequent and extreme. Without adaptive measures, higher costs will result. Many decision makers in developing cities are already confronted with such events in the form of flooding and storms. Building a climate-resilient system is thus essential to safeguard the value and function of transport infrastructure, ensure reliability, and guarantee public health and safety.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>The targeted audience is decision makers and their advisors, but the populations referenced and affected include all urban transport users and urban residents generally in developing cities.</td>
</tr>
</tbody>
</table>
| Topics Covered | Module is divided into three main sections dealing with:  
- Cities and climate change, examining impacts, vulnerability, and challenges specific to developing cities;  
- Likely impacts on urban transport systems and possible adaptive measures. Subsections deal with transport infrastructure, public transport, private transport, and the costs and benefits of adaptation, The infrastructure section covers roads, bike lanes, walkways, and rail-based and water transport;  
- Taking action on adaptation, which covers basic approaches, a framework for climate-proofing transport, and supportive policy context for adaptation.  
A final section addresses the synergies of mitigation and adaptation in urban passenger transport. |
| Type of Sponsoring Agency or Organization | This appears to be a form of international development advisory assistance from the German Federal Republic, produced for the Federal Ministry for Economic Cooperation and Development by a hired consultant. |
| Geographic Distribution | This is pretty much an international document covering examples worldwide that are of broad applicability. There are examples from almost every continent. |
| Type of Transit Mode(s) | Road infrastructure; bicycle lanes; pedestrian walkways; commuter rail systems including subways; waterways; BRT and other bus systems; motorized and non-motorized private transport. |
| Type of Vulnerability | Almost anything potentially caused or related to climate change, specifically including:  
- Heat waves  
- Drought  
- Sea-level rise and coastal erosion |
### Goals and Motivations
Module is “intended to raise awareness, describe the expected impacts of climate change on urban passenger transport, and provide an orientation on how to integrate climate proofing into urban transport planning and policy implementation.”

### Context
Because this module and the overall sourcebook were intended as general policy-making guidance for developing cities worldwide, it is nearly impossible to specify a context within which this was developed, other than the emerging and growing threats produced by climate change to urban transport needs.

### Tools
An annex to the module provides a series of checklists for Section 4.2, which provides the framework for climate-proofing urban transport. The checklists cover the following topics:

1. Assess climate risk and vulnerability
2. Invite different groups of actors in adaptation planning
3. Adaptation measures for road infrastructure, bike lanes, walkways (this differentiates the various types of vulnerability noted above)
4. Adaptation measures for rail-based (public) transport (same format as 3)
5. Adaptation measures for waterways (same format as 3)
6. Adaptation measure for vehicles and operations (same format as 3)

### Noteworthy Aspects
A series of tables in Chapters 3 and 5 summarize impacts and possible adaptation measures related to particular relevant climate impacts in relation to particular transport modes as listed above. I found these a visually effective means of summarizing a significantly varied amount of data.

### Captivating Value
“Synergies between adaptation and mitigation are located especially within the first two pillars, transport avoidance and modal shift.”

### Decision Question
As this is broad, international advice, key decisions will inevitably be local and outside the scope of this document, which notes as much. But the key decision question in most instances appears to be how best to balance development overall to reduce stress on urban transport systems and improve overall quality of life and air quality, while reducing emissions.

### Decision Maker
City, region, state or province

### Relevance
This was chosen largely for international balance and to include guidance for developing cities.
- Accepted practices: retreat and avoidance for high-risk areas.
- Most of these are in the sets of tables in Chapter 3 outlining possible adaptation measures for specific climatic impacts on specific transport modes.

### Status
N/A

### Critical Assessment
This probably serves best as overall, general starter guidance for urban transport policy makers who need to establish a solid grasp of the fundamental issues related to impacts of climate change.

### Additional Comments
N/A

### Essential Vocabulary
Not much particularly specialized vocabulary. Resilience is defined specifically as indicating “a capacity to maintain core functions of a system” in the face of impacts. Box 2 on page 3 provides definitions as used in the module for adaptation, vulnerability and resilience.

### Potential Keywords
Urban transport
Resilience
Developing city
Climate
Adaptation
| Document Type | Research Document |
| Intended Audience | Transit Agencies |
| Abstract | The paper outlines a conceptual framework for understanding the resilience of a transportation network before an incident occurs. The process aims to identify the system’s weaknesses providing decision makers with information to quantify resiliency and therefore prioritize investments to enhance that resiliency. |
| Populations Referenced | Decision Makers, Engineers |
| Topics Covered | Conceptual framework and methodology for scoring resiliency of system and aspects of the system to provide a prioritization to decision makers to agencies. |
| Type of Sponsoring Agency or Organization | N/A |
| Geographic Distribution | All, but the case study focuses on Salt Lake City. |
| Type of Transit Mode(s) | All |
| Type of Vulnerability | Applies to all but earthquake used as example. |
| Goals and Motivations | Expand on the conceptual framework to assess the network resiliency of a system before a destabilizing event providing a method for prioritizing transportation investments to enhance network resiliency. |
| Context | N/A |
| Tools | The paper outlines four metric groups for developing the quantifiable number for resilience of a network. Those four metric groups are individual, community, economy, recovery. |
| | o “Individual resiliency metrics show whether the transportation network provides options and utility to individual users.” (p. 110) |
| | o “Community resiliency metrics show whether the transportation system fulfills the needs of the community. The network can safely and efficiently accommodate unusual conditions, including construction projects, emergencies, special events, and large gatherings without major impact.”(p. 110) |
| | o “Economic resiliency metrics show whether the transportation network provides services even if a particular resource, such as fuel, becomes scarce or expensive (14).”(p. 110) |
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>The framework outlines 3 parameters highlighting the importance of time as a component of resiliency (e.g. time to get service back) for the 2nd (annealing) and 3rd (recovery) component. The 1st parameter is “breakdown” the measure of degradation caused by an event. This seems like an important aspect which breaks away from the single mindset that resilience is adapting infrastructure and capital improvements and considers the effectiveness of an agency to respond to the impacts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captivating Value</td>
<td>May not be helpful but puts things in perspective. - Understanding the resiliency of a transportation system after a disaster has occurred does little to mitigate the effects of the event.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>Developing a resilience score to allocate investment.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>All transit agencies.</td>
</tr>
</tbody>
</table>
| Relevance         | • The article outlines a conceptual framework for scoring pre-disaster resiliency. The concept seems necessary and it’s unclear if the other frameworks which outline vulnerability assessments consider some of the issues considered as part of the network resiliency. The interesting piece which this article outlines is the consideration for post-event preparedness and ensuring the impacts can be minimized through planning and coordination. This builds resilience as well for a system to rebound/return to normal operations as fast as possible.  
  • The variables and metrics the framework considers as part of measuring resiliency includes: (p. 112 – 115)  
  o Mobility Index – used by some engineers and outlined in the “Highway Capacity Manual” in terms of level of service as one definition;  
  o Delays encountered – additional time a traveler will experience because of network disruption;  
  o Food medicine index – Available of food or medicine within the network to support immediate recovery;  
  o Personal transport costs – cost incurred by customer to use network;  
  o Personal mode choice – Availability of other mode choices as alternative means of transport;  
  o Network redundancy – backup systems within a system to reduce impacts;  
  o Infrastructure alignment – availability of secondary infrastructures such as alternative routes;  
  o Good and materials access – Availability of resources within the network to support immediate recovery;  
  o Commercial mode choice – Availability of mode choice which will allow commercial entities to react to an incident and get goods to consumers;  
  o Industrial mode choice - Availability of mode choice which will allow industrial entities to react to an incident and get goods to consumers;  
  o Network management – A measure of the preparedness for a networks operations, maintenance, administration and tools to begin to “dull” the impacts of an incident;  
  o Fuel and energy costs – A metric of the available fuel and energy within a network; |

---

Copyright National Academy of Sciences. All rights reserved.
Commercial transport cost index – Cost for commercial entities to use the transport network;  
Industrial transport costs index - Cost for industrial entities to use the transport network;  
Emergency response – A measure of the region to mobilize resources to respond to the incident. It measure response time;  
Resources available – Represent the general availability of people, equipment and organizations available to procure and assist in responding to an incident.  
The study is able to obtain quantifiable numbers for each area to support the methodology.  
- Additional work may be needed to determine the weighting of the scores and information is limited on some low tier metrics scoring criteria.

<table>
<thead>
<tr>
<th>Status</th>
<th>N/A</th>
</tr>
</thead>
</table>
| Critical Assessment | The concept is interesting but seems to be applied at a higher level than transit agencies may need. The examples and framework look at a transportation network as a whole. Furthermore, there are weighting considerations and suggestions by the author to develop a sensitivity analysis.  
However, many studies focus simply on the mitigation efforts to prevent impacts while resilience includes the ability to quickly respond to and mitigate the impacts after they’re occurring. This research highlights the importance to look beyond simply adapting infrastructure and building an organization capacity to respond quickly and effectively to reduce impacts after an incident occurs. Although not specified, one could imagine having alternative route plans for loss of infrastructure, mobile response teams for various use. |
| Additional Comments | N/A |
| Essential Vocabulary | “The definition of resiliency used in this paper is the ability for a transportation network to absorb disruptive events gracefully and return itself to a level of service equal to or greater than the predisruption level of service within a reasonable time frame.” (p. 110) |
| Potential Keywords | Resilience  
Network Resiliency  
Prioritization  
Earthquake  
Framework |
### Citation

### Website/Source

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

### Document Type
Policy Announcement

### Intended Audience
Stakeholders and FTA components.

### Abstract
The policy outlines official recognition of climate changes increasing impacts to transit including many of the vulnerabilities transit agencies around the country are seeing. The purpose of the statement highlights the need for the changing environment to be incorporated into aspects of the agency’s programs. This includes aspects of planning, operations and policies.

### Populations Referenced
Federal Agencies and FTA programs.

### Topics Covered
- The FTA identified vulnerabilities which may have an impact on the agency.
- The statement highlights the agency has billions of dollars at its disposal and takes on not only a fiscal responsibility to include climate change into its programs but the assurance of reliable transit services millions of Americans rely on.
- Process (p. 2)
  - FTA will establish an inter-office adaptation working group to address climate change impacts through the development of strategies for incorporating climate change adaptation into FTA policies, programs and operations;
  - The same working group will propose strategy options to the FTA Policy Council;
  - FTA will coordinate with other agencies through the U.S. DOT Center for Climate Change;
  - FTA will coordinate with the US EPA, USHUD, and other agencies through the Council on Environmental Quality Communities Adaptation Working Group.
- Programs and Resources (See Captivating Value)
- Guiding Principles & Framework
- Authority which simply outlines the policy is based on Executive Order 13514

### Type of Sponsoring Agency or Organization
Federal

### Geographic Distribution
National

### Type of Transit Mode(s)
All Transit

### Type of Vulnerability
Heat-high Days, Severe Storm Events, Coastal Storms, Flooding/Sea-level Rise, Other (drought)

### Goals and
“FTA is responsible for the stewardship of tens of billions of dollars in taxpayer investments in
<table>
<thead>
<tr>
<th>Motivations</th>
<th>public transportation assets. But this is more than a fiscal responsibility: tens of millions of Americans rely on these resources and the services they provide every day. We must build upon and share our knowledge of climate change impacts on transit and the best response strategies if we are to protect these assets and the mobility they provide.” (p. 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
<td>N/A</td>
</tr>
<tr>
<td>Tools</td>
<td>See Captivating Value which identifies FTA adopted framework they will use.</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>FTA officially states that funding will include considerations for climate change and resilience. “Funding from FTA’s major capital programs can support capital investments that increase resilience of transit assets and services to the impacts of climate change. Planning activities such as climate change vulnerability and risk assessments are also eligible under FTA’s current statewide and metropolitan transportation planning programs.” (p. 2) See Captivating Value for more noteworthy aspects.</td>
</tr>
</tbody>
</table>
| Captivating Value | “FTA adopts the guiding principles and framework for adaptation planning established by the Interagency Climate Change Adaptation Task Force. These guiding principles are:  
- Adopt integrated approaches,  
- Prioritize the most vulnerable,  
- Use the best available science,  
- Build strong partnerships,  
- Apply risk management methods and tools,  
- Apply ecosystem-based approaches,  
- Maximize mutual benefits, and  
- Continuously evaluate performance.” (p. 2) Recognition of the issue and taking ownership of issue. “The Federal Transit Administration (FTA) will integrate consideration of climate change impacts and adaptation to the extent practicable into the planning, operations, policies, and programs of the agency...” (p. 1) |
<p>| Decision Question | At the direction of an executive order, FTA is formally following the EO and releases statement how it will begin to do so. |
| Decision Maker | FTA |
| Relevance | As outlined in the captivating value, the FTA outlines a framework for considering climate change which may be followed by transit agencies. |
| Status | N/A |
| Critical Assessment | Though short, it provides some concrete guidance FTA is following, funding sources and general backing of climate change being incorporated into decisions. |
| Additional Comments | The primary issue with these briefs is that it seems to flex back and forth with the intended audience between the agency itself and the programs and stakeholders it supports. The policy briefly hits on the FTA process. It may be of interest to look into what the FTA Policy Council saw as far as recommendations proposed. |
| Essential Vocabulary | N/A |</p>
<table>
<thead>
<tr>
<th>Potential Keywords</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Type</td>
<td>Federal investigative document.</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Congress</td>
</tr>
<tr>
<td>Abstract</td>
<td>Given constraints on capital investment in transit system improvements, the assumption is that better monitoring and measurement systems regarding the impact of investments in transit infrastructure can make the necessary investments more cost-effective. GAO supports this proposition and recommends greater attention to systems for documenting and tracking the condition of transit infrastructure.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Transit system operators and managers; transit financial managers, transit policy makers, maintenance workers, planners, transit riders</td>
</tr>
</tbody>
</table>
| Topics Covered      | • Leading practices in transit system investment management  
|                     | • Asset management practices  
|                     | • History of federal actions and appropriations related to state of good repair initiatives  
|                     | • “State of good repair” backlog  
|                     | • Lifecycle management planning  
|                     | • Information and data systems for all the above |
| Type of Sponsoring Agency or Organization | Congress |
| Geographic Distribution | • At least nine specific local transit agencies examined  
|                     | • Agency size examined ranged from the very large (Chicago) to mid-level metro transit agencies  
|                     | • Regions covered in specific examples covered the entire nation plus the London Underground |
| Type of Transit Mode(s) | Bus, Bus Rapid Transit, Light rail, heavy rail, trolley, other |
| Type of Vulnerability | This study was not related to specific natural hazard vulnerabilities. It is more oriented to the question of best use of investment in assets to maintain transit systems in good repair. |
| Goals and Motivations | The primary goal of this study was to examine the various facets of asset management to optimize the value of improvements in transit infrastructure. |
| Context             | This is really not about any specific transit system but rather a national study of best practices in asset management. |
| Tools               | This study does not propose any new metrics or tools because its primary purpose is to examine existing best practices and their dissemination among transit agencies nationally. However, it specifically examines the following: |
### Noteworthy Aspects

The biggest question seems to be how to help transit agencies adopt a more comprehensive package of the above tools. The review of practices in specific systems seems to show that many use some of the practices and are better in one area or another, but none use all the tools or have the resources in place to do so.

### Captivating Value

“While tools exist that help some transit agencies identify their investment asset backlog, transit agencies could better prioritize their capital investment decisions knowing how their investments relate to future ridership.”

### Decision Question

Equipping transit agencies with the means to make more effective investment decisions. This is really aimed at two entities: Congress itself, which makes the appropriations; and FTA, which is responsible for the grant programs that may make this possible.

### Decision Maker

- Congress, with regard to appropriations to support the program
- FTA, for implementing assistance to transit agencies
- Local and regional transit agencies that must adopt and implement the recommended practices.

### Relevance

Documents evaluate the extent transit agencies use asset management plans. None of the investigated agencies took into consideration future ridership when making decisions on capital investment, which limits their prioritization of capital investments. (summary page)

### Status

FTA grant programs for State of Good Repair Initiative are ongoing.

### Critical Assessment

This seemed overall a solid assessment of the state of the art on capital investment management by US transit agencies.

### Additional Comments

N/A

### Essential Vocabulary

Asset condition; state of good repair; lifecycle management

### Potential Keywords

Lifecycle management
Asset condition
Asset inventory
Condition assessment
### Citation

### Website/Source

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Document Type
Training

### Intended Audience
Practitioners who plan capital investments.

### Abstract
This presentation describes the derivation, use, and value of decay curves used in the Transit Economic Requirements Model (TERM) of the Federal Transit Administration.

### Populations Referenced
Managers and financial planners of transit agencies

### Topics Covered
- Decline (decay) in physical condition of assets over time, rated in five levels: excellent, good, adequate, marginal, and poor
- Research on rate of decline of physical condition of 11 categories of transit assets over time
- Use of decay curves as basis for generating investment strategies
- Savings gained by pre-breakdown replacement of many parts and systems
- Standard for considering an asset as part of SGR backlog is a condition rating (based on decay curves) of 2.5 out of 5.0. 2.5 is the midpoint between “marginal” and “adequate.”

### Type of Sponsoring Agency or Organization
Federal Agency

### Geographic Distribution
All

### Type of Transit Mode(s)
All

### Type of Vulnerability
N/A

### Goals and Motivations
Describe how asset data, used with decay curves, can establish a rational basis for forecasting expenditures and generating alternatives for investment strategies

### Context
The context is the general need for capital investments to ensure continuity of safe and effective transit operations.

### Tools
Decay curves were generated from inspection of more than 1,000 buses, 300 rail vehicles, 150 maintenance facilities, 100 rail stations, and samples of train control, electrification and communications systems.

### Noteworthy Aspects
The decay curves and the implied updating of the curves were innovative.

### Captivating
This presentation demonstrates the value of decay curves for forecasting and suggests transit...
<table>
<thead>
<tr>
<th><strong>Value</strong></th>
<th>agencies can make even better forecasts by using the curves as part of analyses that focus on “cost” rather than condition.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decision Question</strong></td>
<td>All investment decisions in infrastructure, systems, and rolling stock are addressed in this document.</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>Transit agency must make decisions on investment. Federal and state agencies can use the same methods to validate the decisions of agencies that request grants.</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>It seems likely that the planning of resiliency investment decisions, especially “repair v. rebuild” will benefit greatly from the decay curves that FTA has generated. It seems likely that use of the curves will make funding requests more understandable, credible, and useful for planners and public officials charged with investment decisions.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Curves are complete.</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>This is a concise, clear presentation.</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>This presentation, or some slides from it, may be useful in the suite of digital presentation materials required by TCRP A-41.</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td>N/A</td>
</tr>
</tbody>
</table>
| **Potential Keywords** | Decay curves  
TERM  
Transit Economics Requirements Model |
| Document Type | Periodical article. |
| Intended Audience | Transportation researchers, academics. |
| Abstract | This article discusses three models developed at Rutgers’ Center for Transportation Safety, Security, and Risk using the Northeast Corridor. The first simulates the normal operation of a passenger rail corridor and “then perturb it with natural or man-made events.” A second model examines the potential health impacts of a contaminant plume on passengers, transit workers, and people in the area. The third deals with the economic impacts of a bottleneck in delivery systems. |
| Populations Referenced | Passengers, transit workers, surrounding area residents. |
| Topics Covered | • Terrorist attacks<br>• All-hazard natural events<br>• Failure to deliver goods or<br>• System bottlenecks people<br>• Models for simulation of impacts of all the above |
| Type of Sponsoring Agency or Organization | U.S. Department of Homeland Security, Science and Technology Directorate |
| Geographic Distribution | Northeast Corridor |
| Type of Transit Mode(s) | Rail transit, bus, Amtrak, freight rail |
| Type of Vulnerability | • Natural hazard events (flood, hurricane, etc.)<br>• Terrorist or other man-made event<br>• Contaminant plumes<br>• System failures that result in delivery failures |
| Goals and Motivations | Motivations relate to cascading impacts of the events cited above. Goals are to simulate such events and determine means of mitigating such impacts. |
| Context | • This is a highly urbanized region with multiple modes including heavy rail, freight rail, major interstate highways, bus systems, etc.<br>• The Northeast Corridor has virtually every type of transit asset imaginable, as well as |
| Tools | The tools are the three simulation models noted above, all funded by DHS. |
| Noteworthy Aspects | The models as described, to the extent they can be replicated elsewhere. The article did not go into any detail on that last point. |
| Captivating Value | “The tools can help staff understand the vulnerabilities of the systems and the impacts of system disruption.” |
| Decision Question | How will transportation agencies ensure customer safety, and security while minimizing risk? |
| Decision Maker | Mostly regional and state transportation agencies. |
| Relevance | • The main benefit would appear to be an improved understanding of cascading impacts of system disruption in multiple forms.  
• The article states that the models can be used in statewide strategic planning exercises focused on mass transit disasters.  
• Educational benefits in university programs. |
| Status | Scenario planning. |
| Critical Assessment | There seems to be a good deal of promise in the models being developed. However, this is just a short news article that does not provide a great deal of detail, which might be developed in another format. |
| Additional Comments | N/A |
| Essential Vocabulary | Cascading impacts, contaminant plumes. |
| Potential Keywords | Cascading impacts  
Contaminant plumes  
Passenger rail corridor  
Simulation model |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Type</td>
<td>Case study with numerous narratives of asset management implementation processes and practices and many examples of materials that reflect the practices of St. Louis Metro that can be evaluated and, perhaps, emulated by other transit systems.</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Practitioners who may need to demonstrate the utility, and value of systematic asset management in transit systems and who may need to prove that that asset management is not an unsurmountable challenge from work or budget perspectives.</td>
</tr>
<tr>
<td>Abstract</td>
<td>This report shows how urban rail transit agencies can leverage data within their maintenance management systems to build asset inventories for higher level analysis. Although resiliency is not highlighted in the report, the “mainstream” of the arguments presented clearly require consideration of resiliency as a factor in many asset management analyses and decisions.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Transit agencies, light rail and bus maintenance and asset managers, transit riders.</td>
</tr>
</tbody>
</table>
| Topics Covered   | • Current asset management practices  
                   • Current asset management data system  
                   o Database system  
                   o Maintenance requirements analysis, scheduling, and parts management  
                   o Lifecycle management of assets  
                   ▪ Asset condition monitoring  
                   • Developing priorities for asset management  
                   o Step-by-step procedures  
                   o Software tools  
                   • Best practices in asset management in transit maintenance and asset management |
| Type of Sponsoring Agency or Organization | Federal agency in cooperation with St. Louis transit agency |
| Geographic Distribution | National, Large urban/suburban |
| Type of Transit Mode(s) | Light Rail Rapid Transit, Bus |
| Type of Vulnerability | Vulnerability is not a topic of this report. It discusses “mainstream” activities of transit agencies. |
| Goals and Motivations | The goals are effective customer service, and efficient, economical planning, operations, and maintenance. |
| Context          | • Resilience is not mentioned. |
The transit context is an LRV and bus system that operates in five counties in Missouri and Illinois.

The authors followed a standard sequence of study steps. Key components included inventory of the assets of the St. Louis systems, and determination of the software tools that would best support asset management in the St. Louis system.

Clarity, simplicity, and comprehensiveness. Appendices are examples of outputs of asset management that may be useful as examples for other transit practitioners.

This study shows clearly how data, if verified and used every day to keep the transit system maintained, can be integrated into an asset management system that maximizes state of good repair over the life cycle of the transit agency’s assets. Such a clear report may be valuable as a reference in the handbook and digital presentation to stakeholders included in TCRP-41.

This document proves the value of asset management. For example, the mean distance between breakdowns of buses, after implementation of asset management, has increased from 6,000 miles to 20,000 miles.

This document, although it does not say so, shows that the following resilience issues fit squarely within the asset management systems that support state of good repair:

- Asset inventory as basis for evaluating the budgetary value of resilience
- Asset location, bases on use of GIS, as basis for evaluating vulnerability of various types
- Asset condition assessment as basis for decisions concerning resilience planning, scheduling, and budgeting

Observation of ongoing practices.

The authors followed a methodology that produced an effective report. Were they to conduct the study in 2015, however, it is likely that they would highlight resilience considerations.

Asset management
Preventive maintenance
Asset condition monitoring
GIS
Lifecycle management
### Abstract

The MOWE-IT project: The goal of the MOWE-IT project is to identify existing best practices and to develop methodologies to assist transport operators, authorities and transport system users to mitigate the impact of natural disasters and extreme weather phenomena on transport system performance. The project is funded by the European Commission’s 7th RTD framework program between October 2012 and September 2014. This document contains guidelines and recommendations for the improvement of resilience of rail operations in extreme weather conditions developed by the project team and reviewed by rail sector experts at the MOWE-IT rail workshop. Following an extensive review of previous projects on the impact of weather on rail operations including EWENT (www.ewent.vtt.fi) and WEATHER (www.weather-project.eu), case studies were identified in three broad weather categories; Heavy rain, wind and snow/winter conditions. Case studies are split into long-term planning and resilience building measures and actions which can be implemented before, during and after a given event. These include a range of actions including improving the resilience of physical infrastructure to specific weather conditions, learning from past events and dealing with affected passengers.

### Type of Sponsoring Agency or Organization

European Union, European Commission research program for transport agencies.
over $1 Billion.
  o Flooding leading to lines and bridges undermined or destroyed by landslides, bridges washed away. Total damage was estimated to cost around €2.7 billion in Austria and CHF 3 billion in Switzerland.
  o Intense convective storms with flash flooding, closing sections, causing delays.
    • Wind/Storm
      o Leading to power cuts, damage from precipitation. Includes Hurricane Sandy.
    • Snow/Winter Conditions
      o Depth
      o Exceptional cold/no melting, heavy snowfall - train failure and traffic disruption
      o Extraordinarily long/heavy winters

Goals and Motivations
- Weather specific guidelines and recommendations, reduced risk.

Context
- Highly variable context of existing transit and resilience planning across western and eastern European countries.
- Multiple modes – all.
- National rail to local transit agencies, all sizes, extensive interdependencies.
- Highly interconnected, networked.
- High levels of expertise.
- Different languages and systems for estimating weather, issues, etc.
- Sophisticated asset management and operations and maintenance, but still exploring and growing in Adaptation planning.
- Limited resilience planning. Beginning to examine cascading effects.

Tools
- Case studies and lessons learned.

Noteworthy Aspects
- See relevance section.

Captivating Value
- Gaps, shortcomings and difficulties related to transit operation in extreme weather events – these were found to often result from poor preparation, lack of buffers, resources for preventive maintenance and the number of skilled staff among others. These deficiencies result from political and/or management decisions.

Decision Question
- Greater preparation for resilience, based on lessons learned from previous impacted areas and networks, is being implemented in planning and operations. The importance of staff and local knowledge were key findings.

Decision Maker
- Political and management decisions at the state, local, and national levels.

Relevance
- Notes, preparations and some of the impacts of not making adequate preparations, in a robust transit sector.

Heavy Rain/Flooding
A key determining factor in the level of preparedness appears to be the history of past experience of relevant conditions. For example, it was observed during the Alpine flooding of 2005 that Southern Bavaria was more prepared than other regions because of prior experience with the Whitsun flooding incidents of 1999. This included technical measures put in place for flood protection in the intervening period.
(Long-term preparation)
- Have flood response plans in place - prioritize use of limited resources during flood events
- Use improved flood prediction models incorporating better weather forecasts and much more detailed information on topography, infrastructure, geology and hydrology
- Enhance flood resilience of infrastructure where necessary or provide movable flooding walls. Work together with local authorities to have general local flood defense, e.g., use inflatable dams.
• Improve and maintain drainage network along the rail network
• Clean drainage especially after autumn (in Essen there was flooding on the roads in November 2010 after some days normal rain due to clogged drainage by leaves)
• Incorporate climate change projections into the design of drainage to cope with predicted future flooding frequency and magnitude
• Consider infrastructure interdependencies. This especially applies to ensuring energy supply
• Explore relocation of important infrastructure to higher elevations and areas of lower flood risk
• Develop tailored plans for flash flooding and seasonal flooding

(Immediately before event)
• Flood warnings should be given in plenty of time
• Monitor drainage and solve problems quickly
• Deploy trouble shooting teams (drainage, bank repair teams)
• Install flood protection walls or inflatable walls
• Prepare water pumps for affected areas
• Interrupt operations before events occur

During:
As would be expected, a common response is to remove any accumulating debris from tracks to enable trains to run once flood water across the track has subsided. The use of inflatable dams to contain flood water is a new response being used by Network Rail. It was used for the first time in south west England in December 2012 to contain flooding at Cowley Bridge near Tiverton. The dams were successful in holding back water and preventing even more damage to the railway tracks following extensive damage to both tracks and the ballast beneath which had been washed away by floodwater. When travelers’ journeys are disrupted due to closure of railway lines during heavy rain events, alternative transport has to be found for passengers, be it replacement bus services or taxis. Of course, where there is also disruption on the road network then it is not possible to arrange alternative transport and passengers may be stranded as a result.

• Quick responses are essential to limit further damage – having flood response plans in place helps to facilitate this
• Reduce speed limits or stop trains in flooded areas where appropriate
• Clear tracks of any accumulated debris
• Personnel – having extra personnel on standby to help with additional duties during a flood event or to replace crews displaced by delayed/cancelled trains

After - Following heavy rainfall events, practices are often implemented to ensure that infrastructure is able to withstand a similar event in future. Infrastructure is often repaired to the same specification as before the event or modified to meet a higher specification. Track drainage is often surveyed following a flooding event to ensure there are no blockages which may impede drainage during future rainfall events. Where lines have to be reconstructed, priority tends to be given to long-distance railways first and then to local networks with repairs to stations and remaining infrastructure being of the lowest priority.

• Where repairs and reconstruction are carried out, damaged infrastructure should be upgraded to improve resilience to future flood events.
• Survey track drainage - identify and remove any blockages which may impede drainage in future.
• Implement flood control measures to protect tracks.
• Reinforce embankments which are particularly susceptible to landslides (construction of hillside fixing).
• Consider line relocations where tracks are particularly susceptible to flooding
• Construction of further sub surface drains in areas where flooding is a persistent problem.
## Wind / Storm

Before – Prior to such events collaboration should be made with weather services in order to assess the weather situation and to initiate the proper operations beforehand. This led to the result that citizens prepared by using trains beforehand or by cancelling their travel plans. This was a good measure to prevent further disruption. Since predictions for extreme weather events like Kyrill are very important, the Austrian Federal Railways implemented a meteorological information and warning system. The requirements for such a system differ from existing official and private forecasts and meteorological information systems. In Sweden severe weather scenarios were already rehearsed beforehand so that the crisis management activities could be realized effectively.

### Long-term preparation
- Have wind response strategy in place - resources should be put in place before the events occur
- Use improved wind prediction models - wind warnings should be given as soon as possible
- Keep the areas close to tracks clear of vegetation and dangerous objects that may be blown around
- Improve the resilience of catenary masts, the tracks and station buildings
- Strategies for cutting departures and reducing passenger capacity should be put in place (special timetables, rerouting models)
- Train personnel (and subcontractors) to understand the specifics of clean-up and repair works after heavy wind events (during the clean-up works following the windstorm Kyrill there were several fatalities)
- Design a risk-based approach for speed restrictions and line closures

### Immediately before event
- Interrupt operations before events occur and be prepared for this interruption
- Check the affected areas close to tracks and keep them clear of vegetation and dangerous objects that may be blown around
- Advance preparations for dealing with predicted impacts of wind event should be discussed (identification of persons/groups to coordinate the work, identification of critical locations, deployment of subcontractors, ensure the availability necessary resources like cranes, chain saws etc.)
- Deploy diesel engines in the areas likely to be most affected in the case of disruption to electrical equipment

During

Regional special crisis management and executive groups were activated. These groups consisted of chiefs responsible for different sectors (material service, production, information) at the Swedish Rail Administration. This type of group could provide the required speed and proactive response in decision making. The most important task for groups was to create an operating strategy and operating plan. Furthermore, groups took care of communications, creating a general view of the event as well as assigning personnel and resources. They also determined priorities for measurements in the railway network in cooperation with other operational actors. Additionally there were several differences concerning the quality of information. In these weather situations airplanes and helicopters should be used to get a quick overview of the impacts if it is safe to do so.

It is also necessary to establish certain criteria, when the use of a corridor should be cancelled or when certain measures should be taken into action beforehand. Additional criteria are needed when the cancellation should be revoked. It is also possible to ensure the transport of essential goods. During such an event the communication is very important and passenger information has to work. All participants should be trained beforehand and it is also possible to use the help of
external coordinators.
- Ensure that the tracks are free of foreign obstacles
- Have additional personnel on standby to help with additional duties during a heavy wind event or to replace crews displaced by delayed/cancelled trains and to take care of passengers
- Reduce speed limits and cancel traffic where appropriate
- Use special timetables where traffic on lines needs to be reduced
- Keep trains inside the depot overnight

After – During the event it is necessary to get an overview of the damage. Following the overview of the extent of damage it has to be decided how the damage can be fixed and how much time these repair works require. Resources need to be classified and arranged. Additionally it might be necessary to install replacement schedules with differing departing times, delays and redirections.

In addition to regional crisis management and executive groups, a national leading group was set up at the head office of the Swedish Rail Administration. The national leading group decided that during the crisis, freight traffic was prioritized at the expense of passenger traffic. In general, in order to get the rail traffic to operate properly again, large repair works were implemented. All workers were primed for their duties in special conditions in order to avoid accidents. Due to power and communications disruption, some railway sections and grade crossings were guarded by special road guards. Furthermore, diesel trains were used so that the most important goods could be delivered. On some railway sections freight traffic was operated on special terms during the traffic cancellations. Because organizations had practiced crisis management in advance, they could manage the event relatively well. In addition, persons belonging to crisis management and leading groups were used to working together and it didn’t take long to activate the operation of groups. Some additional resources were supplied even before the storm.

In some cases it was hard to put compensatory power stations and generators into use because it was not properly noted where these stations and generators were located. Some of the actions took too much time due to safety regulations because some works are only allowed to be executed while there is a connection to the control center. Because of the lack of power supply communication connections were often discontinued so the repair works could not be executed. This has to be handled in a different way in future events.

In the future it should be possible to get a quick overview over the impacts of the event with the use of special software in order to issue instructions directly.

It also might be necessary to implement rail replacement services. It also is important to keep passengers informed about replacement schedules and about the schedules of rail replacement services. Customers of rail freight also have to be informed about changes to schedules.
- Return to normal schedule as soon as possible
- Where repairs and reconstruction are carried out, damaged infrastructure should be upgraded to improve resilience to future wind events
- Regular clearing of vegetation along tracks
- Identification of critical locations
- Update of plans and strategies in light of lessons learned

**Snow/winter conditions**
Before - Based on the case studies the preparations for the heavy winter conditions tended to be ineffective in many ways. In Sweden (at the end of 2001) the railway organizations had raised their level of preparedness due to the received meteorological information but there was still not enough maintenance personnel, machines and equipment for snow and ice removal.

(Long-term preparation)
- Increased preventative maintenance (critical switches, pantographs and carbon strips, outdoor signaling equipment)
• Install snow covers of switches
• Install switch heaters
• Build snow barriers
• Keep culverts and ditches open to keep the track areas and embankments dry to prevent damage due to ground frost
• Train personnel and subcontractors to understand the specifics of winter operations
• Ensure the availability of spare parts, additional cables and other materials which are known to break in hard winter conditions
• Obtain snow and ice melting equipment and investigate options to modify the rolling stock to prevent snow and ice accumulation on undercarriages
• Specify and test new infrastructure (especially switches) to resist winter conditions or avoid snow build-up.
• Focus winter-proofing/snow-proofing in key areas

(Immediately before event)
• Ensure that the track profile is free of foreign obstacles (no branches of bushes covered with snow hanging low and avoidance of ice formation at tunnel entrances)
• Increase defrosting capacity (increased depot space), and cover of the most important railway yards
• Deploy reaction teams and equipment (engines, rotary snow ploughs)
• Deliver spare parts, cables and engines to local critical areas
• Prepare rolling stock and infrastructure for snow and cold weather (e.g. heating, removal of ice and snow)

During - During the heavy winter conditions the focus was on snow removal to keep the tracks and switches operational (with and without machines), to keep the rolling stock in operational condition and to repair the damaged track areas (caused by ground frost) by supports. It had been identified both in Finland and in Sweden that the cooperation between the different operational actors did not work well enough. The actions were put in place too late and the snow removal took too long. It was also identified that the subcontractors’ resources for snow removal were inadequate. Several problems in gathering and sharing information to passengers, between operators, and to the general population were also identified. The passengers were either helped to reach their station of origin or destination. In some cases this was done by buses when not enough trains were available in reserve. In Finland, special timetables with fewer trains were taken into use.
• Manual cleaning of switches (brushes, spades, blowers, excavators)
• Remove snow (snow blowing machines, snow blow trains, by hand)
• Keep trains inside the depot overnight or cover sensitive parts (couplings, pantographs, switches)
• Heating of trains through the night
• In areas using third rail electrical systems keep trains moving across track overnight to reduce ice build-up
• Resistive heating of OLE to reduce ice build-up
• Take measures to keep platforms free of snow and ice

After
Following the Channel Tunnel event the recommendations were divided into three broad categories which were (i) increasing train reliability, (ii) establishment and regular updating of evacuation and response plans and (iii) improved communication and management of the situation.
Several recommendations that resulted from the other case studies fit into these same categories. In Finland it was emphasized that the cooperation between different actors needs to be improved and the management procedures need to be made systematic and documented.
Therefore, the establishment of new working groups to improve the cooperation between the different actors participating in operative traffic management was recommended. The aim was to provide speed and proactiveness in decision making. In Sweden it was recognized that the cooperation between traffic control centers was challenging since technical systems for controlling railway traffic varies in every traffic control center and thus improvements are needed. It was also emphasized in Sweden that practical training should be organized so that every actor knows how to carry out the work in extreme situations. There were also several recommendations concerning the need for additional resources (personnel, machines, equipment). The need for new glycol based snow and ice melting equipment and new switch-heating systems was identified (Finland and Sweden) with special attention paid to the most critical points in the railway network. More attention should also be put to preventative maintenance (maintenance processes will be made systematic and be documented) and on the availability of additional (competent) resources for the snow removal.

- Identification of critical locations
- Update plans and strategies in light of lessons learned
- Elimination of the worst bottlenecks such as single-track sections

<table>
<thead>
<tr>
<th>Status</th>
<th>Project finished. Outreach meetings to transit agencies occurred in London, Sept. 2014.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>This is a qualitative more than a quantitative approach, but it does distill key lessons learned that will be useful for other transit agencies.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Transit, Europe, Operations, Planning</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source
https://www.fema.gov/media-library/assets/documents/24174?id=4995

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Document Type
Update on Strategic Foresight Initiative regarding emergency response planning

### Intended Audience
High-level planners who are responsible for emergency response

### Abstract
This study reports foresight efforts of the emergency management community, including uncertainties that must be considered; strategic needs and gaps; a vision of emergency management in 2030, and suggested next steps.

### Populations Referenced
The stakeholders mentioned are all those responsible for emergency management and resiliency.

### Topics Covered
- Increasing complexity and decreasing predictability in threat environment
- Evolving needs of at-risk populations
- Limitation on resources for emergency response and resiliency
- Roles to be played by individuals, families, neighborhoods, communities and the private sector
- Disparities in fiscal resources and it access to know-how, skilled personnel, etc.
- A large and growing body of global best practices
- Importance of trust between public and government

### Type of Sponsoring Agency or Organization
Federal agency

### Geographic Distribution
All areas

### Type of Transit Mode(s)
All types of transportation systems are included in this discussion

### Type of Vulnerability
All types, including threats of terrorism, including cyber-terrorism

### Goals and Motivations
The Strategic Foresight Initiative seeks to improve the readiness of the emergency management community and to suggest a common sense of direction and urgency to drive for readiness, including resiliency.

### Context
All threats, those well-known and others merely imagined must be considered by planners of emergency response. The experience of practitioners and the insights of students of conditions that may evolve contribute to the ability of practitioners to confront the need for resiliency.

### Tools
Scenario building and exercise

### Noteworthy Aspects
N/A

### Captivating
The report summarizes the interdependent nature and range of threats to communities and...
| **Value** | demonstrates the community-wide potential for loss in disasters, thereby requiring and justifying community-based collaboration in immediate and ongoing emergency management and resilience initiatives. |
| **Decision Question** | What will it take for communities to be prepared for all emergencies and to be resilient in the face of them? |
| **Decision Maker** | A message of this report is that decisions makers at all level, down to the individual, should be prepared for emergencies and build resiliency into their lives. |
| **Relevance** | This document emphasizes the community-wide nature of emergency planning and resilience. Understanding that context and the dependence of people on transit and other transportation gives proper emphasis to the importance of transportation resiliency. |
| **Status** | By definition, this is an issue that will require revisiting repeatedly. |
| **Critical Assessment** | This report relies on analysis of facts, but primarily for provoking logical opinion and imagination. It broadens concerns over uncertainty, and emphasizes the necessity of community action. |
| **Additional Comments** | N/A |
| **Essential Vocabulary** | N/A |
| **Potential Keywords** | Models of threats of disaster  
Scenario-based planning  
Technological support for emergency management and resiliency  
Risk management  
Volunteer capabilities |
<table>
<thead>
<tr>
<th>Citation</th>
<th>Kumar, P. 2015. “Magic Quadrant for Energy and Utilities Enterprise Asset Management Software. Blog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website/Source</td>
<td><a href="http://assetmaximo.blogspot.com/2015/03/maximo-vs-other-players-oracle-eam-ifs.html">http://assetmaximo.blogspot.com/2015/03/maximo-vs-other-players-oracle-eam-ifs.html</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Document Type</td>
<td>Blog entry.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Purchases of enterprise asset management software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstract</td>
<td>Many companies produce enterprise asset management software for use “off-the-shelf” or with modifications. They vary in complexity, usability, price, and utility. The author summarizes the features, benefits, limitations of nine of the leading enterprise asset management products, [some of which are used in the transit industry].</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>All managers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topics Covered</td>
<td>This report lists the author’s opinion of the “strengths” and “cautions” of the enterprise asset management systems offered by the following companies:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>Private, commercial sales representative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>All</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Focus is on asset management of energy and utility companies, but the tools apply to all enterprises that face large asset management challenges.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Vulnerability is not mentioned.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>Author wants to inform potential customers of the advantages of his product (IBM-Maximo) in relation to the other leading products in enterprise resource management.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Context</td>
<td>Context is the worldwide push to distribute enterprise management tools, and the growing acceptance of the tools, especially by large organizations, but also by small organizations that depend on efficient asset management.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The author emphasizes two criteria for selecting enterprise asset management products: “ability to execute” [essentially ease of use] and “completeness of vision” [essentially the variety and power of the features of the software]. He does not mention price as a consideration.

<table>
<thead>
<tr>
<th>Tools</th>
<th>The availability of enterprise asset management tools is growing, and the competition among the vendors of the tools is increasing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noteworthy Aspects</td>
<td>N/A</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>The availability of enterprise asset management tools is growing, and the competition among the vendors of the tools is increasing.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>If a transit agency were to purchase and adopt enterprise asset management tools, which vendor should be chosen?</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Transit Agency</td>
</tr>
<tr>
<td>Relevance</td>
<td>Transit agencies face many asset management challenges, and resiliency will intensify the pressure to support financial programming and operations and maintenance with hard facts. Enterprise asset management tools facilitate achievement of that objective. In the phase of TRCP A-41 that includes the handbook and the suite of digital presentation materials, it will be helpful to list for practitioners the names of key products that are in use widely.</td>
</tr>
<tr>
<td>Status</td>
<td>Ongoing as new products and improvements in products evolve</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>The author simply sized up the market he addresses. His credibility concerning the strengths and cautions he mentions about each product must be questioned because he is making arguments intended to increase sales. One cannot be sure that he believes he is best served by making and reporting objective judgments.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>The value of this document is the list of vendors and tools and the assurance that any transit agency that is interested in enterprise asset management in support of resiliency can find vendors that have tools that are very robust and useful for asset management in the transit industry.</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>• EAM – enterprise asset management – a process and system that provides planning and scheduling, work order creation, maintenance history, inventory, procurement, equipment, component and fixed asset tracking. (Add-ons may include financial and human resource management databases and analytical tools.)</td>
</tr>
</tbody>
</table>
| Potential Keywords | EAM
Enterprise asset management
Cloud-based systems
Scalability

Copyright National Academy of Sciences. All rights reserved.
### Citation

### Website/Source

### Focus Area(s)
- **Policy and Administrative Procedures**
- **Systems Planning**
- **Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction**
- **Asset Management**
- **Operations and Maintenance**
- **Emergency Preparedness, Response, and Recovery**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Conference presentation

### Intended Audience
Metropolitan areas (MPOs) and their partners including federal and state agencies, subregions, and transportation planners in general

### Abstract
This conference presentation examines how the current U.S. transportation planning framework can respond to climate and extreme weather, and contribute to resilient communities through MPOs and their partners.

### Populations Referenced
MPOs, State and Federal DOTs, Subregions, Coordinating Agencies; anyone impacted by investments in transportation infrastructure

### Topics Covered
- How the current transportation planning process can respond to climate and extreme weather, and contribute to resilient communities
- How MPOs and their partners can bring climate and extreme weather, resilience and adaptation into the transportation planning process.
- Best practices to planning for climate resilience by MPOs
- Challenges and opportunities in bringing climate adaptation planning into the U.S. Framework for transportation planning and decision making via MPOs
- Case study of the Netherlands and how they provide the ‘gold standard’ for resiliency

### Type of Sponsoring Agency or Organization
Federal Agency, part of the U.S. DOT

### Geographic Distribution
This presentation addresses national level (MPOs across the U.S.; national transportation planning framework) and regional level (Individual MPOs, subregions and their neighboring MPOs) issues in regions of all sizes and types.

### Type of Transit Mode(s)
Commuter Rail, Heavy Rail, Light Rail/Bus Rapid Transit, Bus/Commuter Bus, Demand Response, Ferryboat (and roadways)

### Type of Vulnerability
No specific vulnerabilities are addressed; they are all addressed generally.

### Goals and Motivations
The goal of this presentation is to illustrate to transportation planners and agencies how planning for resilience fits within the existing U.S. Framework for Transportation Planning, and should be integrated into MPO planning through best practices.

### Context
The presentation focuses on existing complex transit networks and greater transportation networks across the country, any affected by the national transportation planning framework or a regional MPO.
| Tools | Provided examples of best practices:  
|       | o New York City and Northern Jersey Planning Post-Sandy  
|       | o Hampton Roads Partnerships for Climate Change Impacts in Virginia  
|       | o Adapting the San Francisco Bay Area to Rising Tides Through transportation Infrastructure  
|       | o FHWA Climate Scenario planning pilots, including Albuquerque and Cape Cod MPOs |
| Noteworthy Aspects | Performance-based planning and programming to integrate resilience into federal transportation planning.  
|                  | Integration into Map-21, even though it doesn’t directly say resilience or climate, the principles can be applied to adaptation. |
| Captivating Value | The established transportation planning framework provides policy, planning and funding mechanisms for integrating resiliency; however, MPOs need to take the initiative to bring performance measures for resiliency into the long-range planning and prioritization process; and need to step outside existing MPO boundaries to integrate regional resiliency. |
| Decision Question | N/A |
| Decision Maker | N/A |
| Relevance | Given that MPOs are responsible for long-term multimodal transportation planning and investments at a regional level, with impacts on commuter rail, heavy rail, light rail, ferry transit networks, this session provides a relevant perspective on integrating resiliency into future transit planning and investments.  
|            | Accepted practices mentioned include:  
|            | o Foundation in the national transportation planning framework  
|            | o Cooperative, continuing, comprehensive  
|            | o Cross sectoral approach  
|            | o Consensus building  
|            | o Scenario planning  
|            | o Performance-based planning and programming  
|            | o Long-range transportation planning  
|            | o General planning for adaptation, mitigation and resiliency  
|            | All four best practices (see ‘tools’ above) provide noteworthy studies that should be reviewed (when available) if not already included in the literature review.  
|            | Barriers to MPOs implementing effective resiliency methods for transit systems threatened by natural disasters include:  
|            | o Voluntary approaches vs. requirements for resiliency  
|            | o Capacity limitations  
|            | o Defining roles and responsibilities: need for new partners and cooperation  
|            | o Planning across MPO boundaries  
|            | o Funding  
|            | o Private vs. public risk  
|            | o Insurance sector |
| Status | Single conference presentation, no plan for implementation. |
| Critical Assessment | No critique as this was a summary conference presentation. |
| Additional Comments | N/A |
| Essential Vocabulary | Mitigation: “Reductions in emissions.”  
| | Adaptation: “Preparing or adjusting to climate change; preparing or adjusting in response to anticipated climatic effects with a focus on infrastructure.” (NP, min. 7:55)  
| | Resilience:  
| | The main definition of resiliency provided is:  
| | o “Focuses on systems, including the multimodal transportation system and the greater community systems (all sectors), to withstand shocks and provide a dynamic response to survive, recover and prosper; applies to individuals, communities and infrastructure; requires flexibilities and redundancies in capacity for responses; planning with foresight; integration in existing systems and planning framework.” (NP, min. 7:55)  
| | o Additional definitions noted include, “Increasingly, governments and disaster planners are recognizing the importance of social infrastructure: the people, places and institutions that foster cohesion and support” and “Effective climate proofing...should provide benefits not just when disaster strikes but day to day, like Singapore’s Marina Barrage, which created new waterfront, parkland.” (NP, min. 7:55)  
| | Metropolitan Planning Organizations: “Intergovernmental forum for cooperative regional planning with a Board of Officials and a Staff Agency.” (NP, min. 7:55)  
| | Performance-based Planning and Programming: “Application of performance management within planning and programming to achieve performance outcomes for multimodal system. Includes federally-required plans and processes: long-range transportation plans; strategic highway safety, asset management and safety plans; congestion management process; programming documents (STIPs and TIPs).” (NP, min. 7:55)  
| Potential Keywords | Resilience  
| | Adaptation  
| | Performance-Based Planning  
| | MPO  
| | National Transportation Planning Framework |


Document Type | Research report | X

Intended Audience | Transportation researchers, policy makers, transportation planners

Abstract | The fundamental concern is the outlier possibility of a black swan event affecting a transportation system and the resulting impacts on system resiliency. The research consists of three parts:

1. Examines the regional impact of a dramatic fuel price increase of 1.5X, 2X, and 3X and the resulting impact on work trips, deemed to be most nondiscretionary among transportation choices.
2. Focuses on city-scale resiliency by accounting for infrastructure in a detailed manner not feasible at regional scale by considering erring actual modal choices in specific locations.
3. Develops a Transportation Economic Resiliency (TER) rating system to help understand resiliency and vulnerabilities across different geographic areas.

Populations Referenced | Drivers, transit riders, bicyclists, and pedestrians; in the second section, specifically those in Denver.

Topics Covered | Impacts of sudden fuel price increases on transportation behavior

| Analysis of existing or current behaviors
| Traffic stress methodology as applied to auto, bike/pedestrian, and transit modes
| Census tract analysis within Denver and surrounding areas of impact of transportation options and income levels on response to hypothetical black swan event
| Elaboration of TER rating system and its implications for modal choice

Type of Sponsoring Agency or Organization | Mountain-Plains Consortium is a research consortium of major public universities in the Rocky Mountains and Great Plains states devoted to research on regional transportation issues.

Geographic Distribution | What geographic area does this document address? Please consider:

| Regional multistate areas of the Rocky Mountains and Plains states
| In part 2, only the city of Denver and immediate surrounding suburbs
| Some analysis is at a neighborhood scale within the city of Denver

Type of Transit Mode(s) | Auto, bicycle, pedestrian, light rail transit

Type of Vulnerability | The “black swan” event referenced for study is a sudden fuel price increase.

Goals and Motivations | This study seems to focus exclusively on concerns about the economic dislocations within the regional transportation sector of sudden and unexpected fuel price increases. The primary motivation for this focus seems mostly to be that it has happened before in a politically volatile
## Context

- Most of the larger region is rural and auto-dependent, and thus less resilient to fuel price shocks on the cost of auto transportation, particularly for work-related trips. However, there are more options available in Denver, depending on neighborhood infrastructure and income levels.
- Within Denver, distance to work varies, along with opportunities for some modal shifts, for instance, use of bike trails or even walking to work or telecommuting, but these vary with specific neighborhood locations. In addition, Denver’s light rail system offers low cost alternatives for some commuters, particularly for work-related trips.
- Denver Transit, but the study did not present any data on size of the agency.
- The region is largely auto-dependent except for urban neighborhoods in or in the immediate vicinity of Denver.
- No natural disaster is considered; the black swan event is hypothetical. There are, however, sources of resilience in place, which the authors characterize as mostly either access to modal shift alternatives (bike, trail, light rail) or income level that shields users from the financial impacts of the postulated fuel price spikes.

## Tools

The primary metric resulting from this study is the development of the TER rating system. This is aimed at measuring “the resiliency of households to significant price shocks at different geographic levels.” They model a baseline condition for the Denver Metro area. Scenarios were derived from an activity-based model borrowed from the Denver Regional Council of Governments (DRCOG). The focus was on work trips because they were deemed the least malleable choices by transportation users.

## Noteworthy Aspects

The most noteworthy aspect, as stated by the authors, was the focus on sudden price shocks amounting to multiples of current prices, whereas most economic research in this area dealt with elasticity with regard to more incremental price increases.

## Captivating Value

“A community with considerable transit infrastructure—even if experiencing minimal ridership today—would theoretically be able to withstand a rising fuel price shock far better than an auto-dependent region that has not invested in transit.”

## Decision Question

Not clear.

## Decision Maker

The city of Denver and Denver regional transit and transportation agencies.

## Relevance

- As noted above, this document does not in any way deal with natural disasters.
- To the extent that we wish to consider price shocks as a test of transit resilience, it is unique and therefore very useful.

## Status

N/A

## Critical Assessment

No assessment developed

## Additional Comments

N/A

## Essential Vocabulary

Transportation Economic Resiliency

## Potential Keywords

Transit alternatives
Transportation Economic Resiliency
Black swan
Fuel price shocks
### Citation

### Website/Source

### Focus Area(s)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Guide based on research with tools

### Intended Audience
For use by practitioners and planners, particularly transportation stakeholders in the public and private sectors, as well as non-transportation stakeholders, such as emergency managers and first responders

### Abstract
This guide helps referenced stakeholders better understand transportation’s important role in planning for multijurisdictional disasters, emergencies and significant events. The guide sets out foundational principles and uses examples, case studies, tips, tools, and suggested strategies to illustrate their implementation.

### Populations Referenced
Affected stakeholders include all members of the public who may be affected by disasters, emergencies and significant events. Principles of Inclusion and Communication (and multiple examples and case studies) expand the definitions of the general public to include vulnerable populations (due to poverty, language, age, and so forth) and suggest methods for reaching out to such populations.

### Topics Covered
- Foundational principles of the guide
- Individual principles (8 in all, presented below); for each principle present:
  - Characteristics
  - Strategies
  - Tools
  - Tips
  - Examples
  - Case studies (cross reference to back with relevant summary)
- Case studies
  - Pacific Northwest Economic Region and the Center for Regional Disaster Resilience
  - Anchorage, Alaska
  - All Hazards Consortium
  - Southwest Missouri Council of Governments
  - The Association of Bay Area Governments
  - City of Craig, Alaska
  - Marathon Bombing Medical Care: Boston Bombings
  - Hurricane Sandy
  - Regional Integrated Transportation Information System
- Tools
- Additional information
  - Glossary
  - Abbreviations

---

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Type of Sponsoring Agency or Organization</th>
<th>Transportation Research Board, National Cooperative Highway Research Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>Case studies and examples range across the U.S. and Canada (case study and examples of cross-border coordination); regional examples and/or case studies include large/medium, urban/suburban, small and primarily suburban/rural. Specific regional case studies and/or examples include international, U.S. based- Northeast, Southeast, Midwest, Southwest, New England, mid-Atlantic, San Francisco metro area).</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>All modes included, with recommendations, examples and worksheets to include all modes in the regional transportation planning for disasters, emergencies and significant events.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Includes all-hazard planning (including man-made events); also includes planning for special planned events as complementary to emergency planning</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The study began with the title theme of regional coordination; as the study evolved into the focus on principles, resilience emerged as the central facet and focus of all the principles.</td>
</tr>
<tr>
<td>Context</td>
<td>Most case studies and examples include transit; a few examples focus specifically on transit systems (e.g. the San Francisco Bay Area Rapid Transit District (BART) under the Comprehensive principle (p. 20), Houston Metro under the Cooperative principle (p. 25), City of New Orleans City Assisted Evacuation Plan under the Inclusive principle (p. 39), and WMATA under the Exercised principle, (p. 44).</td>
</tr>
</tbody>
</table>
| Tools | Tools include the following:  
  - Checklist of potential stakeholders  
  - Checklist of potential transportation assets (high-level)  
  - Transportation resources (detailed checklist)  
  - Sample transportation security and hazard mitigation strategies for various project modes and types  
  - Checklist for emergency events affecting multiple jurisdictions, transportation and interdependencies  
  - Key steps to effective collaboration  
  - Questions for collaborative partners and other stakeholders to ask each other  
  - Strategies to exercise regional transportation plan for disasters, emergencies and significant events |
| Noteworthy Aspects |  
  - Action strategies and tips are provided throughout the document, pertinent to each principle. Examples:  
    - Comprehensive strategies. Assess the multijurisdictional transportation situation (7 key questions); consider the interdependencies, priorities and contingency plans that are needed when multiple systems fail simultaneously (suggestions on what to include, questions for action strategy); evaluate the hazards and risks pertinent to the region, even those that may be relatively rare but still pose a risk (6 action steps).  
    - Comprehensive tips.  
      o Any hazard assessment tool is no replacement for serious, in-depth conversations and investigations among multijurisdictional stakeholders.  
      o Regional transportation assets must be inventoried.  
    - Unique strategies, tips, and examples are identified to support each of the eight principles. Relevant tools and case studies are cross-referenced, with elaboration on the |
### Captivating Value

Successful multijurisdictional planning for resilience is taking place across the country in many different frameworks and settings (one size does not fit all!) Resilience is an achievable goal when multijurisdictional, multidisciplinary relationships, communication and planning are in place prior to an emergency. The principles in the guide foster such relationship building and planning.

### Decision Question

How can transportation systems in a multijurisdictional setting help the region become more resilient? What can transportation “bring to the table” in term of transportation resources, leadership, and collaborative processes to generate and facilitate the often-difficult conversations about potential hazards and resiliency?

### Decision Maker

Examples and case studies examine many different frameworks for collaboration and decision making. Case studies examine how some of these critical and successful conversations got started.

### Relevance

Resilience is the central objective of TCRP A-41. It also is the central focus of NCHRP Report 777, even though it is not listed as such in the title. Understanding basic principles that facilitate resilience for regional transportation planning is expected to be relevant to principles required for resilient transit systems.

The principles can be visualized as a planning circle or wheel. The wedges or spokes of the wheel (the principles) are joined at a hub (resilience) and held together by a rim (communication and collaboration).

The two precepts that hold together all the principles are Communication and Collaboration. Without these, no other part of a multijurisdictional planning process can be functional. Resilience is the goal at the center of the regional planning.

**Categories of communication**

1. **Communication** related to the planning process or to the resulting plan itself (such as the work of developing the plan, sharing, and implementing the plan once it is complete);
2. **Risk communications**, which are discussions about “what could happen and what might we do about it,” that are the impetus for planning as well as one of the outcomes of a plan; and
3. **Emergency communications**, before, during, and after a disaster, emergency, or major event.

Each category has requirements for intra-agency and key stakeholder communication, but also for the general public. Transportation planners have specialized knowledge and capabilities that are important to each communication category.

**Cornerstones of Collaboration**

Collaboration is the cornerstone of many types of activities, especially those requiring high levels of interaction for mutual gain and high levels of trust of others. Collaboration delivers the following direct benefits to regional transportation planning for disasters, emergencies, and significant events:

- Responding to public needs that require multimodal or multijurisdictional strategies;

---

### Diagram

The diagram illustrates the concept of resilience as a central hub, surrounded by principles such as communication, collaboration, flexibility, and coordination, which are connected to the hub through spokes and circles, symbolizing the integrated nature of these components in a resilient system.
Using new technologies to integrate system and traveler information that crosses modal and jurisdictional boundaries;
Improving the probability of securing new funding for a particular region or organization (by expanding the constituency base for the proposal); and
Preparing for both planned and unexpected events (such as freeway reconstruction and natural disasters) that could disrupt the transportation system. (Campbell et al. 2005)

Planning Principles

Comprehensive: Regional transportation planning for disasters, emergencies, and significant events looks at the full range of potential events with widespread impact that could conceivably affect the region and considers all possible stresses on the transportation system, including interdependencies with other critical infrastructure systems. Planning develops, examines, and tests a range of solutions to address the resulting impacts on critical services, constituents, response capabilities, and the short- and long-range recovery of the community and the region.

Cooperative: The regional transportation planning process is cooperative, not “top down” or single government-agency driven. The process seeks, values, and uses input, suggestions, concerns, insights, and critiques from all public, private, and nonprofit stakeholders.

Informative: Regional transportation planning encompasses data acquisition, analysis, decision making, guidance development, and the transfer of information in a timely, accurate, clear, simple, and useful way to travelers, first responders, and other stakeholders. This principle guides action-oriented plans for specific communication messages, methods of presentation, and means of delivery.

Coordinated: Regional transportation planning establishes a coordinated system that identifies both problems and possible solutions. It takes into account the needs and capabilities of all relevant stakeholders.

Inclusive: Regional transportation planning for disasters, emergencies, and significant events includes services, entities responsible for providing them, material requirements, and persons to be served. This includes every relevant transportation mode; public and private stakeholders, including emergency managers, businesses, owners and operators of critical infrastructure, layers of government, and community organizations that work with people with access and functional needs and transportation-disadvantaged populations.

Exercised: Regional transportation plans for emergencies, disasters, and significant events are exercised regularly to improve planning and operations. Some of the planning and exercising can take place concurrent with planning for significant events.

Flexible: Regional transportation planning incorporates flexibility, adaptability, and the ability to make rapid decisions in times of uncertainty. It is also aims at restoring transportation systems and the communities they serve to normal operations as quickly as possible.

Continuous/Iterative: Regional transportation planning must be ongoing and regular. For readiness and resilience, planning for disasters must be part of usual transportation project plans and updates, but it requires long-term commitments to participation in emergency planning activities. Readiness and preparedness need a body of knowledge and set of relationships that increase without interruption over time. Regular assessments, plan updates, and regionally effective approaches to building community-wide networks continuously strengthen the level of communication and collaboration that disasters require and maintain critical relationships. This process also helps to ensure the continuous transfer of knowledge from one generation of personnel to the next and among agencies as new roles and responsibilities change over time.

- Provides a good annotated list of resources, as well as references.

<table>
<thead>
<tr>
<th>Status</th>
<th>Consider most stages of planning rather than implementation, focused on pre-event planning.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>Well laid out with graphics to assist in place finding. Short enough to not be intimidating, while still substantive.</td>
</tr>
<tr>
<td>Assessment</td>
<td></td>
</tr>
<tr>
<td>Additional</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
## Essential Vocabulary

- **Collaboration:** A purposeful process of working together to plan, to create, and to solve problems and/or manage activities." (Campbell et al. 2005).
- **Emergency:** Usually an adverse event that can be handled with existing community resources. The Stafford Act defines a federally declared emergency as “any occasion or instance for which . . . federal assistance is needed to supplement state, Tribal, and local efforts and capabilities to save lives and to protect property and public health and safety, or to lessen or avert the threat of a catastrophe.”
- **Disaster:** A large-scale adverse event that overwhelms the resources of the affected community. The Stafford Act defines a federally declared major disaster as “any natural catastrophe . . . or, regardless of cause, any fire, flood, or explosion” which causes damage of sufficient severity to warrant disaster assistance to supplement resources of states, local governments, and disaster relief organizations (Stafford Act, PL 100–707).
- **Uses the National Academies definition of Resilience:** The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.

## Potential Keywords

- Resilience
- Regional transportation planning
- Regional emergency planning
- Special event planning
- Collaboration
<p>| Focus Area(s) | | | | Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction | Asset Management | Operations and Maintenance | Emergency Preparedness, Response, and Recovery |
| | Policy and Administrative Procedures | Systems Planning |
| Document Type | Report of survey of state of practice in asset condition assessment at 50 largest transit agencies; two case studies |
| Intended Audience | Transit agencies; scholar; national policy makers |
| Abstract | Current (2010) practices of asset condition management in transit agencies |
| Populations Referenced | Financial and capital programming managers in transit agencies |
| Topics Covered | • Rational methods for establishing level of need for investments | • Enhancing programming of cost-effective investments | • Strengths and weaknesses of estimating condition based on age of assets and inspections | • Data systems that support condition assessments that provide various levels of leverage for financial and capital programming | • Use of scenarios for financial and capital planning | • Evolution of sophistication of asset condition management within two large transit agencies |
| Type of Sponsoring Agency or Organization | Federal agency |
| Geographic Distribution | • National | • 50 largest transit systems | • All regions of U.S. |
| Type of Transit Mode(s) | All |
| Type of Vulnerability | Vulnerability is not discussed. |
| Goals and Motivations | The study examined and documented the state of practice in transit asset condition management. |
| Context | Asset condition management is a necessity for making investments in infrastructure and other capital equipment in transit agencies to ensure SGR. Initiation of the survey reflected expectation that significant variation characterizes the methods used by transit agencies in performing condition assessment and using the results of assessments to support investment decisions. Survey was intended to show the variations and identify approaches to improving assessments that might be used by many transit agencies. |
| Tools | The authors used standard survey and case study approaches. |
| Noteworthy Aspects | MBTA has a data system that establishes a priority for investments based on data that reflect the condition of all MBTA assets. |</p>
<table>
<thead>
<tr>
<th>Captivating Value</th>
<th>Assessment of conditions of assets in transit agencies, in general, had achieved only rudimentary progress by 2011.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Question</td>
<td>This study did not seek a basis for making any decision.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Decision makers in transit agencies can use the results of the study to evaluate potential improvements in assessment of asset conditions. Federal decision makers can use the study to evaluate potential federal actions to support such improvements.</td>
</tr>
<tr>
<td>Relevance</td>
<td>Investments in resiliency will depend on accurate estimates of their value, projections that funding sources will find credible. Valid condition assessments are essential for such assessments. This report shows that it is highly likely that the “mainstream” asset management activities of transit agencies, without their accepting the additional burden of resiliency challenges, are only barely acceptable. Improvements in inventory management and condition assessment may be a prerequisite of resiliency improvement in many agencies. This report, especially in the case studies, shows the value of asset condition assessment in the mainstream activities of transit agencies and, thus, for resiliency planning.</td>
</tr>
<tr>
<td>Status</td>
<td>Completed.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Study approach is persuasive. Response rate of the survey was 82%. No gaps were noted in the approach.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>“State of Good Repair Backlog” – unfunded replacement and renewal needs</td>
</tr>
</tbody>
</table>
| Potential Keywords | Condition assessment  
Life cycle planning  
SGR backlog  
Decay curves |
### Citation

### Website/Source

### Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Synthesis of research literature

### Intended Audience
Transit operators, Governments, civic leaders and researchers

### Abstract
“Infrastructure systems are required in all civilized and industrialized societies and must be maintained at capacities that meet social needs well when challenged by complex variables such as weather and climate, national emergency or disaster.” (p. 1) “Losses of major infrastructure components such as a major bridge, transit mode or roadway, access to water, communications systems or fuels can result in cascading effects that degrade the levels of service that are normally expected by society as a whole.” (p. 1) “Infrastructure systems are complex and will require advanced levels of analysis and design review to ensure service and operability when stressed by future weather impacts.” (p. 11)

Although “many transportation authorities in the United States and internationally are proactively addressing the assessment and engineering of infrastructure and increasingly engaged in the appropriate response to CC,” (p. 11) additional work using methods and survey methodologies to establish a working and meaningful model to index the risk/vulnerability infrastructure is recommended.

### Populations Referenced
The affected stakeholders include: transit agencies, governments, transit users and research academics.

### Topics Covered
This report explores current climate change adaptation practices related to rail transportation and provides:
- an introduction to the evidence of climate change
- an overview of infrastructure vulnerabilities as they relate to climate change
- discussion on the relationship between climate change and infrastructure resiliency and sustainability
- a compendium of studies demonstrating the vulnerability of rail systems to extreme weather-related events
- a discussion of the need for quantitative metrics around climate change risk, vulnerability and cost
- a discussion on the need for vulnerability metrics for rail transportation systems
- provides relevant case methodologies and conclusions
- provides strategies recommended by the American Association of State Highway and Transportation Officials (AASHTO)

### Type of Sponsoring
The author is the communications manager at SYSTRA in New York, NY. SYSTRA is an international consulting firm specializing in mass transit and rail focusing on practical solutions for

---

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Agency or Organization</th>
<th>engineering, operations, and maintenance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>All of United States</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>Discussion is applicable to all modes, however the primary focus is on rail transit systems</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Vulnerability associated with climate change: primarily severe storm events and high heat days</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The goal of the paper is to motivate additional research in the development of methods and survey methodologies to establish a working and meaningful model to index the risk/vulnerability infrastructure. The nexus to resiliency is the secondary goal to provide designs that are sustainable and reduce negative environmental impacts in response to climate change events.</td>
</tr>
</tbody>
</table>
| Context                | • Recognition of the interdependencies of transportation systems  
                        • Summarized the climate change strategies of three very large transit agencies of the world  
                        • Argues the need for metrics relating to risk, vulnerability and costs associated with adapting to climate change and becoming resilient |
| Tools                  | The following risk, vulnerability and cost assessment model for the Metropolitan Area Transit/Rail Agencies was provided in the document. |
|                        | “1) Model Characterization ______________________  
                        2) Volume/Service Levels ______________________  
                        3) Hazard associated with Weather Impact___  
                        4) Climate Change Agent ______________________  
                        5) Replacement Cost_________________________  
                        6) Remediation/Adaptation Strategy and Cost ___  
                        7) Probability and Impact Severity _________  
                        8) Expert panel of subject matter expert’s _______  
                        9) Statistical determinations of event and impact on public activity __________  
                        10) Appropriate technology for monitoring of infrastructure _________  
                        11) Cost benefit, NPV or IRR means testing of adaption strategy ___________  
                        12) Service level requirements or targets _______  
                        13) Infrastructure Interdependencies ___________  
                        14) Innovations in Infrastructure Technologies ___  
                        15) Service Life/Technology Refresh of Systems ___  
                        16) Existing and desired levels of redundancy and resilience ___  
                        17) Long-term public needs and benefits _________” (p. 9) |
| Noteworthy Aspects     | One adaptive measure identified in a study by the Swedish National Railway and Defense Research Agency was the establishment of tree-free zones along the railway corridor to reduce tree downing impacts to service. (p. 9 (not a direct quote, but should be cited)) |
|                        | The review of the Los Angeles Metropolitan Transportation Authority’s climate adaptation options include the following specific considerations: |
|                        | • Improved weather collection information and technologies  
                        • Exploring the use of more heat resistant track and wayside materials  
                        • Improving flood defense systems  
                        • Develop improved construction practices to reduce the impact of adaptation upgrades (p. 10 (not a direct quote, but should be cited)) |
| Captivating Value      | “Infrastructure systems are complex and require advanced levels of analysis and design review to ensure service and operability when stressed by future weather impacts.” (p. 11) |
Because additional work establish a working and meaningful model to index the risk/vulnerability infrastructure is recommended, the paper suggests the role of government needs to be reckoned. Since infrastructure is commonly funded by government, the role of government as it relates to resiliency needs to be defined. The author states that government has the responsibility of establishing the means to spur economic reinvestment to create infrastructure resiliency which has real costs and necessities for sound societal returns.

**Decision Maker**  
Federal and state level policy makers

**Relevance**  
The paper summarizes the author’s research of literature from both international and US sources.
- The climate change strategies of three very large transit agencies were reviewed and summarized, as was the strategies recommended by AASHTO provided a helpful overview
- The lack of quantitative metrics and methodologies to index the risk/vulnerability of infrastructure remains a barrier to the prioritization and implementation of adaptation strategies

**Status**  
Additional research was anticipated to be completed in 2013.

**Critical Assessment**  
The paper provides a review of other work and identifies gaps in the development of metric and methodologies. There were very few specific tool, recommendations, or case studies identified in the paper. The paper does cite works that collectively demonstrate a wide range of research literature.

**Additional Comments**  
N/A

**Essential Vocabulary**  
Resiliency is defined in several ways in the paper:
- “Resiliency consists of three elements; lower probability of failure, less severe consequences and faster recovery times.” (p. 4)
- Resilience is “the ability to deal with change and to maintain continuity of function of the system; develop the means for graceful degradation of services, the ability to recover quickly to a desired level of function and to require the cooperation between the public and private sectors.” (p. 4)

**Potential Keywords**  
Climate change  
Vulnerability  
Resiliency  
Rail transportation  
Metrics

http://www.national-academies.org/trib/bookstore; Project 20-05 (Topic 44-12)

| Website/Source | http://www.national-academies.org/trib/bookstore; Project 20-05 (Topic 44-12) |

|---------------|----------------------------------|-----------------|---------------------------------|-----------------|--------------------------|-----------------------------------------------|

| Document Type | Case studies, a screening survey and follow-up communications, a literature review, and organizations such as AASHTO, the American Public Works Association (APWA), FHWA, the International Municipal Signal Association (IMSA), the Local and Tribal Technical Assistance Program (LTAP/TTAP) centers, TSA, the university transportation center (UTC) consortia, the National Association of County Engineers (NACE), and the National Emergency Management Association (NEMA). |

| Intended Audience | Maintenance and operations (M&O) personnel of state departments of transportation (DOTs) and the field personnel of tribal and local public works agencies (PWs) |

| Abstract | “The maintenance and operations personnel of state departments of transportation and the field personnel of local public works agencies are on the front lines during emergencies and disasters. Therefore, their preparedness is essential to public safety. The goal of this study was to identify interactive emergency training tools and sources appropriate for these field personnel, identify obstacles to implementation, and create a toolkit of relevant training and exercise information. The key focus for the synthesis is maintenance and operations field personnel and their managers.” (p. vii) |

| Populations Referenced | General Public |

<table>
<thead>
<tr>
<th>Topics Covered</th>
<th>CHAPTER ONE INTRODUCTION</th>
</tr>
</thead>
</table>

| - Background, 5 |
| - National Incident Management System, 6 |
| - Definitions, 6 |
| - Training and Exercises, 7 |
| - Emergency Operations Plan, 7 |
| - Other Plans and Procedural Documents, 8 |
| - Study Approach, 9 |
| - Report Organization, 9 |

<table>
<thead>
<tr>
<th>CHAPTER TWO EMERGENCY TRAINING AND EXERCISE NEEDS</th>
</tr>
</thead>
</table>

| - Systems, Frameworks, Plans, and Goals Resulting from Presidential Directives, 10 |
| - NIMS Training, 13 |
| - Mutual Aid and Grants, 16 |
| - Hazards Awareness, Safety Training, and Hazard-Specific Training, 18 |
| - Traffic Incident Management Training, 21 |
| - Winter Maintenance and Operations Training, 24 |
| - Evacuation, 24 |
| - Continuity of Operations, 24 |
TCRP A-41: Literature Review

CHAPTER THREE EMERGENCY TRAINING AND EXERCISE DELIVERY METHODS
- Supervisor Training, 25
- Exercises, 26

CHAPTER FOUR EMERGENCY TRAINING AND EXERCISE PRACTICES
- Implementation Challenges, 43
- Training Needs, 44
- Training Solutions, 45
- Additional Findings, 51
- Findings on the Use of Exercises, 53

CHAPTER FIVE EMERGENCY TRAINING AND EXERCISES TOOLKIT
- Structure of the Toolkit, 59
- Key Courses and Catalogs, 61
- Accessing the Guidance Documents, 62
- Categories of Source Organizations, 62
- Using the Source-Specific Sheets, 65
- Searching Effectively Within the Toolkit, 66

CHAPTER SIX CONCLUSIONS
- Key Findings, 67
- Strategies and Tools to Deliver Emergency Training and Exercises, 68
- Further Research, 69

Type of Sponsoring Agency or Organization | Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration
---|---
Geographic Distribution | National - US
Type of Transit Mode(s) | Transit highways
Type of Vulnerability | Traffic incidents
Goals and Motivations | “Identify interactive emergency training tools and sources appropriate for the M&O field personnel of state DOTs and PWs, identify obstacles to their implementation, and create a toolkit of relevant training and exercise information.” (p. 1)
Context | • “Training and exercises enable state department of transportation (DOT) and public works (PW) field personnel to prepare for and respond to emergencies and disasters. Emergency training and exercise issues, challenges, and solutions (including delivery methods and training sources) were identified in this synthesis.”
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

- Emergency training and exercise needs are identified using federal guidance and requirements, as well as an agency’s emergency operations plans, standard operating procedures, and other plans and procedural documents.
- Evaluating the National Preparedness system, training for personnel.
- One of the primary federal sources—the Federal Emergency Management Agency (FEMA)—offers training through the Emergency Management Institute (EMI), the Center for Domestic Preparedness (CDP), and the National Training and Education Division (NTED). Other important sources include the National Highway Institute (NHI), universities and colleges, local and tribal technical assistance program (LTAP/TTAP) centers, and the National Transit Institute (NTI). OSHA offers numerous resources and training guidance on occupational health and safety. Some NCHRP and TCRP products also provide useful training content.” (p. 3)

**Tools**

- Toolkit 44-12: The sources in the toolkit are organized as follows:
  - Federal (FEMA)—sources within FEMA
  - Federal (Other DHS)—sources in the U.S. Department of Homeland Security or its agencies
  - Federal (U.S.DOT)—sources in the U.S. Department of Transportation
  - Federal (Other Federal)—Federal Government sources that are not part of DHS or U.S.DOT
  - State—state-level sources identified from the survey and from case examples
  - Local—local sources identified from the survey and from case examples
  - University—sources in universities and university affiliated training and research centers
  - Associations and Coalitions—sources in trade associations and regional coalitions
  - Private Firm—sources in private firms.

**Noteworthy Aspects**

- N/A

**Captivating Value**

- “Over the past decade, their roles in all-hazards emergencies have been expanding; at the same time, public expectations for a safe and secure transportation infrastructure and quick restoration of public services after emergencies and disasters have been growing.” (p. 1)

**Decision Question**

- “This synthesis identified the following strategies and tools to deliver cost-effective emergency training and exercises:
  - Field crew meetings
  - Just-in-time training (JITT):
  - Interjurisdictional and interagency training and exercises
  - Joint training
  - Asynchronous training
  - Train-the-trainer (TTT):
  - Planned events, incidents, and exercises
  - Classroom training
  - Online training with live instructors
  - Computer simulations and virtual exercises” (p. 2)

**Decision Maker**

- N/A

**Relevance**

- “Implementation challenges identified by the screening survey, case example participants, and panel members included the following:
  - Scheduling difficulties and conflict with work priorities
  - Limited budgets
  - Lack of qualified training staff
  - Personnel turnover
  - Limited training content
  - Insufficient information about available training

Copyright National Academy of Sciences. All rights reserved.
- Infrequent need for training
- Lack of PC/Internet access
- Distance issues.” (p. 67)

<table>
<thead>
<tr>
<th>Status</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>No assessment developed</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Highways, Maintenance and Preservation, Security, Emergencies, Preparedness</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

<table>
<thead>
<tr>
<th>Document Type</th>
<th>Annual Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended Audience</td>
<td>MPO subregions (counties, cities), Federal agencies (FHWA, DOT), State agencies (DOT, MTA), Regional agencies (Port Authority of New York – New Jersey), General public</td>
</tr>
<tr>
<td>Abstract</td>
<td>This annual report by the New York Metropolitan Transportation Council, the MPO for the New York City – Long Island region, focuses on lessons learned/recommendations for NY Transit (and greater transportation) system post-Sandy, with discussions on adaptation to climate change.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Users of the New York-New Jersey transportation system following Superstorm Sandy including commuters, transit riders, operations personnel, and first responders.</td>
</tr>
</tbody>
</table>
| Topics Covered | Overview of Hurricane Sandy’s impacts on regional transportation system (nymtc planning area)  
Transportation system planning in the aftermath of Hurricane Sandy  
Lessons learned from Superstorm Sandy and next steps for resiliency planning |
| Type of Sponsoring Agency or Organization | MPO: New York Metropolitan Transportation Council |
| Geographic Distribution | The annual report addresses a regional level. The New York Metropolitan Transportation Council (NYMTC) is a regional council of governments that is the Metropolitan Planning Organization for New York City, Long Island and the lower Hudson Valley. “The NYMTC planning area covers 2,440 square miles, with a population of approximately 12.4 million people in 4.5 million households, or about 64 percent of the New York State population in 2010. The area is large with a mixture of urban and suburban land uses comprising the New York Metro Area.” (p. 2) |
| Type of Transit Mode(s) | Commuter Rail, Regional Rail, Light Rail/Bus Rapid Transit, Heavy Rail, Bus/Commuter Bus, Ferry (in addition to roadways) |
| Type of Vulnerability | Severe Storm Events, Coastal Storms, Flooding/Sea-level Rise (specifically, Hurricane Sandy) |
| Goals and Motivations | “In the aftermath of Sandy, members of the New York Metropolitan Transportation Council (NYMTC) have focused their efforts on adapting the transportation system to increase resiliency to the impacts of extreme weather and climate risks, and to the vulnerabilities exposed as never before by the storm.” (p. 3) The Annual Report is meant as an account of the effects of the storm and lessons learned to provide perspective on future resiliency planning efforts. |
| Context | Multiple modes exist in the region, including commuter rail, heavy rail, light rail/bus rapid transit, ferry and regional rail networks. “The storm had devastating impacts to people, property and the economy. A lack of |
transit service combined with closed roads throughout the region diminished people’s ability to get to work. Many stores and offices were closed throughout the region, deliveries of goods – including gasoline – were delayed, retail sales plummeted and visits to tourist sites were curtailed.” (p. 7)
- Transit agencies include the Port Authority of New York and New Jersey, New York Metropolitan Transportation Authority (New York City Transit, Long Island Railroad, Metro-North Railroad). The NYMTC organizational chart is provided in Figure 1.
- There are numerous interdependencies between transit agencies in the New York Region due to shared infrastructure, especially tunnels, several of which were inundated during Superstorm Sandy.
- Limitations of the region include aging infrastructure and “susceptible to damage from extreme weather events or seismic threats, and many facilities, such as tunnels and airports, have been built-in locations that are increasingly at risk of flooding.” (p. 11)
- The report does not provide an overview of specific asset management plans or operations and maintenance systems that are in place, but it does note that even before Hurricane Sandy, NYMTC’s members had undertaken various planning initiatives to begin to address the possibility and risks of climate change and weather extremes. “A premier example of this type of planning is contained within New York City’s PlaNYC, a long-range sustainability plan partially funded through the NYMTC planning process.” (p. 11)
- Ongoing resiliency planning efforts reviewed in the report include:
  - NYS 2100 Commission
  - NYMTC helped to organize New York-Connecticut Sustainable Communities, a bi-state collaboration of cities, counties and regional planning organizations which won a $3.5 million grant from the U.S. Department of Housing and Urban Development’s (HUD) Sustainable Communities Regional Planning Grant Program. One of the elements of the work program is a climate resiliency project undertaken by the New York City Department of City Planning to build on PlaNYC by identifying strategies that can be used throughout the region to minimize damage and disruption from coastal flooding and storm surges
  - MTA plans to enhance operations planning response, agency coordination, protect vulnerable zones, and investigate concepts to harden assets
  - Port Authority review of facility systems to control flooding and anticipate events
  - NYS DOT identification of critical transportation infrastructure
  - NYC DOT bike routes for emergency access
  - Westchester County adaptation of services and infrastructure
  - Rockland County efforts with utility companies
  - Suffolk County CONNECT LONG ISLAND study for innovative mass transit – bus rapid transit
  - Nassau County DPW FEMA projects

<table>
<thead>
<tr>
<th>Tools</th>
<th>No new tools or metrics of study were identified.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noteworthy Aspects</td>
<td>No innovative, non-standard, and/or quickly/inexpensively adaptive techniques that have proven (or promising) value, the report was more of an update rather than a study.</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>“Lessons learned to date and to be learned from Hurricane Sandy are many, but they recognize the transportation network’s vulnerabilities to extreme weather events and risks associated with climate change. The New York metropolitan region’s topography and land-use patterns present huge challenges, which cannot be fully addressed in a fragmented fashion. An integrated approach to managing these risks, including coordinated regional planning, will help prepare the region to ensure that people and goods can continue to move throughout the area with minimal possible interruption during urgent situations, and that the transportation system can recover quickly from any disruptions.” (p. 15)</td>
</tr>
<tr>
<td>Decision Question</td>
<td>N/A</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>N/A</td>
</tr>
<tr>
<td>Relevance</td>
<td>The document does not provide any accepted practices or guidance, but was selected because it provides updates on post-Sandy planning while underscoring the need for regional integrated planning for transit resiliency.</td>
</tr>
<tr>
<td>Status</td>
<td>Subsequent annual report released in 2014.</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>No critique necessary as this is not a study, but rather an update report.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Potential Keywords | Subway  
Superstorm / Hurricane Sandy  
Resiliency  
New York |

Figure 1. NYMTC Organizational Chart
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Website/Source</strong></td>
<td><a href="http://docs.trb.org/prp/13-1198.pdf">http://docs.trb.org/prp/13-1198.pdf</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Document Type</strong></td>
<td>Case study</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intended Audience</strong></td>
<td>Practitioners, Agencies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
<td>“Development of performance measures to evaluate corridor resiliency for transportation corridors in megaregions and their performance of these corridors in terms of resiliency.” (p. 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Populations Referenced</strong></td>
<td>Commuters, Transit Riders, Operations Personnel, Manager, Coordinating Agencies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Topics Covered** | • “Review of literature related to megaregions, Megalopolis, resiliency and performance measures;  
  • Identify megaregional challenges faced by practitioners via a workshop to obtain the perspectives of stakeholders and define resiliency;  
  • Develop performance measures, specifically resiliency indicators for megaregions;  
  • Identify variables that measure, using GIS, stressors and impacts on the corridor;  
  • Determine categories of resiliency and related indicators;  
  • Develop strategies that support the implementation of the indicators impact;  
  • Develop an implementation plan to support the use of resiliency performance indicators by an agency, recognizing the institutional constraints that are present in a multijurisdictional corridor;  
  • Apply indicators and methodology to a case study of the BosWash corridor;  
  • Recommend strategies for future work and implementation. “ (p. 4) |
| **Type of Sponsoring Agency or Organization** | Other – Educators/researchers |
| **Geographic Distribution** | Level (regional); Regional size & type (large/medium, urban); Specific region(s) - U.S. Based- Mid-Atlantic to the Northeast (BoWash Corridor) |
| **Type of Transit Mode(s)** | Surface transportation systems |
| **Type of Vulnerability** | • Population and Economic Growth – Pressure on the corridor due to population and economic growths continue to increase.  
  • Rail Spine – Rail lines created the spine of the corridor.  
  • Highway Skeleton Becomes the Transportation Trunk – The highway network serves as the skeleton of the corridor.  
  • Land Use and Metropolitan Structure – The transportation networks supports urban sprawl. |
<table>
<thead>
<tr>
<th>Goals and Motivations</th>
<th>The goal of this research was to develop resiliency indicators that can be used and integrated into 30 agencies' planning process.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context</strong></td>
<td>The most formative types and stages of surface transportation were the railroad system followed by highways for automobiles and trucks. The BosWash, or the Northeast Megapolitan Corridor, is the oldest and most complex transportation corridor in the United States, and its rails and roads, in particular, demonstrate the complex networks in the region. Limitations include temporal and spatial scales in congestion, and increased growth. Research has shown that the corridor is not very resilient to increased growth. Next steps within this research would be undertaken in the context of the planning process of the agency using this process.</td>
</tr>
<tr>
<td><strong>Tools</strong></td>
<td>“The implementation plan is a step-by-step process that agencies, as part of a megaregion corridor, can follow in order to integrate resiliency measures into their planning process at a holistic, large-scale. The steps are: 1. Define corridor study area and characteristics - Determine the jurisdictional boundaries of the megaregion and agencies involved as well as geographical, infrastructure, environmental, socio-political, and economic characteristics of the corridor. For example, a Metropolitan Planning Organization (MPO) may choose to focus on the specific boundaries of that megaregion, as defined by the agencies within the region. 2. Identify potential stresses - Based on observations of the current status and historical trends, determine relevant stresses that might be present as well as key variables that can be modeled using GIS. 3. GIS analysis to determine trends specific to that corridor (historical and projected) - Based on stresses identified and their associated variables use GIS to map and model the trends both spatially and temporally. 4. Assess relevant resiliency indicators to corridor - Based on the resiliency indicators developed in this research, determine those that are relevant to the corridor as well as identify any additional measures, specific to the corridor and implement throughout agencies within the study area. 5. Develop and apply strategies for addressing impacts - Similar to the strategies identified in this research, determine practices or methods that can be used to address impacts and implement throughout agencies within the study area. 6. Repeat process over time - Iteratively complete the process every year to determine changes in the network, process, or system and revise.” (p. 9-10)</td>
</tr>
<tr>
<td><strong>Noteworthy Aspects</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Captivating Value</strong></td>
<td>“The concept of resiliency, as captured by performance measures at different temporal and spatial scales, serves as a useful tool for understanding the corridor, putting the issues in context and addressing these issues.” (p. 16)</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
<td>“The next challenge remains to quantify the proposed measures of resilience and connect the measures to the decision-making process.” (p. 16)</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>Practitioners, Transit Agencies</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>• Guidelines were laid out as discussed above to determine the performance measures of a megaregion corridor system. Agencies would be able to use the process outlined but it is not known if one has. • Congestion, environmental degradation, structural deterioration, and social inequities</td>
</tr>
</tbody>
</table>
result from the current form of urban development in the U.S. and have not been adequately resolved through past approaches of delegating authority of sections of the corridor to state DOT’s or local MPO’s.

- “When applied to 7 transportation corridors in megaregions, and represented by performance measures such as 8 redundancy, continuity, connectivity, and travel time reliability, the concept of resiliency 9 captures the spatial and temporal relationships among the attributes of a corridor, network, and 10 neighboring facilities over time, at both the regional and local level.” (p. 1)

<table>
<thead>
<tr>
<th>Status</th>
<th>Stage of planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>No assessment developed</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>“Resiliency was defined as the “ability to recover from or adjust easily to change” is the inverse of vulnerability, and refers to more than simply the recovery of a system after a catastrophic event.” (p. 1)</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>Resilience, Performance Measures, Megaregion, Transit corridor, GIS</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

### Document Type
Political and economic perspective based on case studies.

### Intended Audience
General public; political leaders at international, national, state, and local levels.

### Abstract
The need for resilience can be demonstrated in countless ways, and the economic, social, and political advantages of resilience action are immense. Successful resilience requires involvement of almost everyone, and leaders in all walks of life must support resilience.

### Populations Referenced
The general public

### Topics Covered
- Resilience Framework
  - Aware
  - Diverse
  - Integrated
  - Self-regulating
  - Adaptive
- The “mindset” of resilience
- Practice of resilience (readiness, responsiveness, revitalization)
- The broad range of disruptions that stress and shock the world
- How crisis becomes disaster
- Awareness of the probability of threats
- Readiness for threat events
- Getting ahead of threats
- Responsiveness
- Leadership
- After the crisis
- Revitalization
- The resilience dividend

### Type of Sponsoring Agency or Organization
Commercial book publisher

### Geographic Distribution
All

### Type of Transit Mode(s)
Resilience of transit systems is not discussed specifically, except that the transit system of Medellin, Colombia is cited as a resilience project because the transit system allowed the city to grow away from the drug trade and support a thriving tourism market.

### Type of Vulnerability
All kinds of vulnerabilities are discussed in the case studies to which the vulnerabilities apply.
The goal of the book is to persuade people to encourage and support resilience.

The context is the history of resilience in the face of disaster and the near certainty that other disasters will occur.

The book is a series of summaries of cases

Disasters happen, and resilience reduces the impact of disruptions, accelerates recovery, and creates opportunities for overall improvement.

Should communities, however defined, invest in resilience?

The author argues that every individual and group of individuals has a stake in resilience and that success of resilience efforts grows with the number of people involved.

This book cites countless examples of resilience of many kinds. The stories told in the book will help practitioners who advocate resilience to support their case to the audiences they address.

The approach is logical and comprehensive, but it is very general. Its practical value for the transit community seems limited to attracting attention to the value of resilience and persuading the public that people have benefited many times because they invested in resilience.

- Resilience – “the capacity of any entity – an individual, a community, an organization, or a natural system – to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience”
- “Failing safely” – the result of the ability of a system to “island” or “de-network,” so that the failures caused by disruption are discrete and contained.

**Goals and Motivations**

**Context**

**Tools**

**Noteworthy Aspects**

**Captivating Value**

**Decision Question**

**Decision Maker**

**Relevance**

**Status**

**Critical Assessment**

**Additional Comments**

**Essential Vocabulary**

**Potential Keywords**

Resilience
Costs of disasters
Insurance
Disaster preparedness
Leadership
--- | ---
--- | ---
Document Type | Extended abstract of research presented at annual conference of Institute for International Policy Studies (IIPS) in 2007
Intended Audience | Railroad operators, Rail planners and safety researchers, Policy makers
Abstract | “Weather conditions exert a major influence on U.S. railroads. These conditions may affect operating efficiency, physical infrastructure, and the safe passage of freight and people.” (p. 1) This analysis examines the Federal Railroad Administration (FRA) Railroad Accident and Incident Reporting System (RAIRS) database for the period 1995-2005 to understand the relationship between railroad incidents and adverse weather events. The paper recommends exploring the use of “Intelligent Transportation System (ITS) based mechanisms” to improve the understanding of the impact of weather events on railroad incidents and reduce injuries, fatalities and damages caused by adverse weather. Finally, the paper recommends that the meteorological community works with the railroad industry to develop new products to meet the operational and safety needs of the railroad community.
Populations Referenced | Passengers, Railroad operators, meteorological community
Topics Covered | • Summary of rail accidents by weather condition based on RAIRS data  
• Issues with RAIRS data  
• Qualitative discussion of the impact of different weather events on railroad operations  
• Existing railroad operating procedures related to adverse weather  
• Potential use of Intelligent Transportation Systems (ITS) such as Clarus (i.e., FHWA initiative to develop an integrated surface transportation weather system) by railroad sector.
Type of Sponsoring Agency or Organization | Federal Agency
Geographic Distribution | US
Type of Transit Mode(s) | Rail
Type of Vulnerability | Adverse weather conditions in general (liquid precipitation, frozen precipitation, wind velocity, temperature extremes, fog, slides, frozen loads and lightning)
Goals and Motivations | Reduce weather effects on the railroad system to prevent injuries, fatalities and release of hazmat and reduce economic damages through improved weather information
Context | N/A
<table>
<thead>
<tr>
<th><strong>Tools</strong></th>
<th>Federal Railroad Administration (FRA) Railroad Accident and Incident Reporting System (RAIRS) database</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Noteworthy Aspects</strong></td>
<td>Lack of industrywide standards for obtaining weather information and prescribed actions to avoid injuries and damages</td>
</tr>
<tr>
<td><strong>Captivating Value</strong></td>
<td>Need for better data to understand the effect of weather on railroad incidents and weather information products tailored to the rail community.</td>
</tr>
<tr>
<td><strong>Decision Question</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Decision Maker</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>Researchers used large FRA database to learn more about the effect of adverse weather on rail operations but due to the data quality the analysis is of limited value.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Complete</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>Paper is more a qualitative than a quantitative assessment because of the lack of comprehensive, quality data. Analysis performed in paper based on existing data only demonstrates correlation between weather events and rail incidents, not causality.</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
<td>Weather-related incidents Railroad Accident and Incident Reporting System (RAIRS) Rail</td>
</tr>
</tbody>
</table>
## Citation

## Website/Source

## Focus Area(s)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Document Type
Report and Guidebook

## Intended Audience
- Transportation executives or asset owners
- State and local transportation departments and agencies responsible for multiple modes, transit agencies, port authorities, turnpike authorities and bridge and tunnel authorities
- Transportation officials with capital budgetary discretion

## Abstract
Supports mainstreaming an integrated, high-level, all-hazards, National Incident Management System (NIMS)–responsive, multimodal, consequence-driven risk management process into transportation agency programs and activities by providing a convenient and robust planning tool for top-down estimation of both capital and operating budget implications of measures intended to reduce risks to locally acceptable levels. The CAPTA methodology provides a means for moving across transportation assets to address system vulnerabilities that could result in significant losses given the threats and hazards of greatest concern.

## Populations Referenced
CAPTA is intended for use by senior managers whose jurisdiction extends over multiple modes of transportation, multiple asset classes, and many individual assets.

## Topics Covered
CAPTA components include:
- Asset Categories
- Hazards/Threats
- Consequence Threshold
- High-Consequence (Critical) Assets
- Countermeasures
- General Countermeasure Attributes

The Basic CAPTool Guide (Part II) includes:
- Step 1: Relevant Risks
- Step 2: Thresholds
- Step 3: Asset and Asset Class Inventory
- Step 4: Inventory of High-Consequence Assets/Asset Classes
- Step 5: Countermeasure Opportunities
- Step 6: Results Summary

The Enhanced CAPTool Guide includes:
- Step 1a: Threat/Hazard Vulnerability Table
- Step 5a: Countermeasure Costs
- Step 5b: Selection of Additional Countermeasures
- Step 5c: Countermeasure Filter Selection

## Type of
Transportation Research Board, National Cooperative Highway Research Program

Copyright National Academy of Sciences. All rights reserved.
### Sponsoring Agency or Organization
A forum for coordinated and collaborative research, the National Cooperative Highway Research Program (NCHRP) addresses issues integral to the state Departments of Transportation (DOTs) and transportation professionals at all levels of government and the private sector. The NCHRP provides practical, ready-to-implement solutions to pressing problems facing the industry.

The NCHRP is administered by the Transportation Research Board (TRB) and sponsored by the member departments (i.e., individual state departments of transportation) of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA). Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

### Geographic Distribution
United States

### Type of Transit Mode(s)
All types of surface transportation

### Type of Vulnerability
Heat, Cold, Storm, Coastal, Flooding, Winter, Earthquake, Fire, Other

### Goals and Motivations
Identification of challenges to adaptation planning and implementation as well as best practice.

### Context
The loss of a high-consequence transportation asset could result in casualties, billions of dollars worth of direct reconstruction costs, economic losses, and mission failure for responsible agencies. However, resources do not exist to safeguard every asset owned or operated by an agency. CAPTA attempts to bridge this gap, providing a transparent means to prioritize multimodal assets for resource allocation (p. 13).

Making transportation systems safe and secure is a complex problem that requires balancing mobility, access, and personal freedom with access control, intelligence gathering, screening, and other means (p. 13).

This guide and accompanying computer-based tool provide a resource that transportation owners and operators can use in addressing this challenging problem. The most critical element of success for the CAPTA product is to place the tool in the hands of concerned users so that they can be more effective in evaluating multiple modes of transportation. Transportation industry associations and professional organizations are the natural choices for disseminating this approach (p. 13).

### Tools
Basic CAPTool Guide and Enhanced CAPTool Guide

CAPTool is Microsoft® Excel based and requires that the user have a rudimentary knowledge of that application. The tool uses Microsoft® Excel macros and Visual Basic embedded in a Microsoft® Excel spreadsheet. Changes to the Visual Basic subroutines will change the results, and thus changes should not be made without careful testing (p. 71).

### Noteworthy Aspects
CAPTool results depend upon the quality of the information and judgments used in applying it. Missing or unsubstantiated data concerning asset characteristics—such as length, cost, and usage—skew results inappropriately. Inconsistent input data also cause assets to be identified as, more or less, consequential than they should be. Efforts should be made to ensure consistent inputs to the CAPTool (p. 108).

CAPTool is designed to be iterative. Users can apply different consequence thresholds to assets and consider various countermeasures. CAPTool is more effective when the user alters thresholds and reviews results of these scenarios. This iterative process allows the user to determine the assets of highest consequence for further evaluation. CAPTool makes the iterative process...
### Captivating Value
CAPTool identifies assets and asset classes that are of highest consequence and thus most important to the functionality of the transportation mission (p. 108).

### Decision Question
CAPTool allows users to compare multiple modes of transportation assets on a common basis. CAPTool provides an effective means to analyze assets in an objective, transparent manner (p. 108).

### Decision Maker
State and local transportation departments, transit agencies, port authorities, turnpike authorities and bridge and tunnel authorities.

### Relevance
The CAPTool provides decision support to the difficult task of resource allocation across multiple modes. CAPTA combines a transparent means to capture management judgments on consequence thresholds with the objective characteristics of the assets analyzed to produce a list of high-consequence assets that merit further examination. CAPTool identifies high-consequence assets and links them to objective data and user choices (p. 108).

### Critical Assessment
I am not familiar enough with this tool to provide a critical assessment. I am also not an expert in Asset Management and/or Operations, which this tool seems to be focused on.

### Additional Comments
N/A

### Essential Vocabulary
Below is Appendix F – Glossary of Terms Used in CAPTA, pp. 54 - 56

**Risk Assessment Terms**
- **Risk**—The quantitative or qualitative expression of possible loss that considers both the probability that a hazard or threat will cause harm and the consequences of that event.
- **Target/Asset**—Persons, facilities, activities, or physical systems that have value to the owner or society as a whole.
- **Threat/Hazard**—The potential natural event or intentional or unintentional act capable of disrupting or negatively impacting an asset. In the case of natural events, the hazard is the frequency and magnitude of a potentially destructive event. Hazards can be expressed in probabilistic terms where data are available.
- **Consequences**—The loss or degradation of use of an asset resulting from a threat or hazard. Consequences may also be determined by loss of life (casualty). Mission-related consequences include destruction or damage causing real loss or reduction of functionality. Potential for consequences grow as a function of an asset’s criticality. However, a critical asset may be damaged without total loss of functionality.
- **Vulnerability**—A weakness in asset design or operations that is exposed to a hazard or can be exploited by a threat resulting in negative consequences. Specific hazards or threats may expose or exploit different vulnerabilities. Note that an asset may be susceptible to hazards or threats that may increase its vulnerability, such as having publicly accessible information (e.g., drawings, schedules, secure areas) that could assist a terrorist in planning and executing a successful attack.
- **Consequence Threshold**—The planning factor used to set the level of consequences at which the decision maker or agency assumes greater responsibility for managing the risk.

**Consequence Categories**
- **Potentially Exposed Population (fatalities and injuries)**—This consequence is concerned with the number of people who may become a casualty. Occupancy limits, or capacity is a surrogate data point for this category.
- **Property Loss**—This concerns the cost to repair or rebuild a damaged or destroyed structure. These monetary estimates are standardized unit cost estimates based upon square or linear footage of an asset, or an amount provided by the user for special
Threats

- Chemical/Biological/Radiological
- Large Explosive Devices—Explosive materials containing greater than 500 pounds of TNT or equivalent. The method of delivery is either by vehicle or through multiple persons acting in concert to transport the payload.
- Criminal Acts—Lower intensity threats representing the range of illegal activities as defined by federal code, state statute, or local ordinance. Examples of criminal acts include handgun violence and illegal discharge of hazardous waste.
- Fire—Sources may be disparate and triggered by any combination of flammable material and ignition. Fire may result from happenstance and does not require an intentional act to occur. Fire, or the pre-fire hazard of smoke, will immediately have a negative impact on the transportation system. Other types of fire include arson, arson prevention, fire equipment, and fire prevention.
- Fleet—Regularly used individual passenger vehicle. The most common assets in this category will be buses and passenger transit/rail cars. The base unit for this category is one asset, whereby a train may consist of four to six individual fleet cars. The similarities of fleet vehicles readily lend themselves to groupings into classes.
- Ferry—All watercraft used in the regulated transportation of passengers and vehicles for a scheduled service. The size of the vessel does not matter. In the rare cases where ferries constitute a significant portion of the transportation agency’s passenger capacity, an effort should be made to separate the vessels into classes.
- Administrative and Support Facilities—Fixed asset facilities a transportation operator may own or operate, with the exception of transit or rail stations. The fixed facilities in this category may range from offices of executives, to airside passenger terminals.
- Road Tunnels—All tunnels bored, mined, or immersed that convey rubber tire vehicles, buses, and trucks.
- Road Bridges—Any aerial structure designed to carry vehicular traffic across a body of water or land. This category is most effective when used to capture structures whose length spans greater than one beam.
- Transit/Rail Bridges—All raised aerial structures designed to carry rail rolling stock.
- Transit/Rail Tunnel—A transit system with a major rail capability is likely to have an extensive network of tunnels.
- Transit/Rail Station—Classes of access rail transit points in CAPTA. Length of platform, capacity, and building type can serve as common characteristics for a class.
- Mission Disruption—This concerns the adverse impact on the transportation system due to the loss of the functionality of an asset. Implying the redundancy of the road and rail networks, detour lengths to and from a disabled asset are used as a surrogate for mission disruption level. Detour length is readily available in current agency databases for bridges and tunnels. Transit facilities are assessed using ridership levels of an asset.
- Social/Cultural Disruption—The social consequence reflects how the population might respond to the event through significant behavioral changes. These may include fear of travel or avoidance of a transportation mode or route. Fear and avoidance of transportation modes will lead to a decrease of commercial activity. There may also be adverse reaction by the public to the imposition of security measures, such as personal searches, needed to prevent a disruption or mitigate the effects of a disruption.

Major Asset Categories

- Road Bridges—Any aerial structure designed to carry vehicular traffic across a body of water or land. This category is most effective when used to capture structures whose length spans greater than one beam.
- Road Tunnels—All tunnels bored, mined, or immersed that convey rubber tire vehicles, buses, and trucks.
- Transit/Rail Bridges—All raised aerial structures designed to carry rail rolling stock.
- Transit/Rail Tunnel—A transit system with a major rail capability is likely to have an extensive network of tunnels.
- Transit/Rail Station—Classes of access rail transit points in CAPTA. Length of platform, capacity, and building type can serve as common characteristics for a class.
- Administrative and Support Facilities—Fixed asset facilities a transportation operator may own or operate, with the exception of transit or rail stations. The fixed facilities in this category may range from offices of executives, to airside passenger terminals.
- Ferry—All watercraft used in the regulated transportation of passengers and vehicles for a scheduled service. The size of the vessel does not matter. In the rare cases where ferries constitute a significant portion of the transportation agency’s passenger capacity, an effort should be made to separate the vessels into classes.
- Fleet—Regularly used individual passenger vehicle. The most common assets in this category will be buses and passenger transit/rail cars. The base unit for this category is one asset, whereby a train may consist of four to six individual fleet cars. The similarities of fleet vehicles readily lend themselves to groupings into classes.

Threats (Intentional Actions)

- Small Explosive Devices—Explosive materials containing less than 250 pounds of TNT or equivalent. Delivery is by means of one to five aggressors transporting the payload.
- Large Explosive Devices—Explosive materials containing greater than 500 pounds of TNT or equivalent. The method of delivery is either by vehicle or through multiple persons acting in concert to transport the payload.
- Chemical/Biological/Radiological (C/B/R) agents—Gases, liquids, or solids introduced with the intent of causing physical harm or property loss.
- Criminal Acts—Lower intensity threats representing the range of illegal activities as defined by federal code, state statute, or local ordinance. Examples of criminal acts include handgun violence and illegal discharge of hazardous waste.

Unintentional Hazards

- Fire—Sources may be disparate and triggered by any combination of flammable material and ignition. Fire may result from happenstance and does not require an intentional act to occur. Fire, or the pre-fire hazard of smoke, will immediately have a negative impact on the transportation system.
upon all transportation assets by inducing the evacuation of persons and equipment within the structure and surrounding areas. Fire and smoke will decrease visibility to unsafe levels, precipitate collision of vehicles and equipment, and cause personal injury. A fire controlled by firefighting may still result in smoke and water damage at a level sufficient to render a transportation asset unfit for use or occupancy.

- **Structural Failure**—Any decrease in the physical integrity of the transportation asset to bear the weight required to carry passengers or freight. The loss of physical integrity requires the asset be inspected and major repair be completed prior to its reopening for beneficial use by the public.
- **Hazardous Materials (HAZMAT)**—Liquid, solid, or gaseous materials for which the quantity of material introduced may be minimal but that cause a hazard to users of the system. Hazardous materials include common industrial cleaners used by transportation workers and canisters of pepper spray set off by transit users. In both circumstances, it is unlikely that the maintenance worker or the commuter entered the transportation system with the intent of discharging material into the air. Materials may also include hazardous liquid, which include debris or waste products moved into the transportation system by a vehicle, truck, or rail car. For CAPTA purposes, hazardous materials require specialized remediation that will close a roadway or transit transportation to allow processing.

**Natural Hazards**

- **Flooding**—The condition of excessive water inflow to an asset exceeding the engineered pumping capacity, and causing a hazard or threat to people and property. Flooding is typically caused by a calamitous weather event; however, it may be caused by defective pipeline transfer.
- **Earthquake**—A seismic anomaly that weakens the fitness of a structure to standards less than that designed and intended by the owner. The earthquake will present a hazard to transportation users while it is occurring, due to flying debris and geotechnical instability. The earthquake may present a hazard upon its conclusion by weakening assets such that they are no longer usable.
- **Extreme Weather**—All means and methods of extreme wind, rainwater, snow, ice, or other act of God that is unusual for its ferocity. An extreme weather event will be characterized by the exhaustion of all available equipment previously assembled for remediation and the exceeding of all planning thresholds in place at a transportation agency for the conditions of snow, ice, wind, water, and other acts of God. This characteristic would normally include exceeding the “100-year storm” guidance gathered through observation.
- **Mud/Landslide**—The sudden massive movement of soil causing actual or potential harm to person and property, prompted by water or geotechnical shift. The most common historical data in this category involves soil shifts onto roadways or rail facilities because of wet conditions. (pp. 54 – 56)

<table>
<thead>
<tr>
<th>Potential Keywords</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transportation</td>
</tr>
<tr>
<td></td>
<td>Climate change</td>
</tr>
<tr>
<td></td>
<td>Europe</td>
</tr>
</tbody>
</table>
## Citation

## Website/Source
[www.planning.org/research/postdisaster](http://www.planning.org/research/postdisaster)

## Focus Area(s)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Document Type
Applied research study in report form

## Intended Audience
This document is aimed primarily at planning practitioners who are likely to engage in planning for post-disaster recovery. Secondary audiences would include city managers and policymakers, emergency managers, public works managers.

## Abstract
Planning for Post-Disaster Recovery: Next Generation outlines a broad approach to the challenges of post-disaster recovery. It first discusses the role of resilience in local government and their relationship to recovery planning. It provides a typology of recovery plans, both those developed pre-disaster and afterwards. The core of the report details the preparation of those plans, in terms of goals and policies, the planning process, and the implementation and financing. The report concludes with observations pertaining to the development of community vision and related big-picture aspects of recovery.

## Populations Referenced
Community residents, city or county staff, planners, elected officials, city managers and department heads.

## Topics Covered
- The role of resilience in local government
- The relationship of resilience to recovery planning
- Typology of recovery plans
- Federal framework for disaster recovery planning
- Scale and spectrum of disasters as factors in recovery planning
- Institutional learning after disasters
- Goals and policies for recovery plans
- Planning process for recovery plans
- Financing and implementation for recovery plans
- Metrics of recovery
- Community visioning in recovery

## Type of Sponsoring Agency or Organization
Federal Emergency Management Agency

## Geographic Distribution
- Most of this report focuses on planning in the context of local government, but it also addresses intergovernmental cooperation on a regional scale because most disasters are larger in scale than a single municipality.
- The report also discusses to some extent the role of state assistance with disaster recovery and provides national context as well. Larger disasters such as Hurricane Sandy obviously affect multistate regions and affect federal assistance at that level.

## Type of Transit Mode(s)
For the most part, the study does not specifically focus on transit, but on broader principles and practices related to disaster recovery. That said, it applies to almost all modes of transit, but mostly in the context of restoring and rebuilding such systems after disaster.

---

Copyright National Academy of Sciences. All rights reserved.
### Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

| Type of Vulnerability | This report in some way covers or relates to all natural hazards, most notably referencing in case studies and other text:  
| --- | ---  
|   | - Floods  
|   | - Hurricanes  
|   | - Earthquakes  
|   | - Wildfires  
|   | - Tornadoes  

| Goals and Motivations | The overarching goal for this study was to establish a modern, forward-looking framework for local planning for post-disaster recovery, with an eye to differentiating those things that can be done before disaster strikes from those that must await an assessment of the pattern and extent of damages suffered in a real event. The motivation was to move communities forward in their understanding of the value of such planning in an integrated context where recovery fits into, and has a clear relation to, the overall planning process of the community, including comprehensive planning.  
| --- | ---  

| Context | There is no specific context for transit in this report. There are broader principles of post-disaster recovery that can readily be adapted to transit planning as a particular planning function within the community or region, and for fitting transit recovery into the larger scheme of recovery planning.  
| --- | ---  

| Tools | One major tool provided is a Model Pre-Event Recovery Ordinance that is intended to establish a framework within local government for planning and guiding recovery. It provides a managerial framework and process for enabling quick movement on standing up a local recovery function to expedite recovery planning.  
| --- | ---  

| Noteworthy Aspects |  
| --- | ---  
|   | - Model recovery ordinance, as noted above  
|   | - Typology of recovery plans, which provides a straightforward analysis of the benefits and limitations of pre-planning versus recovery planning after the disaster  
|   | - Table and explanation of the scale and spectrum of damages and how this affects expectations for the type of recovery that the community must plan for  
|   | - Discussion of resources for financing recovery  

| Captivating Value | “When communities push the ‘reset’ button after a disaster, they need to do so thoughtfully but creatively, with an eye on the high price already paid for placing too much of the built environment in harm’s way. It is not enough—not nearly enough—merely to repeat the mistakes of the past.”  
| --- | ---  

| Decision Question | The big question facing most decision makers after reading this document is whether they are prepared to move their community forward with pre-disaster planning for recovery, and how they will use this to build local resilience.  
| --- | ---  

| Decision Maker | Primarily, this is aimed at local governments, but to some extent regional planning agencies that may be involved in coordinating recovery at a wider level. Secondarily, state and federal disaster recovery officials have influence on this process.  
| --- | ---  

| Relevance | While this document does not specifically focus on transit resilience, it provides some of the most advanced overall thinking on disaster recovery and its relationship to resilience that can be adapted into the transit context.  
| --- | ---  

| Status | N/A  
| --- | ---  

| Critical Assessment | N/A  
| --- | ---  

| Additional Comments | This document does not stand alone but is accompanied by substantial web-based resources developed by APA to assist planners with post-disaster recovery. These can all be found on the same web page as the document itself. These include a blog, the model ordinance, online case studies, and a database of federal disaster assistance resources.  
| --- | ---  

| Essential Vocabulary | While the document lacks a glossary, the model ordinance includes definitions that appear on pages 178-179.  
| --- | ---  

---

Copyright National Academy of Sciences. All rights reserved.
<table>
<thead>
<tr>
<th>Potential Keywords</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post-disaster recovery</td>
</tr>
<tr>
<td></td>
<td>Post-Disaster Redevelopment Plan (FL)</td>
</tr>
<tr>
<td></td>
<td>Pre-disaster recovery planning</td>
</tr>
<tr>
<td></td>
<td>Long-term recovery plan</td>
</tr>
<tr>
<td></td>
<td>Green infrastructure</td>
</tr>
<tr>
<td></td>
<td>Plan implementation</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source
ISSN 0097-8515

### Focus Area(s)
- Policy and Administrative Procedures
- Systems Planning
- Finance and Capital Programming; Capital Project Planning, Infrastructure Design, and Construction
- Asset Management
- Operations and Maintenance
- Emergency Preparedness, Response, and Recovery

### Document Type
Research

### Intended Audience
Practitioners

### Abstract
The paper outlines a series of issues surrounding the incorporation of climate change into transportation planning processes. Accepting climate change is occurring, the paper outlines a series of impacts to various regions of the United States while outlining the uncertainty the data provides. Diving into the concerns, it identifies approaches to risk management and the need for long-term planning as necessary but also maintains awareness of potential data uncertainty.

### Populations Referenced
N/A

### Topics Covered
- Outline briefly the impacts of climate change in generality.
- General issues planning for climate change (Data, risk management approaches, and adaptation strategies).

### Type of Sponsoring Agency or Organization
N/A

### Geographic Distribution
National

### Type of Transit Mode(s)
Transportation in general

### Type of Vulnerability
Sea-level rise, heat, storms, coastal storm, arctic warming

### Goals and Motivations
N/A

### Context
- The report identifies that climate change projections may be too broad on scale for applicability on the local level.
- The report identifies the uncertainty surrounding climate science.

### Tools
Provides adaptation process:
### Noteworthy Aspects
The research outlines New York’s risk and prioritization matrices as an example.

The research provides a brief list of adaptation strategies by climate indicator.

**TABLE 1 Illustrative Adaptation Measures for Transportation (3)**

<table>
<thead>
<tr>
<th>Adaptation Strategy</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea Level Rise</strong></td>
<td>• Protect infrastructure with dikes and levees.</td>
</tr>
<tr>
<td></td>
<td>• Elevate critical infrastructure.</td>
</tr>
<tr>
<td></td>
<td>• Abandon or move coastal transportation system.</td>
</tr>
<tr>
<td></td>
<td>• Reduce or eliminate development in coastal flood plans by providing local or federal incentives or by legislative mandate.</td>
</tr>
<tr>
<td></td>
<td>• Provide good evacuation routes and operational plans.</td>
</tr>
<tr>
<td><strong>Heat Waves</strong></td>
<td>• Research on new, heat-resistant or resilient materials.</td>
</tr>
<tr>
<td></td>
<td>• Replacement of bridge and highway expansion joints.</td>
</tr>
<tr>
<td></td>
<td>• Longer runways to account for lower lift-off capacities.</td>
</tr>
<tr>
<td></td>
<td>• Design changes to reduce stresses in rail lines.</td>
</tr>
<tr>
<td></td>
<td>• More nighttime construction to avoid undue heat stress for construction workers with the added benefit of less traffic disruption.</td>
</tr>
<tr>
<td><strong>Increased Storm Intensity</strong></td>
<td>• Revise Federal Emergency Management Agency flood plain maps which are badly out of date.</td>
</tr>
<tr>
<td></td>
<td>• Update hydrological storm frequency curves.</td>
</tr>
<tr>
<td></td>
<td>• Develop new design standards for hydraulic structures, e.g., culverts and drainage channels.</td>
</tr>
<tr>
<td></td>
<td>• Protect existing and vulnerable structures, e.g., bridge piers.</td>
</tr>
<tr>
<td></td>
<td>• Better land use planning in flood plains.</td>
</tr>
<tr>
<td></td>
<td>• Construction of storm retention basins for short, high intensity storms, i.e., flash flooding.</td>
</tr>
<tr>
<td><strong>Hurricane Intensity</strong></td>
<td>• Move critical infrastructure systems inland.</td>
</tr>
<tr>
<td></td>
<td>• Build or reconstruct more robust and resilient structures.</td>
</tr>
<tr>
<td></td>
<td>• Design for higher storm surges that progress further inland.</td>
</tr>
<tr>
<td></td>
<td>• Strengthen and elevate port and harbor facilities.</td>
</tr>
<tr>
<td></td>
<td>• Install surge barriers on vulnerable rivers.</td>
</tr>
<tr>
<td><strong>Arctic Warming</strong></td>
<td>• Identify areas with accelerated permafrost thawing.</td>
</tr>
<tr>
<td></td>
<td>• Develop new designs for constructing transportation systems on less stable soils.</td>
</tr>
<tr>
<td></td>
<td>• Dikes or levees to protect vulnerable coastal communities.</td>
</tr>
<tr>
<td></td>
<td>• Move at-risk coastal communities.</td>
</tr>
</tbody>
</table>

(p. 8)

### Captivating Value
There is value in the outline of the adaptation process whereas identification of co-benefits is called out.

### Decision Question
N/A
<table>
<thead>
<tr>
<th><strong>Decision Maker</strong></th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relevance</strong></td>
<td>Document highlights the need for long-term planning since infrastructure is designed for 50 to 100 years.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>The paper provides a good introduction to the topic of climate change and its impact to transportation.</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
<td>Adaptation, Adaptation Strategies, Climate Data, Risk</td>
</tr>
</tbody>
</table>
**Citation**

**Website/Source**
http://docs.trb.org/prp/15-1119.pdf

|-----------------------------------|--------------------------------------|------------------|-----------------------------------------------------------------------------------------------|------------------|-----------------------------|------------------------------------------------|

**Document Type**
Research paper. Summarizes and highlights results to make it more useful and understandable to practitioners.

**Intended Audience**
This document is targeted at transportation agencies who are working to become more resilient with respect to the effects of climate change. More specifically, the paper seeks to inform state and local DOTs as well as Metropolitan Planning Organizations (MPOs).

**Abstract**
“Transportation agencies are experiencing changes in extreme weather events, and will face increased climate and weather risks in the future, in the form of changing extreme precipitation, heat waves, sea-level rise, and other stressors. Transportation agencies are becoming increasingly aware of the need to plan for the impacts of these changes, yet have struggled with how to do so in the face of uncertainty and finite resources. For example, acquiring and processing locally-relevant climate information has proved challenging. Participants in the U.S. Department of Transportation (DOT) Gulf Coast Study, Phase 2 have been working to understand and address the challenges that transportation agencies face in increasing their resilience to climate change. This paper focuses on two tools developed under this study that each address a major challenge that transportation agencies face in adapting to climate change. The first, the CMIP Climate Data Processing Tool, provides an easy way to gather and process downscaled climate model data, and “translates” that data into information relevant to transportation engineers and planners. The second tool, the Vulnerability Assessment Scoring Tool (VAST), provides a framework for assessing vulnerability in a transparent, cost-effective way. These tools significantly advance the state of the practice for transportation agencies to respond to climate change impacts, and beta-versions have been used successfully by several state DOTs and Metropolitan Planning Organizations (MPOs). This paper presents information about these tools, examples of how they can be applied within transportation agencies, and areas for future research and development.”

**Populations Referenced**
The major stakeholders referenced in the document include planners, engineers, and administrators from state and local DOTs as well as Metropolitan Planning Organizations (MPOs). These would be the people and organizations who would apply this information. However, from an “end-user” perspective, the populations that would see benefits from this knowledge would include any road user or related-business involved in any transportation activity. Thus, the beneficiaries of this knowledge encompass a broad range of people and organizations.

**Topics Covered**
The goal of the study was to identify and address the challenges that transportation agencies face to increase their resilience to climate change. In the study Mobile, Alabama was used as a pilot city to develop and test methodologies for transportation agencies to identify their vulnerabilities to climate change and take action to address them. The study identified several challenges that transportation agencies face in this area.
In the paper, the focus was on two tools developed in the study that each address a major challenge that transportation agencies face in adapting to climate change. The first was the CMIP...
Climate Data Processing Tool. This tool was created to provide an easy way to gather and process downscaled climate model data, and “translate” that data into information relevant to transportation engineers and planners. The second tool was the Vulnerability Assessment Scoring Tool (VAST). This tool was created to provide a framework for assessing vulnerability in a “transparent, cost-effective way.” These tools are thought to significantly advance the state of the practice for transportation agencies to respond to climate change impacts. Beta-versions have been used “successfully” by several state DOTs and Metropolitan Planning Organizations (MPOs).

In addition to presenting information about the CMIP Climate Data Processing Tool and VAST, The paper also used examples of how they can be applied within transportation agencies, and areas for future research and development.

<table>
<thead>
<tr>
<th>Type of Sponsoring Agency or Organization</th>
<th>The sponsor of the original work was the United States Department of Transportation (USDOT), through its Gulf Coast Study, Phase 2 (GC2).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic Distribution</td>
<td>As the effort was focused on coastal hazards the results were most applicable to the US Gulf Coast. The study used Mobile, Alabama as a pilot city to develop and test methodologies for transportation agencies.</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>The tools and methods discussed in this paper are targeted broadly at transportation infrastructure and, in particular, the maintain accessibility and limiting damage/vulnerability of these systems. Modes are named as “asset types” and include roadways, bridges, ports, waterways, airports, rail, and transit assets. A notable area is road segments and networks. As such, transit is discussed as it would be a mode that utilized these networks. For example the paper mentioned “bus routes” along with truck freight modes on truck routes, mainly because these vehicle types would result in increased load levels and resulting damage to pavement structures.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>The vulnerabilities focused on in this work are climate change and sea-level rise related and focused on natural hazards. Specifically weather extremes like rising temperatures, extreme cold, high precipitation (snow/rain), surge flooding, erosion, landslides etc. and how these hazard threats lead to delays and longer-term disruptions and interruptions from closures and detours from damage and destroyed infrastructure in coastal areas.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The authors state that United States is experiencing changes in climate, in the form of higher average and extreme temperatures, changes in precipitation patterns, sea-level rise, and changes in extreme weather events. These changes are already occurring and are projected to continue or worsen in the future. Transportation agencies have a need to understand and respond to these changes, especially when they threaten the infrastructure investments and operational continuity on roads and waterways. This paper focuses on two these challenges to help agencies overcome them. These include:</td>
</tr>
<tr>
<td></td>
<td>• Translating climate projections into potential impacts on transportation systems, and using the information to inform engineering and planning decisions. Often, readily-available climate projections take the form of changes in average temperatures and precipitation amounts, which are informative but do not tie directly into transportation decisions.</td>
</tr>
<tr>
<td></td>
<td>• Assessing vulnerability in a transparent, cost-effective way. Agencies need ways to identify their most pressing vulnerabilities in order to prioritize resources for further analysis where needed or begin to adopt “no regrets” strategies to increase resilience.</td>
</tr>
<tr>
<td>Context</td>
<td>The context of this work is quite broad, but would include transportation agencies (including planners, engineers, and administrators from state and local DOTs and MPOs) in any coastal region. Obviously, the level of applicability would depend upon the specifics of the type and level of threat and corresponding vulnerability.</td>
</tr>
<tr>
<td>Tools</td>
<td>Two tools developed under the USDOT GC2 project both are described below and are available</td>
</tr>
</tbody>
</table>

- **CMIP Climate Data Processing Tool** - This tool is designed to allow users to access local level, practical climate projections. Its outputs are tailored to transportation decision makers, and addresses the need to access and interpret climate information necessary to understand how climate change may affect transportation systems. As an Excel-based tool, it is accessible to transportation agency staff. Derived variables from GC2 effort include temperature and precipitation variables calculated from climate model outputs of daily minimum temperature, maximum temperature, and precipitation. These variables are useful for conducting more detailed, engineering based vulnerability assessments, but the time and effort spent processing the climate information to derive those variables would likely be cost-prohibitive in most circumstances. The CMIP Climate Data Processing Tool is designed to provide those derived variables in a matter of hours. The information can then be used to inform transportation vulnerability assessments and resilience planning.

- **Vulnerability Assessment Scoring Tool (VAST)** - This is a resource to help transportation agencies address challenges associated with adapting to climate change—how to conduct a vulnerability assessment or otherwise narrow the field of possible areas to address. VAST provides a structured framework to help a user conduct an indicator-based vulnerability assessment or screen, whereby a user identifies characteristics of their assets or systems that could serve as indicators of their vulnerability. An indicator’s approach allows for a vulnerability assessment that leverages available data (or facilitates collection of data), and is transparent in its approach. VAST does not provide any “default” information about particular assets or their vulnerability, or even indicators to use. Rather, VAST provides a structured process and guidance to help a user conduct a vulnerability assessment on their own terms, and interpret their data to better understand vulnerabilities in their system.

The underlying framework of VAST is an indicator-based vulnerability assessment, which relies on two key premises. First, that vulnerability is a function of exposure, sensitivity, and adaptive capacity. Second, that characteristics of assets—such as their location, condition, or others—can serve as indicators of their exposure, sensitivity, and adaptive capacity. VAST is based in Excel and provides guidance that permit a user to derive a vulnerability “score” for a set of assets (which can be defined at any scale) based on these indicators.

<table>
<thead>
<tr>
<th>Noteworthy Aspects</th>
<th>This work is noteworthy in that it provides an objective, quantifiable, repeatable, and comparative basis on which to assess vulnerability conditions and use it to predict expected potential damage, losses, and outcomes. Compared to many other existing tools and techniques which can introduce more subjectivity and/or rely on more qualitative data and assessments, these tools have the potential to be useful to support or provide quantitative support/rational for financial investments and other decision making.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captivating Value</td>
<td>Although the work described in this paper would have value to a transportation agency in determining the level of and potential disruption from climate change-related coastal hazards, it is not clear how these would bring significant value to a transit agency in terms of being able to prepare for, respond to, or recover from disruptions in functionality. It is clear that if pavements are damaged and/or route segments are unusable and in need of repair, then such information could be useful to a transit agency from the standpoint of routing and scheduling. However, this would appear to be a secondary application of this information and not the primary intent of these tools.</td>
</tr>
<tr>
<td>Decision</td>
<td>None specified.</td>
</tr>
<tr>
<td><strong>Question</strong></td>
<td><strong>Decision Maker</strong></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td>The direct relevance of this information specifically to transit system agencies appears to be limited. As the tools and techniques are focused primarily on infrastructure design and planning they would not support transit system planning or operation directly. However, if used by related transportation agencies it would have potential to inform transit resilience planning in which, for example, agencies would be more aware of routes that are susceptible to flooding and pavement degradation. In broader sense, the outputs of the CMIP Climate Data Processing Tool can be used for climate model projections. As cited in an included example, they can be used to inform a vulnerability assessment, to determine whether the asset or system under study would be vulnerable to the potential changes. Users can compare variables against known thresholds to aid in vulnerability assessment especially in pavement designs. The projections can also be used to analyze asset vulnerability. While climate model projections are not meant to provide a single target for a design, they can provide a reasonable range of future values that can be used in sensitivity analyses that can aid decision making. VAST can help state DOTs, MPOs, and other transportation agencies—as well as agencies outside the transportation sphere—screen their assets or systems for which specific assets or general areas may be most vulnerable to climate change. This process can help identify areas for more detailed analysis or priority areas to apply strategies to increase resilience.</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>The source states that “beta-versions have been used successfully in several state DOTs and MPOs.”</td>
</tr>
<tr>
<td><strong>Critical Assessment</strong></td>
<td>Although it is stated that these tools and methods have been beta-tested with several agencies, no specific results were reported on in this source.</td>
</tr>
<tr>
<td><strong>Additional Comments</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Essential Vocabulary</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Potential Keywords</strong></td>
<td>Transportation Resilience Climate change Vulnerability assessment</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>Research Report</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Transportation practitioners, researchers, transit agencies</td>
</tr>
<tr>
<td>Abstract</td>
<td>“This report describes the results of a Transit Cooperative Research Program (TCRP) project related to achieving a state of good repair for transit assets, focused specifically on approaches for evaluating and prioritizing rehabilitation and replacement investments in existing capital assets. The research reviewed existing state of good repair practices in transit and other related industries.” (p. 1)</td>
</tr>
<tr>
<td></td>
<td>“Based on the review, an evaluation was performed of the impacts and implications of different investment levels for rehabilitation and replacement of transit assets. The evaluation summarizes the positive and negative impacts of rehabilitation and replacement investment decisions, and describes the performance measures used to quantify those impacts.” (p. 1)</td>
</tr>
<tr>
<td></td>
<td>The research developed “a framework for transit agencies to use for prioritization of capital asset rehabilitation and replacement decisions. This framework builds upon a set of fundamental concepts and provides a basic set of steps for transit agencies to follow when evaluating and prioritizing rehabilitation and replacement investments. An analytical approach and set of spreadsheet tools were also developed to support the framework. These tools address how to evaluate rehabilitation and replacement actions for specific types of transit assets, and how to prioritize candidate rehabilitation and replacement actions.” (p. 1)</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>TCRP Report 157 and the models will be a valuable resource for transit agencies and will be of interest to regional, state, and federal agencies that oversee, plan, or finance public transportation.</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>The report provides guidance on the development of a transit asset management plan to allow a transit agency to make investment decisions. The document provides:</td>
</tr>
<tr>
<td></td>
<td>• a review of existing practices in state of good repair analysis</td>
</tr>
<tr>
<td></td>
<td>• a discussion on the impacts and implications of different investment levels for rehabilitation and replacement of transit assets</td>
</tr>
<tr>
<td></td>
<td>• a framework for prioritization of capital asset rehabilitation and replacement decisions</td>
</tr>
<tr>
<td></td>
<td>• a set of tools and approaches for applying the framework to evaluate rehabilitation and replacement for specific types of transit assets.</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or</td>
<td>This Transit Cooperative Research Program was sponsored by the Federal Transit Administration</td>
</tr>
<tr>
<td>Organization</td>
<td>All of the United States</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Type of Transit Mode(s)</td>
<td>The report presents a framework for transit agencies to use for capital asset investment decisions and is intended for use by transit agencies of all sizes and modes.</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>The document does not speak to a specific vulnerability, rather the focus of the document is assessing asset condition to achieve a desired state of good repair (SGR) and provide a consistent level of service to passengers.</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>The purpose of this research was to provide assistance to transit agencies “to better prioritize their investments in existing capital assets and better communicate the predicted impacts of a given set of rehabilitation and replacement investments.” (p. 1) ‘To accomplish this purpose the research (1) developed a framework for public transportation organizations to use to prioritize rehabilitation and replacement of existing capital assets; and (2) identified methods for assessing the positive and negative consequences of varying investment levels on key indicators of public transportation service and performance.’ (p. 3 (not a direct quote but should be cited))</td>
</tr>
<tr>
<td>Context</td>
<td>“As transit agencies and other transportation organizations attempt to make the case for funds to rehabilitate or replace capital assets, they often encounter difficulty in effectively communicating the consequences of underinvestment, or conversely, the benefits of investing at a given level.” (p. 3) “Without adequate funds, U.S. transit operators could eventually suffer significant reductions in system reliability that result in restricted transit service.” (p. 3) This report provides transit agencies assistance to improve their analysis of state-of-good repair and provides:</td>
</tr>
<tr>
<td>Tools</td>
<td>The report provided a set of tools and approaches for applying the recommended framework to evaluate rehabilitation and replacement for specific types of transit assets. These tools employ an analytical approach for modeling vehicles and other asset types that deteriorate based on age or condition, as well as an approach for project prioritization. The tools are:</td>
</tr>
<tr>
<td></td>
<td>• “Prioritization Modeling Tool: this tool prioritizes a set of asset rehabilitation or replacement projects, and simulates the allocation of rehabilitation and replacement funds over a 10-year period.</td>
</tr>
<tr>
<td></td>
<td>• Vehicle Modeling Tool: this tool uses information on a bus or rail vehicle fleet to estimate the cost-minimizing point at which to replace a vehicle, as well as to predict the priority for replacing the vehicles in a fleet as a function of age.</td>
</tr>
<tr>
<td></td>
<td>• Age-Based Modeling Tool: this tool uses information on how an asset (other than a vehicle) deteriorates over time and the target replacement cycle for the asset to predict the annualized transit agency and user costs of the asset, as well as the priority of asset replacement as a function of age.</td>
</tr>
<tr>
<td></td>
<td>• Condition-Based Modeling Tool: this tool uses information on asset (other than a vehicle) deterioration to predict the annualized transit agency and user costs of the asset, the recommended replacement or rehabilitation action to perform on the asset depending on its condition, and the priority of each action. The modeling approach can be used for any asset that deteriorates as a function of condition.” (p. 47-48)</td>
</tr>
</tbody>
</table>
| | ‘Each of the tools provided in the report is implemented as a Microsoft Excel spreadsheet, all calculations are performed in constant dollars (inflation is in factored into the analysis) and built-
The report contained several noteworthy findings and observations, such as:

“The basic transportation and infrastructure asset management methodologies developed domestically and internationally, though largely developed to support managing highway assets (particularly pavements and bridges), are highly applicable to managing transit assets.” (p. 7)

- “The literature reviewed, particularly the AASHTO and NCHRP guides and reports, emphasizes that high-level investment decisions should encompass all asset and investment categories, consider trade-offs between different objectives during resource allocation, and balance competing needs given an organization’s policies, goals, and objectives. However, these guides and reports provide little information on how to prioritize investments given a limited budget allocation. In the case of highways, rehabilitation and replacement investments are prioritized within each asset/investment category, except for major projects.” (p. 7)

- “In the absence of a national consensus on the definition of a state of good repair, the de facto definition is that used by FTA for its reports to Congress on transit investment needs and incorporated in TERM. Based on TERM, an asset is in a state of good repair if its condition rating is 2.5 or greater.” (p. 8)

- “The most common measures for characterizing impacts of transit asset rehabilitation and replacement investments include: the cost of achieving a state of good repair or backlog of investment needs; several variants of asset age; and average asset condition based on the TERM five-point scale. These measures have the advantage of being readily derivable from available data, but provide little insight into customer impacts resulting from a given investment level.” (p. 10)

- “The approaches used for analyzing transit asset rehabilitation and replacement needs are predominantly age-based models that involve expected service life and age of an asset. These approaches do not provide any direct predictions of other measures of system performance and are of limited value in prioritizing investments when available funds are insufficient for addressing all identified needs.” (p. 18)

- “Analytical approaches used for highway assets may provide insights in the development of new and/or more sophisticated approaches for analysis of transit investments. In particular, the modeling approaches used for pavement and highway assets are well-developed and documented, and incorporate consideration of a wide variety of factors.” (p. 18)
replacement decisions. The report acknowledges that ultimately decisions concerning rehabilitation and replacement of transit assets are motivated by the goal of maintaining or improving performance. Therefore, performance measures are critical and the report recommends that performance measures be defined for all physical assets and that agency costs and user costs be calculated for all assets. The report recommends analyzing assets by utilizing both performance measures and asset condition in the development of rehabilitation and replacement alternatives.

The report identified gaps and/or areas for additional study, which include the need to better quantify the relationship between asset condition and user cost, to develop improved measure of sustainability and to relate investment levels to sustainability. There is also a recognition that transit agencies regularly must prioritize their investments, but little research has been performed to document how agencies prioritize and what constraints they face in the process.

<table>
<thead>
<tr>
<th>Additional Comments</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Vocabulary</td>
<td>The report contained the following definitions and terms:</td>
</tr>
<tr>
<td></td>
<td>• “Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives.” (p. 6)</td>
</tr>
<tr>
<td></td>
<td>• “State of good repair, in the absence of a national consensus the de facto definition is that used by FTA for its reports to Congress on transit investment needs and incorporated in TERM. Based on TERM, an asset is in a state of good repair if its condition rating is 2.5 or greater.” (p. 8)</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>State of good repair (SGR)</td>
</tr>
<tr>
<td></td>
<td>Capital assets</td>
</tr>
<tr>
<td></td>
<td>Prioritization</td>
</tr>
<tr>
<td></td>
<td>Rehabilitation</td>
</tr>
<tr>
<td></td>
<td>Asset management</td>
</tr>
<tr>
<td>Citation</td>
<td>Stamos, I., M. Evangelos, and J.M.S. Grau. 2015. Roadmaps for Adaptation Measures of Transportation to Climate Change. TRB 94th Annual Meeting Compendium of Papers (15-3752). Transportation Research Board of the National Academies, Washington, D.C.</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Website/Source</td>
<td><a href="http://amonline.trb.org/?qr=1">http://amonline.trb.org/?qr=1</a></td>
</tr>
<tr>
<td>Document Type</td>
<td>Report and Guidebook</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>• Researchers • Transportation agencies including road, rail, air and maritime</td>
</tr>
<tr>
<td>Abstract</td>
<td>No strangers to the phenomenon of climate change, transport-related authorities responsible for managing its impacts have lately turned their attention to exploring ways for addressing the increasing frequency and intensity of extreme weather events (EWE) and natural hazards (NH), often referred to as the “face of climate change”. In this quest for identifying optimal alternatives that will reduce the effects of climate change on human ecosystems, they find themselves presented with a series of options. Nonetheless, transportation authorities have no assurances that their choices will best deal with the challenges, therefore substantially contributing to the minimization of negative climate change impacts. Following a detailed literature review of both research efforts and actual case study experiences, this paper consolidates adaptation measures for road, rail, air and water transportation and relate them to the EWE and/or NH they mostly address. The review is concluded in the form of a measures and policies database, which is then evaluated through a series of performance indicators. These include the extent to which each measure contributes to the enhancement of the transport systems’ resilience, as well as the temporal and financial resources required for its implementation. The evaluation is conducted via an expert group survey, covering multiple sectors and disciplines (academia, research, industry, government). Findings are formulated in the form of roadmaps for climate change adaptation measures for the transport sector as they can serve as a useful tool and basis for an improved decision-making approach for different end-users to address climate change (p. 2).</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Road, rail, air and maritime transportation agencies</td>
</tr>
<tr>
<td>Topics Covered</td>
<td>• Introduction • Methods • Literature Review • Roadmaps Formulation • Conclusions</td>
</tr>
<tr>
<td>Type of Sponsoring Agency or Organization</td>
<td>Transportation Research Board of the National Academies</td>
</tr>
<tr>
<td>Geographic Distribution</td>
<td>United States</td>
</tr>
<tr>
<td>Type of Transit</td>
<td>Road, rail, air and maritime</td>
</tr>
<tr>
<td>Mode(s)</td>
<td>Extreme Weather Events and Natural Hazards</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Type of Vulnerability</td>
<td>Extreme Weather Events and Natural Hazards</td>
</tr>
<tr>
<td>Goals and Motivations</td>
<td>A quest to identify optional alternatives that will reduce the effects of climate change on human ecosystems, transportation authorities have not assurances that their choices will best deal with the challenges.</td>
</tr>
<tr>
<td>Context</td>
<td>This is an academic paper published as a compendium of papers from the Annual TRB conference. The study reviewed literature and conducted a survey with 62 participants representing research and academia and the business sector. The survey asked about four thematic areas, including: 1. Basic background information 2. Temporal dimension of adaptation measures 3. Financial dimension of adaptation measures 4. Contribution of each adaptation measure to the enhancement of the resilience of each examined transport system, including road, rail, air, inland waterway and maritime transportation</td>
</tr>
<tr>
<td>Tools</td>
<td>The authors used a multi-criteria analysis (MCA) after the experts’ assessment, concluding with the classification of all measure in the above areas according to their priority and the formulation of the transport mode roadmaps.</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>The tables presented for each mode (Tables 1 – 4) includes the following headings: organizational and decision-making processes, technical options, procedural and operational options, information flow and ICT support, decision and risk models, and legislative options.</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>The authors formulate roadmaps for each mode that include the start of implementation period, time needed for implementation, financial resources needed and contribution of measure to reduced vulnerability and enhanced resilience of the transport system.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>This papers allows for identifying and implementing measures of resilience across modes.</td>
</tr>
<tr>
<td>Decision maker</td>
<td>Transportation agencies</td>
</tr>
<tr>
<td>Relevance</td>
<td>The study shows climate change adaptation measures to alleviate the effects of extreme weather events, which can be linked to transportation resiliency to promote prevention.</td>
</tr>
<tr>
<td>Status</td>
<td>N/A</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>No assessment developed</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>Extreme weather events (ETE) Natural hazards (NH)</td>
</tr>
<tr>
<td>Potential Keywords</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Citation

### Website/Source
http://www.trb.org/Main/Blurbs/172317.aspx

### Focus Area(s)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

### Document Type
Staff interviews, case studies and web surveys

### Intended Audience
Government agencies

### Abstract
“This digest is to identify and recommend a set of best practices that agencies may employ in the emergency context in order to meet their legal responsibilities, respect public environmental objectives, and expedite the recovery process.” (p. 3)

### Populations Referenced
Transportation agencies

### Topics Covered
II. Applicable Legal Requirements for Environmental Review of Transportation Projects,
   A. Introduction and Overview,
   B. Generally Applicable Environmental Laws,
   C. Laws Protecting Particular Resources,
   D. Structuring Environmental Review: Agency Coordination and Public Participation,
   E. Emergency Provisions Applicable to Environmental Review of Transportation Projects,
III. Model Surveys of Governments at the Various Levels for Actions and Processes,
   A. Background on Agencies in the Environmental Compliance Process,
   B. Lead/Coordinating Agencies,
   C. Applicant Agencies,
   D. Resource Agencies and Entities,
   E. Summary of Case Studies,
   F. Web Survey,
IV. Identification of Techniques and Strategies to Expedite Recovery,
   A. Pre-Disaster,
   B. Post-Disaster,
   C. Miscellaneous Considerations,
   D. Conclusion

### Type of Sponsoring Agency or Organization
University of Missouri, Saint Louis University School of Law, TRB Council for Legal Research Projects, National Cooperative Highway Research Board

### Geographic Distribution
National

### Type of Transit Mode(s)
Highways and Bridges

### Type of Vulnerability
Pre/Post Disasters. Environmental Regulations
| Goals and Motivations | “One main purpose of this digest is to identify and recommend a set of best practices that agencies may employ in the emergency context in order to meet their legal responsibilities, respect public environmental objectives, and expedite the recovery process.” (p. 3) |
| Context | The existing transit and resilience planning process has the following traits:  
- Permitting process for transportation projects (mainly highways and bridges);  
- Relationships with state and federal agencies for the permitting process;  
- Use of GIS based systems to further the permit process. |
| Tools | Design-build contracting  
- Environmental stewardship  
- Public outreach  
- Interagency relationships |
| Noteworthy Aspects | Several best practices for expediting recovery while complying with existing environmental laws and regulations  
- Strong interagency relationships at both the working level and the executive level  
- The funding of environmental resource agency positions is one method of improving interagency coordination  
- Formal Pre-Existing Procedures Established with Other Agencies  
- Up to Date Inventories, Information, and Tools |
| Captivating Value | “The urgency felt by all parties involved in the emergency recovery process is one motivation for successful environmental compliance in the case of emergencies” (p. 71) |
| Decision Question | Permitting strategy |
| Decision Maker | Federal |
| Relevance | The most frequently used best practices. (p. 71)  
Pre-disaster:  
- Strong interagency relationships involving trust at both ground and management levels, and the fostering of such relationships on a regular basis;  
- Shared staffing between applicant and resource agencies for developing efficient interagency procedures and mutual understanding;  
- Development and maintenance of critical mass in staffing to provide continuity and consistency in knowledge, expertise, and interagency relationships;  
- Implementation and renewal of memoranda of agreement and programmatic agreements for streamlining emergency compliance; and  
- Utilization of technology for improving access and accuracy of environmental resources data required for planning and permitting.  
Post-disaster:  
- Limiting project scope to prior right-of-way, alignment, and capacity to meet NEPA categorical exclusion classification;  
- Adopting informal emergency review procedures stemming from interagency cooperation;  
- Employing alternative contracting mechanisms such as design-build that provide flexibility for environmental compliance; and  
- Fully utilizing emergency exemptions, waivers, and alternate procedures. |
<p>| Status | Stage of planning |
| Critical Assessment | Nice outline of the federal permitting regulations and procedures. More state coordination would be needed. |
| Additional Comments | N/A |
| Essential Vocabulary | N/A |</p>
<table>
<thead>
<tr>
<th>Keywords</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Disaster</td>
<td></td>
</tr>
<tr>
<td>Post-Disaster</td>
<td></td>
</tr>
<tr>
<td>NEPA</td>
<td></td>
</tr>
<tr>
<td>Interagency relationships</td>
<td></td>
</tr>
</tbody>
</table>
Citation | Webinar: U.S Department of Transportation. 2011. “Using Asset Management to Adapt to Weather Extremes: Lessons Learned from Transport for London.”


Document Type | Webinar slide deck.

Intended Audience | Transportation agencies and stakeholders

Abstract | Overview of the extreme weather impacts which have challenged London and the current management of extreme weather by London Underground. Primary focus was given to incorporation of addressing extreme climate events through the asset management system. The result of the study is future needs in planning and next steps.

Populations Referenced | Commuters and system users, interdependent stakeholders

Topics Covered | • Climate adaptation process including risk assessment methodology and extreme weather impacts to transit assets;  
• Review of an Asset Management Framework from the British Standards Institute (2008) and how LU has progressed in its implementation;  
• A number of resiliency strategies have been identified; and  
• Next steps at LfT to be sure weather is considered to include procedures to triggering consideration.

Type of Sponsoring Agency or Organization | Local government

Geographic Distribution | London, UK

Type of Transit Mode(s) | Bus, Rail, Light Rail,

Type of Vulnerability | Heat, Drought, Cold, Winter, Flooding, Ferry

Goals and Motivations | In reference to the report, the goals seem to be to address extreme weather through the asset management system keeping stakeholder expectations in mind.

Context | The TfL operates a bus and highway system which are dependent upon appropriate asset management. This includes stormwater management, maintenance, infrastructure inspections and more. Standards and requirements of London are an international example and may not have applicable correlation to US issues but require TfL to plan for climate change and report out on their activities in doing so.

Tools | LfT simply used a risk assessment spreadsheet outlining weather type, potential change, assets, descriptions consequence and others not visible in presentation. The slides did not provide anything useful for the report.
| Noteworthy Aspects | • Collaboration between agency and water infrastructure to establish co-beneficial solutions to highway flooding.  
• A number of adaptations have been deployed mostly based on infrastructure design and maintenance.  
• The slides outlined a number of asset management planning which incorporates extreme weather but it’s unclear from the slides if it has been implemented. It does detail planning horizons in the short, medium and long term (2014/15, 2020/21, and 40 years for long term). It further identifies the use of scenario planning along all three horizons.  
• The slides clearly states “Linking Asset Management, management of assets and climate extremes: note not climate change as such”. (Slide 48) It’s unclear exactly what this means and how it may vary from U.S. policies and current practices. |
|---|---|
| Captivating Value | • “Planning for ‘worst case’ is accepted design practice; keep pushing for these extremes  
• Building in resilience from initial design is the only viable way, remediating cases very hard  
• Marginally greater ‘resilience costs’ may not make simple bottom line business case, reputational damage may change this  
• The weather data to make the case exists, use it” (Slide 55)  
“Next Steps  
• Funding impact on long-term ability to manage impacts of climate change  
  o How do we measure the impact of climate change on TfL?  
  o What are the long-term issues of deferring work or engineering out adaptation works due to funding constraints?  
  o Increased costs due to lack of asset resilience?” (Slide 57) |
| Decision Question | N/A |
| Decision Maker | N/A |
| Relevance | Standards:  
• The materials identify the BSI Standards PAS 55. This outlines an approach to asset management and may be the equivalent to requirements in the U.S.  
• The UK Climate Change Act of 2008 requires agencies to report how they are planning for climate change.  
Integration gaps and issues:  
• It appears funding sources for long-term improvement seems to be an issue. |
| Status | TFL understands extreme weather need to be considered but finds itself trying to address the next steps many agencies are, such as funding impacts to addressing resiliency, increasing an understanding of knowledge (e.g. interdependencies) and establishing the best asset and business planning mechanisms. |
| Critical Assessment | The slide deck lends itself to assume the agency has been taking initial steps to address extreme weather and climate change through its asset management system but like many others encounters issues with funding for residency and pushing for expenses with long-term benefits. There is nothing unconventional with their approach and there seems to be an agency understanding of where weather impacts the systems. Data was collected and analyzed creating a risk assessment of assets. It continues to be an issue with prioritizing though an upgrade schedule for its assets has been established, due to the lack of information in the slides it’s unclear if gaps exist or not.  
Overall, it builds support for the FTA pilot projects around the country. It simply provides highlights to the “Providing Transport Services Resilient to Extreme Weather and Climate Change” report by Transport for London. |
| Additional | Value likely within the Transport for London Report. Linkages between asset management and |
| Comments | weather extremes are desired but it’s not clear if it has occurred or examples were simply listed. Concerns surrounding rail identified in presentation and no focus on climate change but extreme climate events. |
| Essential Vocabulary | The slides differentiates between climate change and climate extremes but there’s not enough detail to provide definitions. |
| Potential Keywords | Climate Change  
International  
Risk Assessment |
<p>| Citation | Barami Ph.D., Bahar. 2014.” Transportation System resilience, Extreme Weather and Climate Change: A Thought Leadership Series”. Final report, Office of Strategic Initiatives for Research and Innovation, Volpe. |
| Document Type | Report |
| Intended Audience | All |
| Abstract | “This report summarizes key findings from the Transportation System Resilience, Extreme Weather and Climate Change thought leadership series held at Volpe, the National Transportation Systems Center from fall 2013 to spring 2014.” (Report Documentation Page) |
| Populations Referenced | Transportation Infrastructure systems, Stakeholders |
| Type of Sponsoring Agency or Organization | U. S. Department of Transportation, John A Volpe National Transportation Systems Center |
| Geographic Distribution | National, NYC area |
| Type of Transit Mode(s) | All |</p>
<table>
<thead>
<tr>
<th>Type of Vulnerability</th>
<th>Climate change (air and water temperatures, sea levels and precipitation rates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals and Motivations</td>
<td>A framework for tackling transportation challenges arising from the escalating threats of our changing climate. This report summarizes the strategies and realities within this framework.</td>
</tr>
<tr>
<td>Context</td>
<td>Transportation Networks within the US DOT are limited by size and funding. However, despite the limitations, adaptation strategies remain in place that provide adaptation through re-zoning and ecosystem restoration.</td>
</tr>
<tr>
<td>Tools</td>
<td>“The NPCC Task Force recommended adaptation actions that ranged from incremental to large-scale strategies, with planning horizons that ranged from short-term projects of less than 5 years to long-term projects of over 15 years. Closely following the 5 facets of adaptation, the NPCC recommended an 8-step adaptation process: 1. Identify current and future climate hazards; 2. Conduct risk assessment and develop an inventory of built assets to identify vulnerabilities; 3. Characterize risks of climate change on built areas; 4. Develop an initial list of adaptation strategies; 5. Prioritize strategies and identify opportunities for coordination; 6. Link strategies to development cycles and prepare adaptation plans; 7. Implement adaptation plans; and 8. Monitor progress and reassess strategies.” (p. 23)</td>
</tr>
<tr>
<td>Noteworthy Aspects</td>
<td>“Planning for climate change-resilient infrastructure requires a coordinated process of assessing risks, formulating adaptation and mitigation strategies, and coordinating implementation.” (p. 32) The process of planning for climate change is closely associated with resilience planning in general, and adapting to and mitigating adverse consequences of climate change.</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>“Infrastructure resilience (see Figure 13) depicts resilience as an overarching concept linking infrastructure fault-tolerance and event-monitoring capabilities with elements of adaptation and mitigation of adverse consequences to ensure functional continuity.” (p. 32)</td>
</tr>
<tr>
<td>Decision Question</td>
<td>How should we combine adaptation actions with planning horizons in order to protect against climate and weather change? Should we adopt these strategies at all? No decisions have been made.</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>Federal, US DOT</td>
</tr>
<tr>
<td>Relevance</td>
<td>Included the following accepted practices:  • Make risk-based benefit-cost assessments at the right time using updated flood maps and flood vulnerabilities as a function of sea-level rise, while also accounting for changing physical and social asset configuration and vulnerabilities and optimal resiliency pathway is reached;  • Develop sea-level rise adaptation policies with public-private stakeholders and create land-use plans that balance the merits of temporary protection and medium-term protection, accommodating for sea-level rise, with long-term, sustainable retreat to safer neighborhoods;  • Incorporate climate change data and risk estimates for various time horizons into all strategic planning and capital decisions;  • Use each climate change and sea-level rise challenge as an opportunity for improvement and renewal of urban infrastructure. The costs for the NYC metro region will be upward of $100 billion—some $30 billion of which for the transportation sector alone—but not investing in these resilience measures would be more expensive by factors of 4 to 10 in post-disaster costs;  • Ensure robust planning for interim operational emergency and business continuity of operations. The following guidelines were provided:  • Short-term actions include updating flood maps, installing gates at subway entrances, and</td>
</tr>
</tbody>
</table>

Copyright National Academy of Sciences. All rights reserved.
draining flooded subways;
- Medium- and long-term actions include carbon pricing as well as new zoning and building codes, floodplain buyouts, analyzing hazard-related data to determine where it is safe to build or locate temporary facilities, or developing technologies that could be used to support mitigation strategies.

<table>
<thead>
<tr>
<th>Status</th>
<th>Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Assessment</td>
<td>The approaches presented herein are widely known and used, particularly in the NYC Metro region since Superstorm Sandy. A clear path forward and the next step for the planning process should be more clearly defined.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>Resiliency was not defined.</td>
</tr>
</tbody>
</table>
| Potential Keywords | Climate Change  
|                  | Resilience  
|                  | Mitigation  
|                  | Adaptation  
|                  | Transportation Planning  
<p>|                  | National Climate Assessment |</p>
<table>
<thead>
<tr>
<th>Citation</th>
<th>Victoria Transport Policy Institute (VTPI), Evaluating Transportation Resilience: Evaluating The Transportation System’s Ability To Accommodate Diverse, Variable and Unexpected Demands with Minimal Risk, Updated April 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website/Source</td>
<td><a href="http://www.vtpi.org/tdm/tdm88.htm">http://www.vtpi.org/tdm/tdm88.htm</a></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Document Type</td>
<td>Chapter in online Transportation Demand Management (TDM) Encyclopedia, which is a comprehensive resource concerning innovative transportation management strategies.</td>
</tr>
<tr>
<td>Intended Audience</td>
<td>Transportation planners and policy makers</td>
</tr>
<tr>
<td>Abstract</td>
<td>This chapter presents a method to evaluate transportation resilience and the role that TDM strategies can play in creating a more resilient transportation system. Resiliency is defined as “the system’s ability to provide its critical functions under variable, uncertain and extreme conditions.” (p.1) “Resiliency tends to increase if a system has diversity, redundancy, efficiency, autonomy and strength in its critical components.” (p. 2) The framework to evaluate resilience includes the identification of a system’s critical functions, its vulnerabilities, and ways to reduce vulnerabilities. Examples of TDM strategies that increase transportation system resilience are provided. “Contingency-based planning can be used to address uncertainty by deploying solutions or strategies on an as-needed basis.” (p. 5) The chapter also includes a bulleted list of best practices to increase transportation system resilience and security.</td>
</tr>
<tr>
<td>Populations Referenced</td>
<td>Best practices refer to people with special needs (physical disabilities, low incomes, inability to speak the local language, etc.)</td>
</tr>
</tbody>
</table>
| Topics Covered | • Principles of Resiliency (Foster, 1997)  
• Evaluating transportation system resiliency  
• TDM strategies to improve resilience  
• Best practices to increase resilience  
• Contingency-based planning  
• Case study summaries  
• FTA Transit Service Security and Emergency Response Advice |
| Type of Sponsoring Agency or Organization | Independent research organization |
| Geographic Distribution | N/A |
| Type of Transit Mode(s) | Transportation system; not mode-specific |
| Type of Vulnerability | General evaluation framework and planning process that applies to all types of vulnerabilities. |
| Goals and Motivations | Provide information about the role TDM strategies can play in creating a more resilient transportation system. |
| Context | TDM strategies aim at increasing transportation system efficiency, including reducing uncertainty |
and improving resiliency.

<table>
<thead>
<tr>
<th>Tools</th>
<th>Online encyclopedia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noteworthy Aspects</td>
<td>N/A</td>
</tr>
<tr>
<td>Captivating Value</td>
<td>Not possible to predict every possible future condition. Responsive or contingency-based planning refers to the idea that strategies are able to change over time.</td>
</tr>
<tr>
<td>Decision Question</td>
<td>N/A</td>
</tr>
<tr>
<td>Decision Maker</td>
<td>N/A</td>
</tr>
<tr>
<td>Relevance</td>
<td>The chapter outlines a framework for evaluating a system’s resiliency and identifying ways to improve its resiliency through TDM strategies. While the chapter concerns the evaluation of resiliency at levels that are not relevant to our purpose (e.g., individual level evaluation takes into account how the system handles temporary vehicle failure or loss of driving privileges), it also concerns the evaluation of resiliency at the community and regional levels, which includes the system’s capacity to absorb shocks from natural disasters.</td>
</tr>
<tr>
<td>Status</td>
<td>Complete; last updated April 1, 2014</td>
</tr>
<tr>
<td>Critical Assessment</td>
<td>Sound general principles but general approach may be of limited use for resiliency planning involving natural disasters.</td>
</tr>
<tr>
<td>Additional Comments</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential Vocabulary</td>
<td>Resiliency is defined as the “system’s ability to provide its critical functions under variable, uncertain and extreme conditions.” (p. 1)</td>
</tr>
</tbody>
</table>
| Potential Keywords | Resiliency Evaluation  
Contingency-based Planning  
TDM Strategies |
Hillsborough Area Regional Transit Authority (HART)

Case Study:
Tampa – St. Petersburg, FL

**Highlights:** Resilience efforts at HART are broadly and visibly supported by the agency’s CEO and CFO. The agency has chosen to use its sustainability and environmental management system processes to drive resilience planning and adoption. They are primarily focused on urban/street flooding, hurricanes and coastal storm surge. In this regard, HART has: adopted green infrastructure best management practices to mitigate flooding at parking lots, and other operational facilities; put in place standard operating procedures for temporary flood proofing and to move assets to higher ground when flooding is expected; and adopted an emergency operations plan and standard operating procedures to facilitate the safe, orderly and efficient shut down of services and rapid restoration of services after disaster. HART regularly partners with city government (Tampa and St. Petersburg); the Hillsborough MPO, University of South Florida, surrounding counties; Tampa Bay Area Regional Transportation Authority (TBARTA); other local governments to address stormwater management issues and emergency preparedness.

**Key Resiliency Drivers**
- Leadership
- Emphasis on sustainability and sustainability programs
- Local partnerships
- Disaster events, widely-shared unsafe driver event: water pouring in open door of a local bus, passengers raising feet, spurring further preparation and training for flooding events

**Key Successes**
- Consideration of flooding in alternate route planning, siting
- Development of an Environmental Management System, which the agency plans to use to address resilience needs henceforth
- High level integrated leadership of resilience action, financial side of the house, performance and analytics, external stakeholder involvement and ISO 14001
- Obtaining leadership backing to address resiliency throughout the organizational structure of not just HART but other agencies in the region as well
- Reassessing planned BRT routes prior to full development based on emerging precipitation trends to help relocate major investments from a newly-vulnerable alignments to more resilient ones

**Key Lessons Learned**
- Avoiding risk and undesirable media coverage through better training of drivers for action during flood events
- Coordination with city and others is needed to address areas of chronic flooding
• Temperature rise is already costing substantially more fuel (and emissions) for air conditioning

Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Gulf Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>Light rail transit, metro bus, and paratransit</td>
</tr>
<tr>
<td>System Size</td>
<td>Medium</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Heat, Precipitation, Urban Flooding, Coastal Flooding, Hurricanes and Tropical Storms – wind, Sea Level Rise, Waves, Storm Surge</td>
</tr>
</tbody>
</table>

The Tampa- St. Petersburg region has eight transit agencies. Two of these—the Hillsborough Area Regional Transit Authority (HART) and the Pinellas County “Suncoast” Transit system—have dedicated funding sources supporting capital and operations. HART has 825 employees and an annual budget of $83 million. HART is at the beginning stages of incorporating resilience into planning, but the agency has the advantage of senior staff support and leadership and mobilization of the structure offered by the agency’s Environmental Management System to achieve continuous improvement goals.

Policy and Administration

The Hillsborough-Tampa area is home to some of the most solid cost-benefit analyses performed by regional transportation planning agencies in the county. Transit agencies in the area are using these as a start point to their own resiliency work, which has been prompted by local area flooding, even in the absence of the hurricanes and storm surges that have plagued other Gulf Coast areas.

The Hillsborough Area Regional Transit Authority (HART) is an independent taxing authority, run by a charter and Board of Directors, with 13 members appointed from the various county jurisdictions, citizenry plus gubernatorial appointees.

The area has been free of hurricanes and tropical storms for a long while, but resilience has started to be a consideration for HART due to high temperatures and local flooding during heavy precipitation. Even some of the less severe flooding events have impacted operations and the agency’s ability to get to patrons. These have revealed some system inadequacies due to stormwater; some routes become impassable and HART has to reroute and bypass major connection hubs.

Last summer HART faced some of the worst flooding Tampa has seen in a decade, and some buses were flooded trying to get down normal routes. Maintenance bays flooded, and water poured over the baseboards of buses.

HART does not have a specific resiliency policy, plan or program in place yet, but the agency is working on the ability, in the case of service stoppage, to get back to the normal service levels or restructure the service levels for a short period of time until they can get to full service levels. The agency does not have a specific plan but it is beginning to engage issues related to resilience in capital programming, project design, operations and maintenance, and emergency preparedness. HART has initiatives underway related to sustainability, emergency preparedness, and asset management.

HART is particularly characterized by executive leadership commitment to transit system resiliency. The Chief Financial Officer (CFO) has taken it on as a self-imposed mission, seeing what others are doing
nationally and internationally. What started him and HART on this path was SEPTA’s work on resiliency, getting federal funds to raise some bridges and work on stormwater. Flood levels have been increasing over the last decade. The CFO’s office has been able to jumpstart resilience considerations through contract management, procurement, and the agency’s sustainability program, which this office leads.

As an executive, the CFO can reach out cross-functionally to get the resources he needs. He is also working on getting a project management office going. The CEO has been providing the opportunity with the CFO position to drive resiliency and sustainability initiatives throughout the organization. This support has enabled HART to avoid failure points they have observed at other agencies; i.e., the lack of ownership or leadership at higher level some agencies contend with when a middle management champion is responsible for the initiative. HART has more momentum they think. The CFO can say, “Do it!”

HART’s initial focus is regulatory compliance, using the agency’s EMS, but now HART is also reaching out to the entire region with eight other counties, around transportation resilience issues. HART has taken the MPO cost-benefit adaptation analysis results and is applying those to the transit system. The agency is getting a student from the University of South Florida Master’s Program in Sustainability to identify transit needs and applications and help develop emergency operations programs. HART is aware that many in the region rely on transit to attain health services or food; transit is vital for environmental, cultural, and social sustainability.

The most challenging impediment has been competing priorities; HART hasn’t been able to spend as much time moving resiliency forward regionally as the CFO would like. Commonality of purpose is also likely to be an issue. HART has certain catalysts and specific areas to address for resilience or mitigation. Also HART is an independent taxing authority, but all the other partner organizations except one are components of other larger organizations, which could be a sizable obstacle.

**Measurement and Reporting on Resilience-Related Efforts**

There has been no measurement and reporting on resilience-related efforts to date, but HART expects there will be in the future. The agency is tracking carbon emission reductions and has made progress in this area with transition to CNG vehicles. At this point HART has not conducted any weather, resilience, or stormwater or flooding-related measurement or reporting, but they anticipate doing so in the future.

With regard to communication with the public, policy makers, customers or others about the steps being taken to make transit infrastructure and services more resilient, HART’s primary connection to outside agencies is the Regional Transportation Authority TBARTA, which the state created to coordinate throughout region. The CFO serves as a Chairman of this authority’s Transit Management Committee and brings resiliency issues to that agency, for connectivity to other agencies in the region and he connects resiliency to the sustainability issues that HART is engaging. HART also uses press releases and has added an environmental component to the agency’s website. HART uses social media such as Twitter to communicate with the public when routes are compromised by flooding and need to be moved. With the larger public and a level of lack of acknowledgment of climate change on the state level, HART is trying to simply focus on the fact that the region is seeing more rain than it has in the past.
100 years and more people are taking transit than ever. Further, when it rains heavily, HART needs to be able to operate.

The agency has undertaken many efforts to ensure that maintenance and operations personnel have the information and training needed to incorporate resiliency considerations in their work responsibilities. The agency is also taking resiliency into consideration on an ad hoc basis as they address ADA compliance for bus stops. They are looking at which stops are consistently flooded and may need to change location. Resiliency training for bus drivers covers what not to do as well as what to do. Last year a HART driver was featured on multiple news channels and CNN after he tried to traverse an area that was flooded and too deep.

HART’s service planning department is currently the standout part of the agency in terms of resilience in terms of the re-routing that they do during flooding events. The service planning director comes from Baltimore and the Northeast where agencies she served had to deal with ice. HART is pretty nimble with re-routing and doing parallel routing during events. They have an application that tells riders estimated arrival times, departure times and delays for buses. HART also uses a text feed and Twitter; e.g., they can tell passengers to pick up the bus two blocks over, where they are providing service on a route out of the way of danger.

**Systems Planning**

HART has not mapped its assets and infrastructure in terms of vulnerability to natural disasters and weather-related events but the agency is considering areas of known vulnerability reported by maintenance and operations and is beginning to take this into consideration in decision making. HART also plans to utilize adaptation analyses performed by the MPO.

Transit system vulnerabilities and measures to address the vulnerabilities and the potential costs of implementing resiliency measures are just beginning to be communicated to agency decision makers. Performance monitoring hasn’t included an assessment of performance during extreme weather events but will in the future. HART has performed analysis of fuel impacts during heat waves and noted that air conditioning and fuel demand is substantially higher.

HART plans for back up routes during disruptions from flooding. No formal agreements are in place to ensure the provision of assets and/or services from sister agencies. The agency plans to evaluate what resiliency goals may be achievable and what makes sense (time for return to service) in the next year.

**Asset Management**

HART has an asset management plan that has been consolidated for the whole agency for the first time this past year. It does not yet include specific resiliency goals and policies. HART is in the process of inventoried vehicles, stations, and facilities. The agency knows the most about their equipment, such as the type of vehicle, CNG or diesel, any repairs that could release environmental hazards, and specifications for buses such as wheelbases and heights. They have also inventoried gig equipment within the garages, bays, and buildings, when they will need HVAC systems or new roofs and can the agency bring them up to higher hurricane force wind level? What will it take to get a facility up to a higher hurricane level? HART is also trying to minimize sign profiles so in high wind events they do not
have a very large sign flying into a neighborhood and the agency also has the cost of replacing the sign. HART stores their asset management information in Excel. The agency has not completed a transit infrastructure/asset vulnerability and risk assessment. Only vehicle condition/bus repair information is available. HART does track when air conditioning fails and also fuel consumption. Buses have to cool down before they go out into service. They recently had their hottest summer ever and the agency noticed it in fuel consumption. Buses were running longer and harder. Consumption was about 8.5% higher than last year with the same amount of miles and despite having a newer more fuel-efficient fleet. Employees help alert the agency to problem areas and are trained in what to do, if, for example, a bus breaks down near a stormwater drain or a route is too flooded to operate.

**Capital Planning, Programming and Finance**

HART has a capital investment strategy or plan and an item will receive extra consideration if it helps the organization become more resilient. The agency’s capital plan is updated annually and is informed by asset management, centered on buses, showing when they are coming to the end of their useful life. The agency uses a 10-year time horizon.

In the past there was no real assessment of buildings but now the agency is beginning to have centralized consideration of total capital needs. In the future there will be resiliency performance measures. All project requests will have a check block on whether the project addresses resiliency.

The agency’s first priority is its vehicles and keeping service on the streets (unless there is a security or safety issue). As part of the facilities assessment, HART considers safety of patrons and employees. They plan to prioritize facilities based on what their inventory shows.

If an area is critical, such as a transit center, it can rise to a higher priority. Probability and magnitude of climate or extreme weather impacts are not considered as such, yet. The agency has considered what they would do if certain infrastructure were taken out of service; e.g., if a certain facility is deemed uninhabitable, working with risk and safety, what they would do in case of asbestos or mold.

HART conducts CBA for new projects but that does not include resiliency inputs yet. In weighing long-term benefits against short-term costs, the agency considers quantitative and non-quantitative information. The agency considers long-term savings and also political capital, what will, over time, buy credibility or public support and what will move the agency forward. The CFO deals with uncertainty, including in the context of vulnerabilities to changing climate conditions, by adding a 15% contingency to every CBA. The normal overrun is between 11-15%.

HART is in the process of getting buy-in from local government about stormwater management issues. They want to bring the business case back to them, to go after federal or state dollars, because the flooding affects all agencies and residents.

As of last summer managers are asked to keep track of whether certain categories of expenses are related to flooding. Cost centers highlight or flag what they would consider weather related now. Previously, costs were only tracked as “weather-related” in declared emergency weather events.

HART is self-insured. The agency has stop loss and also a board-mandated financial reserve to mitigate any type of event. They have three months of operating expenses set aside in case of emergency.
Design standards have not been updated to address changing requirements and needs, such as more intense precipitation events and temperature extremes, but the agency does have specific design standards for winds and hurricanes: Level 3.

The agency does not require the use of resilient materials in rehabilitation, reconstruction and new construction projects vulnerable to natural disasters, extreme weather and/or climate risks. Life-cycle costs outside of equipment are considered informally. HART did consider new types of materials on facilities to reflect heat. “The garages are getting so hot in the summer now we are looking for what we can do.”

In the past couple years the agency has begun considering the location of new facilities and equipment and potential risks associated with natural disasters, extreme weather and climate change. The agency no longer considers that because a stop is in a certain place it has to stay there. Flooding considerations and the changing situation in that regard, with rider and operator safety and keeping lines operational, are paramount. No program to elevate infrastructure above future flood levels and install flood proofing, levees, sea walls, and dikes is in place.

Drainage improvements are underway with the operations facility. HART is doing a stormwater assessment now and attempting to mitigate parking lot flooding. HART is also working with Tampa on basins downstream. HART is using green infrastructure solutions to reduce stormwater runoff and mitigate localized flooding for their operations facility.

Two years ago a reassessment study was conducted on multiple BRT routes; HART found that one route was much more vulnerable to precipitation flooding than when the study was first done, six years previous to that. It had changed that much in six years; that route is subject to major flooding, which really altered ability to service that area, according to HART staff, which also note that aged infrastructure is part of the challenge.

**Operations and Maintenance**

HART has plans/standard operating procedures in place to temporarily harden infrastructure (e.g., deploy sandbags and other flood proofing) and protect assets (relocate vehicles and other moveable equipment) when extreme weather and/or a natural disaster are anticipated. The agency also has booms for environmental hazards and stormwater. They relocate vehicles to a lot owned by the school board during flooding events. Also based on wind, if they have to move buses out of the facility the buses can be moved to a designated place further east.

HART has contingency plans and/or standard operating procedures that allow agency decision makers to quickly implement re-routing and/or substitute services in the event of disruption as well as redundant communication systems in place to communicate with front-line workers and field managers in the event of disruption; e.g., alternative megahertz, radio and cellular devices. The buses also have onboard GPS.

HART provides redundant power to key facilities and infrastructure to limit disruptions and facilitate rapid return to service after a disaster by having multiple generators at facilities.
The agency communicates and shares information with customers to manage expectations and ridership demand during times of disaster or major service disruption online and through social media. HART also uses regular maintenance and inspection activities to monitor the condition of potentially vulnerable infrastructure and assets as well as routes; though their formal processes are around buses and preventative maintenance they do collect informal information from staff on route and facility flooding.

HART is employing enhanced maintenance and inspections procedures to ensure the proper functioning of fixed infrastructure. They have culverts and ditches that are not being routinely maintained and now the environmental program has taken this over to ensure that they are being maintained.

Front-line operations and maintenance staff and managers provide information regarding system performance during extreme weather and emergency events to help inform resiliency decisions. They are the eyes and ears of the agency during an event, with regard to how flooded an area is and what HART can do or what needs to be done. “They know what is going to flood.”

Heat is a consideration too. HART has a new maintenance director and they have talked about a pilot doing a comparative analysis of dynamics of drive train systems affected by heat, not just heat generated but ambient heat generated from outside. They would like to couple that with the fuel consumption issue.

Emergency Preparedness

HART has an emergency management and operations plan (EMP/EOP). Heat and precipitation flooding have not been addressed yet, just hurricanes. The Safety and Security office is responsible for developing the EMP/EOP. All departments/divisions play a role in the agency’s emergency management planning process, which is now consistent with the Federal Government’s National Incident Management System and National Response Framework and coordinated with emergency response plans in place at the state and local levels. The plan addresses emergency transportation operations such as evacuation of critical transportation needs populations before, during and after an event on a regional basis, for Hillsborough County. HART has an agreement with the beach communities to help as long as the winds don’t get to a certain level.

HART coordinates regularly with state and local emergency managers and agencies. The agency has a Continuity of Operations Plan addressing all modes and departments. It identifies essential management, operations and maintenance personnel, with a clear line of succession for management decision making. It identifies an alternate location from which to manage transit system operations and/or maintenance if primary operation and maintenance centers are damaged/destroyed. The agency has contingency plans in place to direct the safe, orderly, and efficient shut down of services in the event of a disaster or weather-related event as well as a disaster recovery plan in place to ensure rapid restoration of services after an emergency event or disaster, consistent with the Federal Government’s National Recovery Framework and coordinated with plans in place at the state and local levels. The routes that need to come online first guide service restoration priorities. The agency has a financial contingency plan but does not have plans to borrow equipment or for mutual aid. Contingency plans for refueling vehicles have been established, in case infrastructure is damaged or destroyed.
These plans include mutual aid or other agreements to ensure that refueling capability is available when needed.

HART has used tabletop exercises to train personnel regarding the protocols and procedures included in the EMP/EOP, COOP and/or other contingency plans. The agency has conducted drills for evacuation only and environmental disasters/spills.

HART does not use any kind of forecasting or modeling to anticipate extreme weather or other events. They utilize weather forecasts or anything from state or regional agencies to make plans. HART is engaged in state and local hazard mitigation planning efforts. The agency also has accounting procedures designed to account for severe weather impacts so that they can be entered effectively for insurance, FEMA, FTA and state program reimbursements by being self-insured. The agency uses FEMA forms to ensure their claims will be accepted.

No major natural disaster or weather-related event that required significant response operations and recovery has occurred for many years; however, 2015’s heat and precipitation events were the catalyst for trainings for operators. HART says they have yet to discover what they do not know, regionally.

References

1. Seward, Jeffrey. Interview by author. Chief Financial Officer, Hillsborough Area Regional Transit Authority.

2. The National Transit Database. 2013. Transit Profile.
Hillsborough Area Regional Transit Authority (HART)

Case Study:
Honolulu, HI

Highlights: The Honolulu Department of Transportation Services (DTS) is a part of municipal government. The Department pursues “resilience” as part of preparedness, response, recovery, and mitigation, in particular in the context of flooding, hurricanes and tsunamis. The agency’s focus on emergency preparedness stems from a threat and hazard assessment completed using FEMA’s Threat and Hazard Identification and Risk Assessment (THIRA) Guide. DTS has mapped its critical infrastructure and assets in terms of vulnerability to hurricanes and storm surge and has standard operating procedures in place to ensure assets are protected when severe weather is forecast. In addition, the agency’s infrastructure design standards require the use of resilient materials in all of its rehabilitation, reconstruction, and new construction projects that are vulnerable to extreme weather.

Key Resiliency Drivers:
- State, County and City Legislation;
- Hurricanes and Tsunamis.

Key Successes
- Building a culture of response and preparedness within all governmental and private-sector agencies under the direction of the DEM.

Key Lessons Learned
- The Department of Transportation Services (DTS) does not set policy decisions in regards to resiliency type initiatives. This is done by the DEM.
- Coordination between governmental agencies and the private sector is critical when responding to a disaster.
- Consultant agencies are hired by DTS for implementing infrastructure projects.

Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Pacific Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>Metro Bus</td>
</tr>
<tr>
<td>Vehicles Operated (all modes)(2011)</td>
<td>519</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2012-2013)</td>
<td>75.5 million</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Wildfires, High Winds/Lightning, Hurricanes/Tropical Storms, Flooding, Storm Surges or Wave Action, Tsunami, Volcanoes, Sea Level Rise</td>
</tr>
</tbody>
</table>
Policy and Administration

The Honolulu Department of Transportation Services (DTS) is a part of the municipal government. It consists of four divisions: Public Transit, Traffic Engineering, Traffic Safety and Technology, and Transportation Planning (2). The Public Transit Division (PTD) plans, manages, and maintains the city's public transit systems, facilities, and equipment. Public transportation within DTS consists of TheBus and TheHandi-Van (paratransit) and is operated by Oahu Transit Services, Inc., a private, not-for-profit management firm under contract with DTS (3). DTS policy decisions and spending priorities must be approved by the City Council.

In regards to resiliency type initiatives, DEM sets the policy decisions. However, resilience is a term not used by DEM; instead, they use a framework that includes preparedness, response, recovery, and mitigation when setting plans or policies. DTS has a seat at the Emergency Operations Center (EOC) and is a support agency within the Emergency Operations Plan (EOP).

DTS works closely with all governmental agencies in responding to and preparing for natural disasters and provides support at the direction of DEM. DEM activates the EOC when a disaster strikes and becomes the lead agency.

Every department within the agency has an emergency coordinator that is responsible for making sure resiliency-type measures are implemented when a disaster strikes. DEM provides training classes for each agency and has monthly meetings pertaining to lessons learned, best practices, and after-action and collective-action sessions, highlighting what agencies did right and wrong. DTS also hosts FEMA for training sessions and works closely with the state civil defense agency.

To communicate with the public, policy makers, and customers about steps being taken to make transit infrastructure more resilient (this term is not used) in the face of natural disaster and/or weather-related events, the agency utilizes its website. Customers can also download an application called Nixle, which gives updated weather reports, relevant information regarding public safety, emergency notifications, etc. When the EOC is activated, DTS partners with local organizations such as the Red Cross, NGO's, one electric utility, city departments, other utilities, and the Local Emergency Planning Committee, to effectively plan for an emergency.

Systems Planning

The agency, in cooperation with DEM and the U.S. Department of Homeland Security (DHS), completed a threat and hazard identification risk assessment (THIRA) for assets at risk of being impacted by extreme weather, natural disasters, and/or climate change (although the term is not used). Hurricanes and tsunamis were identified as the largest threats to critical infrastructure, which includes: (1) two bus facilities in Kalihi and Pearl City; (2) all of the agency's rolling stock; (3) bus facilities where vehicles are repaired and maintained; (4) fuel tanks; (5) central control; and (6) radio communication within the rolling stock. These assets and infrastructure have been mapped in terms of vulnerability from hurricanes and tsunamis by the agency's GIS Department.
Project Development, Infrastructure Design, and Construction

DTS solicits consultants to develop and regularly update infrastructure design standards to address changing requirements. However, it is incumbent on the consultant to follow whatever structural building requirements are used. For example, hurricane clips are required as part of the building code and must be addressed by the hired consultant.

DTS also requires the use of resilient materials in rehabilitation, reconstruction, and new construction projects that are vulnerable to extreme weather, especially hurricanes and tsunamis. For instance, when purchasing material for infrastructure, a project information form that includes life cycle and maintenance must be completed and justified. This is the first step if a project is to be approved. However, during the project development process as part of the environmental review, the agency hires a consultant and does not require them to consider resiliency and/or climate change. DTS does however, have a program in place to elevate infrastructure, if flood designation requires it, above future flood levels and install flood-proofing measures such as levees, sea walls, and dikes to protect critical infrastructure.

Operations and Maintenance

When extreme weather or natural disasters are anticipated, the agency has a program in place to relocate its vehicle stock that sits within the inundation zone. The agency also has a standard operating procedure in place with local police and first responders to quickly implement the re-routing of vehicles in the event of a disruption.

Work is also in progress on a communications system that will communicate with front-line workers and field managers in case of a disruption. The agency has recently constructed its main central control center and is currently working on redundant central control centers at other bus facilities as funding becomes available.

In case of a major service disruption, DTS has back up generators and a communications plan in place. For example, if the EOC was activated, information would be placed on the DTS website and Nixle, and the Mayor would send out a press release highlighting the disruption. Also, in the case of a hurricane or tsunami, a siren system is in place. Work is also underway for new sirens that will be strategically located throughout transit stations. In anticipation of a hurricane, DTS has maintenance people who will clear culverts at all transportation facilities that may be affected.

Emergency Preparedness

DTS is a part of an EOP that is in place that addresses most weather-related and human-made hazards, specifically, hurricanes, tsunamis, terrorism, and flooding. The Emergency Management Department is responsible for developing and maintaining the EOP for DTS. Under emergency conditions, as part of the EOP, DTS is responsible for a number of conditions that include: 1) the coordination of all forms of ground transportation, which includes DTS’s contract with TheBus and TheHandi-Van services operator, motorcycle clubs, taxis, tour bus companies, and other private agencies; 2) the city’s point of contact with the Hawaii Transportation Association transportation assets; and 3) provide support for the city’s mass care and evacuation operations (1).
The City and County of Honolulu EOP is also consistent with the Federal Government’s National Incident Management System and National Response Framework. Within this framework, when a state or federal Civil Defense Emergency is declared, it is the role of DTS to coordinate the city's requirements with Emergency Support Function #1, Transportation, of the State and/or National Response Plan, the State Department of Transportation, and State Emergency Response Team (SERT), as required.

References


Idaho Valley Regional Transit (VRT)

Case Study:
Boise City, ID

**Highlights:** VRT, a small regional public transportation authority operating in Ada (Boise City) and Canyon counties in Idaho, takes a very practical approach to resilience planning and adoption. Grounded in concepts of sustainability, asset management, and emergency preparedness, VRT focuses on “event readiness” and restoring service as quickly as possible after an event. The primary threats facing the agency include high heat and flash flooding from severe storms and stream flooding from rapid snowmelt. VRT incorporates basic vulnerability and risk assessment approaches, as part of its service planning, ensuring its assets remain in a state of good repair for as long as possible.

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modes Operated</strong></td>
<td>Bus, demand response, oversees two private transit services</td>
</tr>
<tr>
<td><strong>Vehicles Operated [all modes] (2014)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Annual Boardings (2014)</strong></td>
<td>Bus: 1,428,551 passenger trips, Demand Response: 181,000 passenger trips</td>
</tr>
<tr>
<td><strong>Typical Hazards</strong></td>
<td>High heat, wind, occasional flooding, cold</td>
</tr>
</tbody>
</table>

**Background:** Valley Regional Transit (VRT) is a small regional public transportation authority for Ada (Boise City is in Ada county) and Canyon counties, but it is the largest transit system in Idaho. VRT was created by a ballot initiative in 1998. VRT is managed by an Executive Director who reports to a 28-member board of directors.

VRT provides transit service to:

- Metropolitan Boise, Idaho with nineteen routes operate in Ada, County;
- Six-day-per-week service to Boise and its immediate suburbs;
- Five local and one flex routes servicing Canyon County that run Monday – Friday;
- Five inter-county commuter lines that run Monday - Friday;
  - Both a peak hour express route and an all-day limited-stop version of the same route connect Nampa and Meridian;
  - Boise State University connectivity with the College of Western Idaho in Nampa; and,
  - Two limited express service of one roundtrip each; one connects Caldwell and Boise and the other links Boise with the small towns of Star and Middleton.

VRT is directly responsible for:

- Overseeing the management of Valley Ride transit services in Treasure Valley, which is coordinating transit services in two counties managed by two private firms that are responsible for the daily operations of fixed route services in inter-county services and one shuttle (serves the College of Western Idaho), and one dial-a-ride service.
VRT’s vision is a region with adequate and secure funding to support public transportation options designed to meet the needs of citizens and businesses and to support livable, healthy, and sustainable communities. Its organizational mission is to develop and manage transportation resources and to coordinate the effective and efficient delivery of safe transportation options to the region’s citizens.

Boise is considered a high desert area and its location shields it from most extreme weather patterns found in other states and regions in the United States. High heat, occasional flooding, strong winds, cold temperatures are the expected weather events for the communities. Therefore, VRT has not experienced a major disaster related to a natural or weather event to date.

Consequently, VRT has not done severe weather planning. The agency’s approach to severe weather is very practical: planners and operators know what roads are likely to occasionally flood and reroute the bus trips until the road is clear. Snow events of 10 inches or more are a rarity. VRT and its communities just close down when such a blizzard events occurs. Currently, emergency management governance is managed by the Executive Director, Director of Operations and the Chairperson of the Board. VRT works with the emergency management agencies in the area.

The FTA’s effort on resiliency for transit properties to extreme weather and the TCRP effort have prompted VRT to consider resiliency as a concept and planning in response to severe weather events. Sustainability has been the agency’s major approach to VRT’s emerging asset management program.

The transit asset management program suggested by the FTA has VRT developing a regional policy and program for VRT and other public transportation providers in the two-county region. VRT is prompted by financial issues that require maximizing the useful life of investments. The agency does some risk analyses and vulnerability assessments with respect to sustainability of the system, and in terms of planning for new services in the communities served. However, these analyses are more focused on financial issues and ridership.

VRT is interested in learning about other transit efforts to be considered in future planning and service efforts, and how that may help them to be better prepared for severe weather planning.

**VRT’s Severe Weather-Related Conditions**

VRT’s service area experiences occasional heavy rains, flash floods, flooding (foothill run off and snow melt,) extreme heat, high winds, extreme cold and snow/ice, lightning, winter storms, and wildfires/dense smoke. Its natural disaster related conditions: occasional small earthquakes.

**Recent climate-related events:**

- 2015 saw record heat waves exceeding historical records for example Boise’ June 2015 temperatures topped 106 degrees on a Saturday, breaking the previous record of 104, set in 1892, and on that Sunday, the 110 degree temperature broke the previous record of 102, set in 2010.
- Severe thunderstorms in the foothills can result in flash flooding and mud slides. The peak season for thunderstorms are June - September.
• High runoff can occur from the foothills from rapid snowmelt, especially when warm rain falls on existing snow pack. In these situations, flow rates may not rise rapidly but may last for several days or weeks.
• Only twelve (12) tornadoes have been documented within the county and city. Most days of snowfall in Boise leaves just a skiff, amounting to less than an inch of fresh snow on the ground. For seven days a year on average, the amount of new snow totals at least an inch. (The area can get 3-4 inches of snow in a single setting, but that is usually just once per season, if at all.)
• Heavy snowstorms are uncommon for Boise. Snowstorms of over five inches a day normally don't occur most years. Major blizzards that dump ten inches or more in one day do not typically occur.

Consequences of severe weather events 2010-2015 included no service cancelations, but some rerouting due to possible snow storms.

VRT is working toward building a culture to be event-ready and sustainable. This includes training, building on and celebrating success, development of plans and policies designed to be implemented to sustainability. VRT in a limited and requested way is working with various public partners in planning, funding, operations and communications to ensure each player understands their role and function and to understand how each fit together and affect others. The agency is continuously engages front-line employees, and part of the employee training has included weather events. The “resiliency” piece is called sustainability and is part of asset management.

Policy and Administration

VRT is committed to providing safe mobility to its customers and the community. Its policy on sustainability and its pursuit of asset management are intended to meet the commitment. The asset management program is based on life cycle to achieve the maximum useful life of the investments; and VRT planners are identifying processes and areas of vulnerability to achieve equipment maximum useful life.

VRT uses social media tools, television announcements, public presentations, and radio to inform their customers and the public of VRT events, services, and changes to services. These tools would be used in the event of severe weather emergency and changes to services.

Systems Planning

Both asset management and the sustainability units in conjunction with operations look at system planning to assess what is working and what needs for analyses exist for employees and equipment. VRT does not use any metric to measure weather vulnerabilities, other than how fast can service be restored and event readiness. Given VRT’s oversight responsibilities of the two private transit providers, the agency does undertake a full transit system plan and analyses for the Boise region.

Asset Management

VRT is beginning its asset management program and it is following APTA’s definition. VRT is just beginning to assess its State of Good Repair (SGR) costs.
The asset management program involves at least three elements:

- Vehicle and infrastructure maintenance management system with inventories, conditions and life cycle and maintenance management;
- SGR database, which includes a capital asset inventory and investment priorities; and,
- Asset management planning that includes policies on how assets are to be maintained through the assets’ life cycle.

VRT is developing a full inventory system that is based, in part, on conversations with front-line staff and divisions on critical asset areas. There are plans for the asset management system to identify vulnerabilities and risks.

**Capital Planning, Programming and Finance**

VRT receives no state revenues. For local revenue, VRT is dependent upon the voluntary annual contributions of the communities they serve. The majority of VRT’s funding is from the Federal Government, followed by local grants and transit generated revenues. The local match is intended to match the federal funds and cover most of VRT’s operating costs.

The federal funding for VRT and its other services is a bit complicated and accounts for some of the elements of transit services being somewhat fractured:

- Preventative maintenance budget for Boise and Canyon County is 80 percent federal to 20 percent local match;
- VRT operating budget is 100 percent local for the large urban area, because Boise is too large a city to receive any federal operating assistance;
- In contrast, Nampa receives federal funds up to 50% with a 50% local match for operations.

VRT does have a capital investment strategy within its 5-, 10- and 20-year plans. Those strategies will be altered or updated once VRT has a fully functional asset management program; full assessment of its state of good repair backlog; and, a financial analysis on what level of investment would be required to address the emerging SGR projects over the next 20 years. VRT works with the MPO on the capital program and multiyear transportation plans.

Funding for VRT, as with all transit agencies is limited and requires a commitment to target resources to high priorities. Both VRT’s 5-year and 20-year plans have critical projects and investments to provide for VRT’s future. Resiliency was not incorporated into the plans, but sustainability assessment and programs from which projects or systems are prioritized use FTA’ sustainability guidance. VRT does not conduct cost-benefit analyses for new projects.

**Project Development, Infrastructure Design and Construction**

Within the asset management and sustainability framework, using common sense and in conversations with its staff, VRT regularly reviews its needs and equipment.
Operations and Maintenance (O&M)

With respect to questions 1 and 2 (agency having plans to harden infrastructure, like sand bags, and contingency plans to allow for re-routing) the answer is yes. Question 5 (sharing information with customers) is also yes, VRT uses the available communication tools (social media, press releases to TV and radio outlets, text messages and emails) to inform their customers about service disruptions, service delays or service cancelations in severe weather emergencies.

VRT has regular maintenance and inspection activities to monitor all of its assets. It does not have specific activities for vulnerable infrastructure and assets because it does not have those issues.

Emergency Preparedness

VRT has an emergency management plan (EMP) that is reviewed annually, but focused on operations and getting service restored as quickly as possible. The EMP involves representatives from VRT’s front-line troops. VRT does work with other public agencies to inform them of what to expect from VRT in the case of a weather emergency.

The plan has specific protocols for canceling service(s) and informing customers, identifying and broadcasting service disruptions and estimated service recovery. Designated managers and essential personnel undergo emergency training.

References


Kansas City Transit Authority (KCATA)

Case Study:
Kansas City, MO

**Highlights:** KCATA is a bi-state transportation agency operating in the Kansas City Metropolitan area. The agency is in the preliminary stages of developing a comprehensive strategy to incorporate resilience into its management plan for both emergency situations and as an approach to mitigating the effects of climate change, in particular extreme temperatures. The agency’s resilience efforts are focused on “preparedness” and “service restoration” when weather-related disruptions occur. KCATA relies heavily on the knowledge of managers and front-line workers to identify assets, infrastructure and services potentially vulnerable to extreme weather and works closely with the Mid-America Regional Council (MARC), the region’s MPO, to coordinate system planning across its seven-county service area. KCATA has also begun to use green infrastructure best management practices, such as permeable pavement in its facility designs to help mitigate flooding risk.

**Key Resiliency Drivers**
- State and local legislation
- Leadership
- Facilities
- Emergency Management Plan for Natural Disasters
- Service Restoration Plan
- Leadership

**Key Successes**
- Building energy resilience into facilities and asset management
- Service Restoration Plan implemented following weather events
- Collaboration and relationship-building with other area agencies
- Capacity assistance for other agencies during events outside own jurisdiction
- Leadership conducts preparedness meetings in advance of weather events
- Alternative fuel and energy sources will help financial stability in the long-run
- Major downtown area celebration was an exercise in implementing procedures to transport large population; area-wide emergency event simulation
- Asset listing is being implemented for asset management
- Approximately 15% of the fleet fueled by alternative energy in order to build financial resiliency and free funding for capital improvement projects

**Key Lessons Learned**
- Working with neighboring municipalities and building relationships in the wider region allows for greater resource allocation in the event of a disaster or emergency

B-19
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

- Development of a comprehensive strategy to address climate change is a broad effort that requires a multi-pronged approach with both near-term and long-term considerations
- Working with other local agencies such as police and fire, as well as outside contractors will provide key assistance during an event
- Never sacrifice safety or security for meeting performance goals
- Equipment maintenance and preparation when severe weather is anticipated is paramount to asset management
- A diverse portfolio incorporating multiple funding sources and alternative energy sources ensures financial resiliency

**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Midwest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>MB, vanpool, paratransit</td>
</tr>
<tr>
<td>Vehicles Operated (2013)</td>
<td>400 buses (31 BRT buses) on 89 routes</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2012)</td>
<td>16.1 Million</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Urban Flooding, Severe Winter Storms, Severe Heat, Tornadoes</td>
</tr>
</tbody>
</table>

**Background:** Public transit in Kansas City began similarly as many major North American cities during the horse car and cable car era. The first streetcars in 1870 were horse-powered, and gave way to electrified streetcars by 1908. At the zenith of streetcar popularity, there were 25 routes throughout Kansas City – one of the most extensive networks in the United States. However, with the advent of the automobile, public transportation fell out of favor, simultaneously shutting down many public transportation routes in the metropolitan area. The last streetcar route was closed in 1957. Some area streetcar history is still evident and some former streetcar routes have been converted to trails. Recent developments in the public transportation system includes a streetcar for a length of Main Street in the downtown area by Spring 2016, and studies are currently being conducted to determine viability for extensions of the Main Street Line.

By the 1960s, buses gained favor in the public transportation realm, and in 1969 the Kansas City Area Transportation Authority (KCATA) began operations after it took over bus routes previously run by the Kansas City Public Service Company. Headquartered in Kansas City, Missouri, just over two miles from the Kansas border, it is a bi-state agency formed by an interstate compact between Missouri and Kansas incorporating seven counties on both sides of the state line – Cass, Clay, Jackson, and Platte counties in Missouri, and Johnson, Leavenworth and Wyandotte counties in Kansas. KCATA is governed by a board of ten commissioners comprised of five individuals from each state.

Within its system, KCATA has over 6,500 bus stops with about 64,800 riders per day on average. Each municipality contracts with the agency for bus transit services, which includes the operations and maintenance (O&M), information technology, and financial planning company-wide. While resiliency planning within the agency is in its preliminary stages regarding policy and procedures, asset management, O&M, finances, and emergency preparedness, the heads of these departments are
beginning to move toward implementing a comprehensive approach that will help the system bounce back from shocks during natural disasters or weather-related events.

Policy and Administration

Summary: Policy is set by the Board of Commissioners and implemented by the Chief Operations Officer (COO), Chief Financial Officer (CFO), and Chief Executive Officer (CEO). The Board of Commissioners is a ten-member group made up of an equal number from the state of Kansas and the state of Missouri, respectively.

The Commissioners in Kansas are appointed either by County Commissioners (one from Johnson County and one from Leavenworth County) or the Mayor in Kansas City Kansas. If the Commissioner is one of the three appointed by the Mayor, there is a newly implemented requirement that he or she also must be approved by the city commissioners. In Missouri, the Mayor of Kansas City appoints three of the five Commissioners; one of which is a direct appointment and must be a Kansas City, Missouri resident. The other two are appointed from a list of eligible candidates provided by Clay and Platte County Commissioners. Only one from each county list may be appointed by the Mayor. One commissioner must be appointed by the Jackson County Executive and must represent a community that contracts with KCATA other than Kansas City, and the remaining commissioner, nominated by the County Commission, must reside in Cass County, be appointed by the Governor, and confirmed by the state Senate.

KCATA is the regional collector of state and federal DOT funds. The agency is contracted by local municipalities to provide service and manage general operations, and the Board of Directors sets policy, which is administered and implemented by the Chief Operations Officer. The Chief Operations Officer also holds preparedness meetings in advance of forecasted weather events and institutes public communication in case of service interruption during such an event. While the COO hands down policies, staff department heads are given a voice and feel that decisions are made “jointly” and they “come together” to share responsibility. The agency is also in the process of utilizing a recent grant to implement a Security Emergency Plan that will likely include agency-wide tabletop exercises to help institutionalize emergency response procedures and educate staff in various departments.

The agency is currently in preliminary stages of setting goals toward resiliency and refers to this process as “preparedness” or “service restoration” regarding policy planning for severe weather events. These plans encompass the implementation of procedures that will “ramp up service” following an event that creates moderate delays.

Successes:

• A dialogue has begun regarding policies that will help move the agency toward greater resilience.
• The agency has been awarded a grant to implement Security Emergency Plan (SEP) tabletop exercises, and an opportunity to bring a multitude of perspectives to Resiliency Planning while educating employees.
Lessons Learned:

- While resiliency is in beginning stages of development, it is not yet implemented holistically.
- A culture of joint decision making in all aspects makes pushing new and upcoming priorities such as resiliency more easily implemented.

System Planning

Summary: While changing weather conditions due to climate change have not been priority, and sea level rise is not an issue, extreme weather fluctuations in the region create an atmosphere in which all potential weather events are considered on an ongoing basis. Due to potential extreme cold in winter and the extreme heat in summer, roads are under perpetual construction and evaluation for wear and tear, and KCATA employees are provided opportunities to provide information about road conditions and potential hazards.

Performance is monitored and assessed on a weekly basis for key milestones on an internal network “Dashboard”. The Mid-America Regional Council (MARC), a regional planning agency located in Kansas City, plays a key intermediary role in coordinating system planning across the seven-county system helping to bring everyone to the table to discuss best practices and approach. Aiding in the planning process, amenities at each location are mapped and the interdependent linkages that apply outside the agency itself are part of the discussion.

Since the public transit system is currently single-mode, redundancy is built into the system by simply providing additional resources when needed and nearby agencies may assist with an extreme event if necessary. However, as the streetcar is implemented and perhaps expanded, the agency will consider how to operate in the eventuality that service is interrupted along the route, either due to flooding or some hazard that damages rail infrastructure for an extended period of time.

Energy conservation is an aspect of resiliency the agency considers in its effort to build redundancy. In light of considering alternative fuel sources to diversify their energy portfolio, KCATA has begun building a fleet of compressed natural gas (CNG) vehicles that are more energy efficient and cleaner burning than their diesel counterparts. By 2017 KCATA estimates the fleet will be 65% CNG vehicles. Generators also back up facilities during power outages.

While the agency has started to create a system by which it can proceed into the future with a diverse tool kit for remaining viable, the system is not yet evaluated by useful metrics to determine capacity for bouncing back from a major event. The agency does, however, iterate that “bouncing back” should never sacrifice the safety of either its employees or its customers. In other words, restoring performance is a priority, but the highest priority is its people.

Successes:

- Discussions are underway to address phasing of service during major snow events or extreme winter weather during which roads are impassable
- Mapped amenities at stops and facilities providing a geographic breakdown and visual representation of location and attributes
• Consideration in the systems planning realm of linkages between interdependencies and critical systems outside the agency’s control
• Developed inter-state relations over the years and have come together to provide service to the bi-state area, overcoming various political barriers
• Upgrade to alternative fuels, diversifying energy sources toward energy independence

Lessons Learned:
• Building relationships with outside agencies is helpful when expedient resources are needed in an emergency
• The agency could build capacity to bounce back from events if metrics are developed to understand where deficiencies in the system lie and would help the agency set goals to improve systems planning
• Sacrificing safety for expedient return to services after a disaster or event is not an option
• Providing employees with opportunities for feedback and addressing their concerns and needs are paramount to a resilient company, as they are the resources that respond and perform during an event

Asset Management

The Kansas City area experiences extreme temperature fluctuations in summer and winter months, including ice and snowstorms, drought and ozone alerts. It is number one among cities with the most populous metro areas for unpredictable weather (3). It is not uncommon for locals to experience freezing temperatures one day and leave home in short sleeves the next day—indicative of the local saying, “If you don’t like the weather in Kansas City, just wait five minutes”. In January 2013, temperatures dipped to 8 degrees, and the next day residents could be seen jogging without shirts on a sunny, 74-degree afternoon (2). These types of extreme conditions pose unique challenges to vehicles and equipment for transit agencies.

KCATA has had an Asset Management Plan in place for the last 25 years. Although the Chief Finance Officer was not able to be present during the interview, other Heads of Department provided information regarding asset management and key takeaways regarding the agency’s Asset Management.

Assets under KCATA authority undergo rigorous performance checks, and both equipment and facilities endure routine maintenance on a regular basis. Because equipment is evaluated regularly, some assets have outlasted their estimated lifecycle. Financial constraints dictate that some equipment must contribute to the system beyond their estimated lifetime, but regular conditions checks and maintenance helps ensure the agency gains maximum return on investment.

As mentioned, one key vulnerability is overstretched funding. Therefore, KCATA is continuously tracking new funding sources, but have made key investments in technology solutions to monitor facility conditions so that vulnerabilities can be tracked. This technology allows some advance warning of pending failures due to weather changes. However, the current technological system is not robust
enough to flag potential vulnerabilities that may have not been previously identified. The system in place relies heavily on employee identification of infrastructure vulnerabilities.

**Successes:**

- The Asset Management Plan supplies guidelines for evaluating equipment, vehicles and facilities, providing a working system to predetermine where equipment failures may occur and to maintain equipment longevity.
- Well-documented assets and routine maintenance ensures maximum return on investments.

**Lessons Learned:**

- Better technological solutions could help track assets and provide key vulnerability identification within the system

**Capital Planning, Programming and Finance**

Capital Projects for KCATA are funded by federal, state, and local dollars. Capital improvements recommendations are brought to the table by department heads and reviewed in light of the Strategic Plan and regional goals identified partially through MARC. Identified needs and wants regarding capital improvement project prioritization follows the order of highest need. Ultimately, the CEO, COO, and CFO are primary decision makers and must come to a consensus identifying which projects receive funding during the fiscal year.

The budget allocates funds for a 5-year time period developed around projects prioritized during monthly meetings among department leadership. Each year, priority reassessment and fund reallocation follows budget review. Department heads stated during the interview that the time horizon for engineering projects was likely more long term than other department plans, possibly a 25-year timeframe.

As with many agencies, KCATA must weigh long-term benefits with short-term costs and decide how best to manage funds. This is a balancing act KCATA is familiar with, but has not identified key metrics or a written strategy that acts as a guidebook for the process. At this time, key players identify needs and discuss at monthly meetings, propose a budget, and leadership comes to a consensus. For now, the system in place has been successful, but no plans have been identified to consider how climate change could affect the institutionalized system.

**Successes:**

- Open communication and regular meetings with decision makers allow percolation of high priority projects throughout the process

**Lessons Learned:**

- Climate change considerations and a system to identify cost/benefit of long-term investments should become part of prioritization process
Project Development, Infrastructure Design and Construction

While KCATA has a strict program to maintain its facilities and equipment, they also take seriously the responsibility of ensuring safety and accessibility of their customers, as well as environmental protection. Recent green infrastructure initiatives and environmental planning standards in Kansas City have become an important focus of the city and its primary public transit agency has followed suit. With established ADA standards creating the need to readjust curb cuts, sidewalk corners, and access to properties, redesign of public infrastructure has become necessary.

Recent improvements have begun in earnest, addressing safety hazards and environmental hazards in an effort to practice good customer service and environmental stewardship. While the benefits of these initiatives have only begun to be realized, the social and fiscal advantages are expected to multiply as more infrastructure projects are implemented. For example, a park-and-ride location in the urban core has recently undergone a high-profile permeable pavement upgrade that includes native plants and trees in its design. Not only will these initiatives mitigate some flooding risk by decreasing the amount of surface runoff during major rain events, the beautification of a major urban intersection has made it a more pleasant place for passersby and public transit riders. Area residents take pride in this location and are more likely to respect public property such as bus stop shelters there, as well. Other initiatives include solar-powered electricity at some stops, efficient HVAC systems and LED bulbs within 95% of facilities; all help build resilience into everyday operations.

Successes:

- Improvements incorporating ADA compliance are underway at bus stops and facility locations.
- Green infrastructure and alternative energy sources have been a consideration at key points in the city and upgrades are underway.

Lessons Learned:

- Resiliency efforts through design and construction can have multiple benefits to both the agency and the community as a whole. While green infrastructure can mitigate environmental impacts, it can also beautify, prevent flood and safety hazards, and investments such as these also can improve neighborhood aesthetics.
- Resiliency is a win-win proposition fiscally, environmentally, and socially.
Operations and Maintenance

Since KCATA serves multiple municipalities and is dependent upon those municipalities to provide basic infrastructure services, operations that exceed basic fleet and facility maintenance are dependent upon other city-owned operations. The KCATA does not deploy its own emergency operations crew in the event of a major weather-related disaster, nor does it have a system in place that temporarily hardens infrastructure during an event. For example, if major flooding occurs along a bus route, the agency does not work independently to mitigate flood hazards by either deploying sandbags or other temporary means; for this, other emergency management agencies may deploy flood mitigation strategies. KCATA will reroute bus service in the event of a disaster and resume regular operations after safety concerns are addressed.

The agency does have in place a redundant energy and communications strategy in the event that power is interrupted. They have a backup communications tower with limited functionality, and use two-way radios to dispatch and communicate with field crews. The main facility has a backup generator in case the building loses power during a storm or tornado event. The agency also applied for a grant that would provide a mobile emergency command center. The grant was initially denied, but there are plans to continue to search for other funding options. The mobile command center is a potential next step to improve resilient emergency operations.

Maintenance procedures are recorded and kept on record for 2-3 years within a system called “Fleet Watch”. The data control system is a combination of hardware and software, providing accurate real-time control and data acquisition for vehicles, employees, fuel/fluids and tank monitoring systems. The system tracks vehicle mileage, monitors fuel and fluid usage, and helps schedule preventative maintenance. Data is recorded and available for analysis from any PC in a remote location. This system helps personnel maintain the fleet from a central data system, synchronizing data between multiple facilities, and provides diagnostic reports in a categorical format regarding vehicles, employees, and utilities. The program also provides real-time digital shelter signage, conveniently allowing customers to track transportation times.

Successes:

- Redundant communications and energy generation
- Seeking funding sources for mobile emergency command center
- Hardware and software program implementation to ensure fleet maintenance and performance within a synchronized, real-time system

Lessons Learned:

- KCATA relies on other agencies to perform some temporary infrastructure hardening which could pose challenges, but may also have benefits; challenges can arise by being dependent on other systems and their reliability, but benefits may be that other agencies have more available resources to take on necessary tasks
- Emergency operations and redundant power/communications are a necessary component of transportation system operational resiliency
Emergency Preparedness

KCATA has an emergency management plan in case of severe weather, fire, and flood. Earthquakes are not common, but the New Madrid fault is in close enough proximity to warrant a contingency plan, as well. Currently, the agency is in the process of developing a pamphlet addressing these hazards. Additionally, other local agencies collaborate and perform drills with KCATA to prepare in the event that a major disaster occurs. The EMP is consistent with the Federal Government’s National Incident Management System and the agency is considering providing classes to employees with ICS classes and training through the Transportation Safety Institute.

The agency coordinates regularly with federal, state, and local agencies including the EOC, FBI and Homeland Security. There is nothing in writing, but the agency will institute the safe, orderly, and efficient shutdown of services in the event of a disaster or major weather event. However, since the transportation system operates within such a large land area, shut down and restoration of services would be evaluated on a case-by-case basis. Emergency system activation would depend upon Mayoral state-of-emergency declaration. The implementation of safety and emergency exercises regarding streetcar operations have been conducted and continue to be conducted until the new line is in operation.

Restoration of services following an event depends upon severity of the event and the availability of mutual aid. KCATA contracts with other nearby agencies to provide/receive aid in an event in which additional resources are required. This mutual aid agreement ensures services can continue if an event causes loss of equipment and/or fuel. It would take an estimated week to ten days, for example, to receive aid from St. Louis, over two hundred miles away.

Successes:
- The EMP has been developed and a “quick-guide” pamphlet is in process
- Regular coordination with federal, state, and local agencies to maintain open dialogue
- Mutual aid with partnering agencies has been established

Lessons Learned:
- EMP in place helps address a crisis with actionable items and agreed upon procedures
- Established relationships with partners helps ensure system restoration following a major event on an as-needed basis

References

1. KCATA Organizational Chart. 2016. Print


Los Angeles County Metropolitan Transportation Authority (LA Metro)

Case Study:

Los Angeles, CA

**Highlights:** LA Metro is at the forefront of incorporating resilience holistically across nearly all of its business functions to address both infrastructure and operational resiliency. The agency has integrated resilience considerations into its Environmental Management System (EMS), which helps to retain a focus on resilience in agency decisions related to maintenance, operations, and capital project development. LA Metro has developed a Resiliency Indicator Framework, which provides a comprehensive set of metrics to track infrastructure, and operational resiliency over time. LA Metro is in the process of developing a comprehensive Resiliency Policy and is updating its infrastructure and facility design criteria and construction specifications to include resilience in all capital project construction, operations and maintenance activities.

**Key Resiliency Drivers**

- Executive leadership;
- Success in obtaining grant funding to address resiliency;
- Pilot project successes in understanding climate change and system vulnerabilities which in turn enhances executive leadership and front-line personnel buy-in;

**Key Successes**

- Receiving ISO 14001 certification for its EMS in all bus and rail facilities.
- Advancing resiliency and climate adaptation efforts through funding from grants and financial sources outside of the agency budget.
- Advancing a holistic approach to implementing and operationalizing resiliency.
- Implementing a method to track agency performance regarding the implementation and incorporation of climate change and resiliency agency-wide.

**Key Lessons Learned**

- Utilizing an EMS provides for the ability address resiliency holistically incorporating agency-wide and specifically departmental constraints. Resiliency efforts, regardless of magnitude, should be discussed as an important of agency plans and efforts.
- Continual discussions and meetings can enhance agency understanding of resiliency and act as a surrogate for training.
- Approaching climate change through discussion of resiliency to extreme/severe weather events or operational challenges allowed for ready employee buy-in.

**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>HR, MB, LR, DR</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td>3,372</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>476,299,313</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Earthquake, Urban Flooding, Mudslides, Wildfires, Wind, Sea Level Rise, Dust Storms, Heat</td>
</tr>
</tbody>
</table>

**Background:** The original transit agency, which the Los Angeles County Metropolitan Transportation Authority (LA Metro) was created from, was established in 1873. However, transit rail service ended during the middle of the 20th century. Roughly 25 years ago, LA Metro began re-establishing transit rail service throughout Los Angeles County. As such, its rail network is relatively new in comparison to many of the transit systems across the country. The agency is a state chartered special jurisdiction and not county owned or operated. It is responsible for planning, constructing, operating and to a certain extent funding all transportation systems in Los Angeles County.

The agency operates heavy and light rail as well as bus service and on demand service throughout the county. It also partially funds Metrolink (which is the regional rail [multi-county] operator) as well as other transit systems run by municipalities. In 2008, a measure was approved by voters to expand the current system. The expansion will account for twice as many stations (80 to nearly 200) and about twice as many rail miles (about 200 to 400 rail miles). At this writing, LA Metro has a potential ballot initiative that seeks to indefinitely extend the current measure as well as another tax increase to fund transportation systems across LA County.

In the context of the voter approved system expansion that will ultimately double the size of its rail network, increase capacity of the current system, and expand active mobility networks, LA Metro staff took advantage of the opportunity to think through the long-term impacts climate change and extreme weather could have on the system expansion. Incorporation of climate change adaptation and resiliency strategies was determined to be a necessary in terms of planning and constructing the system expansion.

To achieve this end, staff sought external funding through grants and successfully completed a number of projects including the implementation of an Environmental Management System (EMS) and a pilot project through the FTA Climate Change Adaptation Initiative building upon the EMS. These successes have been recognized by LA Metro executives and as a result, the agency’s Environmental Compliance and Sustainability Department (ECSD) has full backing to continue the work. In addition, LA Metro has developed metrics to understand the progress the agency has made in becoming more resilient, while maintaining awareness of continued gaps in both infrastructure and operational resiliency through a Resiliency Indicator Framework (RIF). This framework supports, measures and prioritizes actions to maintain and enhance resiliency.

**Policy and Administration**

**Summary:** LA Metro is a state chartered special jurisdiction serving the county of Los Angeles. It is governed by a 13-member Board of Directors. The board sets agency policy and provides direction to the CEO who is then responsible for implementing the Board’s directives agency-wide. The CEO is supported by a tier of senior executives who each manage various business units within LA Metro. Although LA Metro Board has not adopted a specific resilience policy, it has adopted a number of...
policies related to use of renewable energy, sustainability, reducing the agency’s impacts on the environment, green construction and water use and conservation.

LA Metro’s Environmental Compliance and Sustainability Department (ECSD) is overseen by an Executive Officer who provides primary support for environmental, climate change mitigation and adaptation, and resiliency efforts within LA Metro. LA Metro defines resiliency as “The ability of a system to respond to threats and changing conditions by resisting damage, recovering quickly and continuing to provide its essential services.” Although the primary responsibility for addressing climate change related resiliency falls within ECSD, LA Metro has been advancing a holistic approach through which all applicable departments and divisions are increasingly becoming involved in the work managed by the ECSD. ECSD coordinates with planning, construction, operations, maintenance, and risk management personnel in its efforts to operationalize resiliency agency-wide. The ECSD recognizes the close link between resiliency and the agency’s sustainability programs, which allows for further integration into agency policies.

An important tool used to advance resiliency within the agency is the Environmental Management System (EMS). According to the FTA, an EMS is a set of processes and practices, which enables an organization to reduce its environmental impacts and increase its operating efficiency. LA Metro’s EMS is managed by an Administrator who also oversees an Administrative Team. Under the Administrative Team are EMS Core Teams consisting of front-line personnel at the Maintenance and Transportation facilities.

The Administrative Team includes representatives from a variety of departments including ECSD, service planning, procurement, homeland security/emergency management, bus and rail maintenance, facilities maintenance, and transportation. This group has an in-depth knowledge regarding the EMS and works to integrate (above environmental compliance and other EMS principles) climate change related resiliency into agency decision making. The Administrative Team is focused on identifying the “best path forward” for the organization as a whole based on regular discussions on issues related to environment and sustainability, including climate change. EMS Core Teams include front-line staff and members of other business units who have a more functional knowledge of the EMS, but are directly responsible for implementing the EMS processes and procedures developed by the Administrative Team within their work areas. As the work has progressed, the Core Teams’ implementation efforts have become more adapted to their specific site conditions at each facility, while maintaining the core EMS principles.

**Systems Planning**

**Summary:**
LA Metro has consistently made effective use of external funding to initiate and sustain its focus on sustainability and resiliency. The use of external funding—primarily from FTA—has helped to address one of the barriers of resiliency adoption among transit agencies, namely limited resources and competing priorities. For example, LA Metro is a participant in the FTA’s Environmental Management Systems Training and Assistance program. LA Metro ECSD saw the FTA EMS program as an opportunity to utilize EMS as a tool to operationalize adaptation and resiliency efforts at LA Metro. They applied for and
received a grant in 2008. The implementation of EMS resulted in ISO 14001 Certification for the Metro’s Red and Purple Line rail yard; the first major rail maintenance facility in the nation to receive certification.

In 2010, LA Metro completed a GHG Emissions Study, which led to the completion of a Climate Action and Adaptation Plan (CAAP) in 2012 (1). The plan not only addresses climate change mitigation through emissions reduction; it also includes climate adaptation strategies for increasing system resilience. Some initial barriers encountered by LA Metro included “employee buy-in” on the topic of climate change. To facilitate discussions, the agency framed vulnerabilities in the context of extreme weather events as these relate to the day-to-day operations and management that most of the staff is focused on. (2)

At the same time it was completing the CAAP, LA Metro once again sought funding through FTA and became one of seven federally funded projects under the FTA’s Climate Change Adaptation pilot program. LA Metro’s participation in the Climate Adaptation pilot program allowed it to develop detailed steps for integrating adaptation into its EMS (2). The FTA Pilot Project identified the CAAP as a guide for LA Metro’s efforts for building the EMS adaptation module. Additionally, the pilot project final report recommended inclusion of resiliency data and consideration in other EMS modules and identified more than 100 resilience-related metrics in the categories of planning, operations, ridership and adaptation. These were narrowed down to seven metrics that LA Metro has been using for near-term measures.

Based on the findings of the pilot project and other related initiatives, LA Metro has updated its EMS system to facilitate the more detailed integration of resiliency into agency decision making. The success of ECSD’s efforts have led to a sustained commitment on the part of senior management and the LA Metro board to provide funding to continue the work.

Building on the pilot project metrics work, in December of 2015, LA Metro completed development of a Resiliency Indicator Framework (RIF) (3). The RIF includes a series of metrics “designed to provide a mechanism through which Metro can measure and prioritize actions to ensure that its assets and networks are resilient in the face of climate change and related extreme weather events.” (4) LA Metro defines resiliency as “the ability to provide core functions in the face of threats, and recover quickly from major shocks or changing conditions.” (3) They define criticality as the “services and assets that are essential to transporting Metro’s customers.” (1) The agency’s most critical assets and services include:

- Bus and rail fleets;
- Right-of-way on bus rapid transit (BRT) lines;
- Heavy rail tracks, stations, and energy infrastructure;
- Light rail tracks, stations, and energy infrastructure; and
- Rail rehabilitation activities.

These assets were chosen because they would be “extremely difficult or costly to replace or to substitute.” (1) Critical facilities were ranked based on “ridership, connectivity to other parts of the transit network, and whether they are the site of current or planned joint development projects.” (1) Maintenance and administrative facilities were based on expert opinions. The RIF study identified
actionable next steps such as incorporating resiliency into Long Range Transportation Plans, Short Range Transportation plans, Metro Rail Design Criteria and an upcoming agency-wide risk assessment.

In addition, the agency works closely with the City of LA including the LA City Mayor’s Office, the LA City Department of Transportation, LA City Bureau of Sanitation, LA City Department of Public Works, LA City Department of Water and Power, LA City Bureau of Street Services, and LA City Department of Recreation and Parks. LA Metro has a Memorandum of Understanding in place designed to coordinate transportation planning, infrastructure siting and water pipeline planning related to LA Metro’s infrastructure expansion projects. Both the City and LA Metro are cooperating to make very long-term infrastructure investments within the City and County of Los Angeles, and to make such coordinated efforts successful, the entities develop strategies to reduce institutional and infrastructural conflicts between them. There has also been conversation to explore alternative forms of financing for building things like water recycling plants adjacent to nearby transit facilities for rail car/bus cleaning, irrigation, and other community resiliency projects.

**Successes:**
- Receiving ISO 14001 certification for the whole agency and institutionalizing the environmental management process to develop, implement and maintain resiliency efforts and projects.
- Advancing resiliency and climate adaptation efforts through funding from grants and sources outside of the agency budget.
- Advancing a holistic approach to implementing and operationalizing resiliency.
- Developing a method to track agency performance regarding the implementation and incorporation of climate change and resiliency throughout the agency.

**Lessons Learned:**
- Utilizing an EMS provides for the ability address resiliency holistically incorporating all agency departments and divisions.
- Resiliency should be considered as part of other agency plans and efforts.
- Continual discussions and meetings can enhance agency understanding of resiliency and act as a surrogate for training; doubling as an avenue to gain employee buy-in to the concept, process, and implementation structure.
- Approaching climate change through discussion of resiliency to be fully relatable to staff’s front-line issues allowed for greater employee buy-in.

**Tools:**
- Resiliency Indicator Framework (3)

**Asset Management and Capital Planning**

LA Metro is in the process of updating its asset management system to comply with MAP-21 and FAST Act requirements. In this regard, the agency’s risk management and asset management teams are beginning to advance a more sophisticated asset management database. The database development team has been very open to including extreme weather event data from past events as well as
vulnerabilities to future threats. The following is an example of how the agency’s asset management framework changed to include resiliency:

In 2012, an extended period of high heat days stressed bus operation causing air conditioning and other equipment failures and a significant increase in maintenance personnel overtime to address the problems. At the same time, LA Metro’s Climate Action and Adaptation Plan was released. The plan notes that more frequent high heat days are a climate threat facing the agency. In the wake of the high heat event, the agency married its operational data with past weather events using data from NOAA. This “marriage” of operational data from the asset management system allowed the agency to see patterns of problems and take steps to address the problem with enhanced asset management procedures. LA Metro now starts an enhanced preventative maintenance program three months prior to summer to improve operational resiliency by reducing breakdowns. This in turn has resulted in cost savings for the agency in the form of less unnecessary overtime and expenses associated with same. In addition, operations data are now monitored more closely alongside weather predictions and occurrences.

LA Metro is also working to address a current disconnect between its asset management systems and the EMS. The two systems are not yet fully integrated they are used differently in terms of internal reporting. The data contained in the EMS is frequently used to “flag” problems with infrastructure from an environmental compliance and performance lens. This has led to the identification of capital projects to address the problems. Reporting limitations inherent in the asset management systems make it challenging to use the system in the same way. For example, a persistently leaky roof at one of LA Metro’s dated facilities was creating a range of public health and operational hazards. EMS data was used to show vulnerabilities in this regard, and highlight the possible consequences of these vulnerabilities in the context of an impending El Niño event. The health and operational issues associated with the facility were being monitored using the EMS. As a result, the facility’s vulnerability to extreme weather made addressing the problem a higher priority than just a state of good repair argument. In the end, performance-monitoring data from EMS helped to make the business case for fixing the leaky roof. Decision makers could see that doing so was a priority for safety, energy efficiency and resilience reasons.

Another example of how resilience-related asset management data was used by LA Metro to inform capital project decision making has to do with overhead catenary systems, a critical piece of infrastructure considered in the RIF. LA Metro’s Gold line is particularly vulnerable to high heat days. To assess the magnitude of vulnerability, the agency overlaid high heat day data with infrastructure maps to identify which catenary systems might be most at risk. This led to a conversation with maintenance personnel about what else should the agency be including to make the case for resilience intervention on the Gold line or system wide. What they discovered was that many of the catenary system’s lead weight counterbalances have no more room for adjustment. Operations and maintenance personnel noted that the lead weight tensioning systems have prematurely elongated to the ground in many places, which prevents them from tensioning sagging catenaries.
By combining the vulnerability assessment data/mapping with the detailed knowledge of asset conditions provided by front-line workers, LA Metro was able to make a business case for repairing/replacing the systems. A standard asset management approach, which relies heavily on recommended lifecycle replacement might not capture the need to for premature replacement. The infrastructure vulnerability lens sparked a conversation with asset management, operations, maintenance personnel that flagged a significant operational problem that might otherwise have gone unaddressed.

In the future, LA Metro hopes that a combined EMS + asset management system approach can result in more win-win-win to capital projects. A step in this direction is the growing collaboration between ECSD and the agency’s risk and asset management teams. Both participate on the EMS advisory committee.

Successes:
- Combining asset management data with data on weather patterns to identify problems and develop solutions that improve operational resilience.
- Using resiliency-related performance data contained with the EMS to identify capital projects that address multiple agency priorities as the same time.

Lessons Learned:
- Integrating EMS and asset management systems can be difficult. The two systems function on different data platforms that must be reconciled over time.
- Asset management systems are focused on monitoring state of good repair and tracking performance of individual assets. Using the data to identify patterns of performance that relate to resilience requires new procedures and ways of using asset management data.
- Resilience considerations can be a catalyst for conversation that leads to enhanced asset management approaches, which can ultimately improve operational resiliency.

Project Development, Infrastructure Design and Construction

Summary:
LA Metro has a Design Criteria and Specifications document that guides infrastructure design and construction. The ECSD has complete ownership on the environmental section of the design standards. Therefore, when updates are made on a regular basis to the design standards, ECSD can incorporate resiliency adaptation strategies as part of the environmental requirements based on these standards. Additionally, they may comment on other sections recommending changes to engineering and other aspects of the design standards and specifications.

In addition to internal knowledge, the ECSD must also adhere to external laws and regulations. One example is the California Green Building Code. This code outlines voluntary and required commitments. Additionally, local ordinances regarding infrastructure may also need to be addressed. Although LA Metro is a state chartered special jurisdiction and is not necessarily within the jurisdiction of local ordinances, it is the agency’s best practice to try and incorporate the ordinances into agency specifications to reduce issues where agency infrastructure intersects with local infrastructure. Additionally, the environmental review process for new projects is required to consider the greenhouse gas emissions impacts of a project and if a significant impact is identified, mitigation measures are
developed and implemented. This could result in actively implementing resiliency strategies during construction and operations and maintenance of a project.

LA Metro now regularly utilizes a design-build approach for its construction efforts. All projects require the development of a Sustainability Plan regardless of size. ECSD staff works with contractors on what can be done for resiliency and adaptation within the context of their Sustainability Plan commitments. ECSD staff usually conducts one or two workshops for project designers and contractors once they are awarded the bids to review sustainability and resiliency expectations. For smaller projects, facilities and maintenance, etc. LEED certification requirements bring in resiliency consideration in terms of “greenness.” Finally, for sustainability-related capital program projects, a full life-cycle cost analysis is completed.

Successes:
- Requiring all major capital projects to include a Sustainability Plan that actively addresses resiliency considerations.
- Working cooperatively with design and construction vendors to incorporate sustainability and resilience considerations from the very early stages of project development.

Operations, Maintenance, and Emergency Preparedness

Summary:
As mentioned previously, LA Metro utilizes enhanced maintenance procedures to improve the operational resiliency of its bus fleet during summer months. The agency also uses its routine maintenance and inspections procedures to collect resilience-related data that is incorporated in the agency’s Environmental Management System and to inform capital planning decisions.

In the area of emergency preparedness, LA Metro has an emergency operations plan, continuity of operations plan and standard operating procedures for shutting down services quickly and safely in the event of an earthquake. They have a combined emergency operations center and bus/rail operations center to manage services during emergency events. The agency also participates as a member of the California Disaster and Civil Defense Master Mutual Aid Agreement. In addition, LA Metro has an active personnel training/drill program and participates in public awareness events to inform the public regarding what to expect during an earthquake and how to protect themselves if using LA Metro services during an earthquake.

References

3. Los Angeles County Metropolitan Transportation Authority. 2015. Resiliency Indicator Framework. 

4. Los Angeles County Metropolitan Transportation Authority. 2016. Environmental Compliance and 
    Sustainability Department. *Metro*. [Online] [Cited: March 14, 2016.] 
    https://www.metro.net/projects/ecsd/.
Maryland Transit Administration (MTA)

Case Study:
Baltimore, Maryland

Highlights: The primary threats facing MTA’s infrastructure and services include flooding, storm surge and sea level rise. The agency’s resilience planning and adoption efforts to date have been primarily focused on operations during extreme weather events. Within this context MTA uses operations and maintenance and emergency management procedures to protect infrastructure. MTA has completed a Climate Change Vulnerability Assessment and is in the early stages of developing an asset management system that will incorporate a climate and weather risk assessment. The agency also has in place procedures to facilitate cessation and rapid recovery of services in response to winter weather threats.

Key Drivers

- Implement State of Good Repair and vulnerability assessment programs;
- Leadership;
- Emphasis on safety, operations and maintenance;
- Disaster events – sea level rise, hurricanes and storm surge, major snow events, high winds and storm events, and riverine flooding.

Key Successes

- Natural disaster impacts such as sea level rise, storm surge, and flooding are being addressed through the agency’s evolving asset management program and related risk assessments.
- Asset management, capital planning and risk assessment are closely linked in the MTA planning framework. This should facilitate the explicit integration of resilience in the future.
- MTA’s collaborative capital planning process specifically involves input from operations, safety, and risk management, helping to ensure that new or rehabilitation projects reflect broad perspectives, including aspects of resilience (whether or not that name is used).
- Monthly safety, operations and maintenance meetings include representatives from all divisions and locations; monthly “all hands” executive team meetings discuss and implement division recommendations as warranted.
- A January, 2016 24”-30” snowstorm implemented operations recommendations to stop service earlier rather than later; avoided major damage to the fleet from stalled or stuck buses; facilitated rapid startup after the storm; customers kept apprised of plans, reacted well.
- Capabilities assessment nearly complete.
- Inventory of known assets nearly complete.
- Development of a life-cycle plan beginning.
- Agency vulnerability assessment underway.
- Improvements to underground communication system underway.
### Key Lessons Learned

- The agency is in an early stage of developing a system for asset management and measuring its state of good repair.
- The agency has completed a Climate Change Vulnerability Assessment and identified critical assets and vulnerabilities; this information will be incorporated in the asset management plan as it develops.
- Proactive suspensions of service under imminent severe weather threats can protect customers, employees, and equipment from harm and severe damage, as long as plans are broadly communicated to staff and customers.
- There are elements of cross-mode coordination for emergency events and resilience, but still at an early stage of implementation.
- The agency has elements of resilience incorporated in its operation and maintenance principles, but has many steps and processes to engage before resiliency is addressable as a key element or as part of a state of good repair standard.
- Involving operations and maintenance and police directly in safety and emergency management decision making, as well as project prioritization, helps embed a safety orientation as well as risk awareness into everyday operations. Having an established mechanism for communication, that is regular, highly visible, and effective, lends credibility to the effort. Together, these can be a good foundation for resilience.

### Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Baltimore, Maryland – Mid-Atlantic East Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>Local and Commuter Buses, Light Rail, Metro Subway, Maryland Area Regional Commuter (MARC) Train Service, and a comprehensive Paratransit (Mobility) system</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td>744 (directly operated), 765 (purchased transportation), 1,509 total</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>107,373,286</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Sea level rise, hurricanes and storm surge, major snow events, high winds and storm events, and riverine flooding</td>
</tr>
</tbody>
</table>
**Background:** The Maryland Transit Administration was originally known as the Maryland Mass Transit Administration, having taken over the remnants of the Baltimore Transit Company in 1970.

Many routes of the agency’s current bus lines are based on the original streetcars operated by the Baltimore Transit Company and its parent companies between the 1890s and 1960s. All of these routes were ultimately converted to rubber tire bus operations, and many were consolidated, extended into newly developed areas, or otherwise reconfigured to keep up with the ridership demands of the times.

With the growth in popularity of the private automobile during the 20th century, streetcar and bus ridership declined, and the needs for public transportation changed. The demise of the Baltimore streetcar took place between the years of 1947 and 1963, as operators found buses to be low maintenance and more cost-efficient. With its rails demolished, Baltimore was no longer a streetcar city.

As transit needs and trends changed, rail transit returned to the city, with the Metro Subway opening in 1983 and the Light Rail in 1992.

According to the agency’s 2014 annual report, MTA’s progress throughout 2014 was highlighted by nationally recognized innovations in data use, solid gains in the efficient use of resources and customer focused improvements that demonstrate MTA’s commitment to providing riders the best transit experience possible.

In addition to meeting the challenge of delivering transportation services safely and efficiently on a daily basis, MTA is committed to addressing the needs of future transit riders as well by continuously improving its internal operations processes, reaching out and responding to customers on various communications platforms, and by focusing on the basics of world-class customer service.

**Policy and Administration**

**Summary:** The MTA is a division of the Maryland Department of Transportation. Its budget is approved by the Maryland General Assembly. Its Administrator reports to the Maryland Secretary of Transportation and is appointed by the Governor with the advice and consent of the state Senate.

Resiliency is not a specific goal or policy principle at the MTA. The agency has, however been working to address disaster recovery planning. Senior MTA staff also report the agency is working on a safety plan that incorporates asset management. A lot of the agency’s efforts have also focused on infrastructure repair based on historical data and other indicators.

MTA will be adopting the accountability approaches identified in Map 21. Additionally, MTA considers itself to be proactively implementing Asset Management, however, the policy is evolving, and is yet to be formalized. Funding for implementation of Asset Management has not been sufficiently available to MTA. However, in its 2013 annual report MTA touted advancements in innovation and customer service as well as a continued commitment to system preservation and safety in order to move forward and deliver reliable, cost effective and modern transit services to Maryland families.

Generally speaking, the agency is led by a ten-member management team. The agency’s CEO reports to the Maryland secretary of transportation, who in turn reports to the Governor. There is no one in the management team with specific responsibility for resilience. There are, however, individuals responsible for safety, quality assurance, risk management, planning, development and program
delivery. The agency’s chief of public affairs and publications is responsible for communicating to the agency’s stakeholders regarding the agency’s performance and plans. The agency maintains a website, and provides a variety of online publications regarding a wide range of customer services, but there is no mention of resiliency in MTA’s statements or publications.

Successes:

- Natural disaster impacts such as sea level rise, storm surge, and flooding are being addressed through the agency’s Vulnerability Assessment program that will then be incorporated into the asset management program, which is currently in development.

Lessons Learned:

- The development and implementation of new policies and programs require significant collaboration among the various organizational units of the agency and more robust funding from the state and the Federal Government.
- Resiliency is not a policy concept that the MTA is familiar with, but as the MTA strives for implementation of its asset management program, integrating the more robust Climate Change Vulnerability Assessment, it may also come to embrace resilience.

**System Planning for Emergency Conditions and Resilience**

Summary: The early January 2016 snowstorm afforded the MTA an opportunity to test the quality of its systems planning for emergency preparedness, response and resilience. Senior management took advantage of the early warnings about the severe approaching storm and communicated with staff and customers about snow emergency procedures and anticipated service interruptions. The service was deliberately halted early in the day, with extensive customer notification, before buses and trains could get stuck in snow.

In previous events, continuing the service as long as possible resulted in buses getting stuck in the snow or ice, with many incurring damages from trying to extricate themselves from snow or from being towed, in many cases potentially endangering customers as well. Customers were satisfied overall with the service cutback in the 2016 storm, as the notifications were widespread in advance of the service halt. There were no damages to buses, which made the restoration of service much easier. Customers were allowed to ride free during the first day of service recovery. MTA cleared the snow-bound portions of the rail systems as quickly as possible, and coordinated with local and state jurisdictions on road clearing priorities.

There was close communication and coordination between senior MTA officials and Baltimore City officials, as well as with other officials in outlying communities including the Washington Metropolitan Area Transit Authority, and the Maryland Department of Transportation.
Successes:

- Overall, MTA considers the effort well done with the exception of some sections of its light rail system where difficulty was encountered clearing the tracks and restoring service quickly.

Lessons Learned:

- Proactive suspensions of service under imminent severe weather threats can protect customers, employees, and equipment from harm and severe damage, as long as plans are broadly communicated to staff and customers.

Asset Management

Summary: MTA has a management committee organized under its capital program that has developed or is in the process of developing a number of reports that address capital inventory, inventory life cycle, asset vulnerability, and performance measures along the lines required under MAP 21. The agency is moving toward determining and reporting on its state of good repair as reflected under ISO 5001. The agency has used various assessment tools to identify and measure its capabilities, and hopes to be able to use its asset management initiative to prioritize and select capital projects in its budget next year. The tool MTA will use is called “Asset Management For Project Solutions.”

In the course of developing the agency’s Climate Change Vulnerability Assessment, (which will be incorporated into its asset management program as that develops), the MTA has identified a category of “vulnerable” assets in draft form; primarily assets that might be affected by three climate change scenarios: sea level rise, hurricane surge, and flooding. There are 75 such MTA-owned assets. They are prioritized in the Climate Change Vulnerability Assessment according to their critical nature and their cost for repair or replacement.

Some assets, such as track, are inspected every day. However, other vulnerable assets may not be on a routine schedule for ongoing monitoring, so their potential for failure in a natural event is not known. Operations and maintenance procedures fostering awareness and reporting, described below, are expected to assist with ongoing monitoring.

Among the vulnerable assets are below-ground stations and assets whose entrances may be subject to storm surge flooding, such as the Shot Tower station and the Gold Street pumping station, as well as some ventilation shafts and related infrastructure. Adaptation plans are still preliminary, as the MTA has not received substantial resilience-related funding.

Of note: MTA only assesses the vulnerability of assets that it owns and controls, with the exception of the shared CSX track for a portion of its light rail line (which MTA does not own, but which it did assess for vulnerability). Therefore, for example, it does not assess the commuter rail track for its MARC service (over 400 directional route miles on multiple lines) or the streets and highways where its buses operate. MTA does coordinate closely with the other owners of assets (track and roads) to prioritize resumption of service after an emergency.
Successes:

- MTA has been in the process of developing its asset management strategies over the past two years, and it appears that it will take at least one more year before MTA will be able to effectively establish capital priorities in line with a comprehensive state of good repair assessment.

- Asset management, capital planning and risk assessment are closely linked in the MTA planning framework. This should facilitate the explicit integration of resilience.

Lessons Learned:

- Effective asset management strategies have many pieces that are evolutionary and iterative in nature. MTA is in the early stages of developing these strategies and implementing the appropriate tools.

Capital Planning, Programming and Finance

Summary: MTA is continuing to develop its capital investment strategy and plan. It hopes to have that strategy fully implemented, and as a result have a capital investment plan reflected in its budget proposal next year.

The MTA has a multi-step propose/review process for identifying and recommending new capital projects, as well for renovating existing capital investments. Emergency managers, risk managers, the safety officer, and key operations personnel have a role in capital project evaluation, alongside capital planning engineers. Senior management uses a matrix to evaluate proposals. The matrix ensures that safety factors such as lighting are appropriately considered in project design and renovation. Resiliency is not one of the considerations made in evaluating the cost/benefit of a proposed project at this time, but could presumably be added to the matrix to be considered in future project decisions.

The cost of repair or replacement of capital assets is determined at the time following a natural disaster event and addressed in the next available budget to the extent practicable. No contingency fund is available per se for repair or replacement. Capital projects damaged by a natural disaster must either be addressed in the agency’s forthcoming budget or by an emergency funding request from the Governor to the general assembly.

MTA staff report that MTA’s Metro has an Emergency Operating System in place. Among its manifestations are improvements to radio communications for underground response for the subway system, with capital funding approved for a 700 MHZ system.

Successes:

- MTA’s collaborative capital planning process specifically involves input from operations, safety, and risk management, helping to ensure that new or rehabilitation projects reflect broad perspectives, including aspects of resilience (whether or not that name is used).
Lessons Learned:

- Securing funding for assets identified as both vulnerable and critical will take time, due to multiple priorities for project funds. Identifying the needs at least begins the process.

Safety, Emergency Preparedness and Operations and Maintenance

Summary Ongoing O&M Safety Culture Procedures: Safety and emergency preparedness are continually reinforced in the operations and maintenance realms. First level front-line employees (drivers, mechanics, police officers and supervisors) for every location and every mode have a representative on the safety committee, to whom they can report concerns and hazards, recommend changes in operating procedures, and recommend capital and operating funding priorities. (Immediate hazards, from potholes to passenger incidents can also be reported by phone, radio or email- see below.) Recommendations then go before an agency-screening panel that includes the operating departments’ leaders. As each recommendation from the various working groups comes forward, its costs are identified and submitted for consideration for inclusion in the agency’s annual budget request to the Governor and the general assembly.

Safety committee representatives meet every month with the scheduling and planning office, the operations group, and the Safety Officer to discuss and resolve issues at the lowest level possible. High priority issues, policy decisions, and funding requests (operating and capital) are raised with the Executive Safety and Security Committee, which also meets monthly. The Executive Safety and Security Committee includes modal and discipline directors including the Safety Officer and the MTA CEO, and works to establish accountability, actions and funding if necessary to resolve problems that are brought to the table.

O&M staff have participated in workshops to develop risk ratings of projects and assets. Asset management staff are involved in these interviews. Past issues have included concerns about erosion, rockslides, and riverine flooding at various locations; future topics are expected to include snow, heat, and the potential for rail buckling. Workshops identify specific procedures to identify potential hazard elements, and develop specific plans to adapt sites to address hazards. These may include backup power for pumps, siting generators above the flood risk zone, and similar strategies.

Summary Emergency Operations Procedures: According to senior MTA executives, there are comprehensive operations plans for every mode and a master plan for operations in the face of storms and emergencies, including procedures and plans for the agency’s emergency operations center (EOC). (See Systems Planning above for an example.) The MTA also has continuity of operations plans for all aspects of its operations.

MTA trains all of its front-line employees (first responders: attendant, bus operator, or police officer) to deal with situations until other appropriate responders can arrive. The MTA uses the National Incident Command Systems guide for its training model. The guide includes videos, handbooks, and train the trainer modules.

MTA applies a high level of awareness and urgency to report and respond to such service interrupters such as track flooding or large potholes that could affect safety of train or bus. Daily track inspections are conducted throughout the MTA rail system and repairs are conducted as quickly as possible. Bus
operators report potholes and any other hazard they encounter. The MTA utilizes a hotline and email to document and report repairs.

The agency’s safety office is leading the vulnerability assessment with input from each of the agency’s operating groups. There is an agency-wide threat assessment underway. There is a risk analysis being done, with an eye toward where to place new facilities to avoid potential natural disasters. System crime prevention is being addressed by the agency’s safety office and police department.

**Successes:**

- Achieving a commitment from all divisions and locations to support representatives to participate in monthly meetings to discuss safety and other operations concerns has made a big difference in effective communications and action planning. Upper management’s commitment to review recommendations and take actions when necessary demonstrates the value of the meetings, and fosters continued interest in participating.

**Lessons Learned:**

- Involving operations and maintenance and police directly in safety and emergency management decision making, as well as project prioritization, helps embed a safety orientation as well as risk awareness into everyday operations. Having an established mechanism for communication, that is regular, highly visible, and effective, lends credibility to the effort. Together, these can be a good foundation for resilience.

**References**


Massachusetts Bay Transportation Agency (MBTA)

Case Study:
Boston, MA

**Highlights:** The Boston Metropolitan region is vulnerable to extreme winter weather and other coastal hazards. In coordination with the Governor and the state Secretary of Transportation, MBTA has developed a comprehensive Winter Resiliency Plan, which will be implemented over the next five years through capital investments, non-federal MBTA capital funds, and operating funds. The plan calls for the purchase of new snow removal equipment, infrastructure upgrades, and operations during harsh weather to improve service reliability. The plan can be a model for other agencies that experience extreme winter weather events.

**Winter Resilience Plan**

**Infrastructure**

Third rail replacements and heater upgrades on vulnerable outdoor sections of the Red and Orange Lines.

- Snow fence installation along the Red and Orange Lines to mitigate snowdrift accumulation.
- Repairs to vehicle maintenance facilities and structures to further maximize recovery efforts.
- Emergency power generators to supplement existing subway and facility power as needed.
- Track access improvements for larger snow removal and track work equipment on the Red Line.

**Equipment**

- New and rehabilitated specialized snow removal equipment to increase removal capacity and reduce use of passenger vehicles.
- For passenger vehicles, vehicle-borne anti-icing equipment, modifications to air and propulsion system resiliency and an increased stock of traction motors to improve availability.

**Operations**

- Additional snow removal contract services, as needed, to remove snow and ice at stations, facilities and other critical operations areas.
- Training and staffing of a Field Inspection Team to be deployed during weather events to monitor staff and contractor field activities clearing snow and returning tracks to an operational status.
- Adoption of incident management software in coordination with the MassDOT Highway Division to track deployment of snow removal operations across the system.
- Formal establishment of an as-needed inmate snow removal assistance program with the Department of Corrections to augment and streamline the services provided this winter.
- Further coordination of interagency planning with the Massachusetts Emergency Management Agency, state agencies and local municipalities to identify efficiencies and synergies in snow removal.
• Similar resiliency enhancements to the commuter rail network.
• Revisions to the MBTA’s severe winter weather operations protocols and customer notification practices to ensure more information, customer safety and the protection of equipment and facilities.

**Key Resiliency Drivers:**

• State and local legislation;
• Leadership;
• Disaster Events.

**Key Successes**

• Implementation of the Winter Resilience Plan into the Capital Investments Program (CIP) in 2015
• Coordination between the state, city, and MBTA
• In May 2012, the MBTA signed the American Public Transportation Association (APTA) Sustainability Commitment Pledge. Commits to instituting procedures, policies, and programs designed to quantify their level of continuous improvements in the areas of water, energy, and fuel consumption, reduction in greenhouse gas emissions, increased recycling, and decreased waste generation, as well as other areas within their organization
• Incorporation of reducing environmental vulnerability into the capital investments program

**Key Lessons Learned**

• Resilience initiatives are based on reactionary situations.
• Experiencing a lack of funding, which has put climate change and resilience (unless reactionary) initiatives on the back burner within the CIP.

**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Mid-Atlantic and Northeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>HR, CR, MB, CR, LR, DR, Other</td>
</tr>
<tr>
<td>Vehicles Operated (all modes) (2011)</td>
<td>2,338</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>395.3 million unlinked trips</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>High Winds, Flooding, Sea Level Rise, Coastal Storm Surge, Severe Winter Weather, High Heat Days</td>
</tr>
</tbody>
</table>

**Background:** The MBTA was established on August 3, 1964. The "T", as it immediately came to be known, was one of the first combined regional transportation planning and operating agencies to be established in the United States, encompassing Boston and 77 cities and towns (1).
Policy and Administration

In 2009, MBTA operations were absorbed by the Massachusetts Department of Transportation (MassDOT). The MassDOT Board is composed of 11 members appointed by the Governor and oversees all MassDOT operations. The MassDOT Board was expanded to 11 members by the Legislature this year based upon a recommendation by Governor Baker’s Special Panel, composed of transportation leaders that was assembled to review structural problems with the MBTA and deliver recommendations for improvements (2).

A five-member Fiscal and Management Control Board (FMCB) was appointed by Governor Baker this year. The Board will enforce new oversight and management support, and increase accountability over a 3-5 year time frame. The goals will target governance, finance, agency structure and operations through recommended executive and legislative actions that embrace transparency and develop stability in order to earn public trust. By statute, the MBTA FMCB will consist of five members, one with experience in transportation finance, one with experience in mass transit operations and three members of the MassDOT Board (2).

The state has a major influence on decision making within MBTA, especially when setting priorities. The agency has completed resiliency-related projects and plans but uses the definition loosely depending on the situation. An example of the state influencing the MBTA can be found in the 2015 Winter Resilience Plan, where the Governor made long-term improvements to the system a high priority. A special panel appointed by the Governor reviewed and made recommendations to fix the MBTA’s structural, financial and operational problems. Also in 2014, MassDot created an MBTA Sustainability Report focusing on sustainability issues such as energy, water, air, recycling and waste, and the community. The goal is to address these items to reduce greenhouse gases and become resilient in the face of climate change. However, due to funding constraints and higher needs within the capital investment program, priorities have shifted.

Overall, funding seems to be a major hurdle to getting things done. The Winter Resilience Plan is the number one priority right now. Matrices have been created to track resiliency measures that MBTA has taken to bounce back from a disaster. Also, day-to-day reports on performance of system, in-time performance and on-time have been implemented as well.

MBTA uses several different communications techniques to inform the public, policy makers, and customers about steps being taken to make transit infrastructure and service more resilient, including board of directors’ meetings that are open to the public, the media, exchange with policy makers and ridership, and social media (tracking problems). As far as communication with other public agencies and/or local governments regarding weather, MBTA will partner with them in returning service to normal.

In planning for resiliency (not specifically called resiliency), the agency excels in coordination between operations engineering and maintenance service and structure. After a disaster, MBTA ensures that support systems are up and running and available so trains and buses show up on time. A drill and exercise program is in place in case of a disaster. There is interaction with emergency response teams
around the area (fire departments, etc.), where they conduct drills and provides access to right-of-way. The agency also has a state-of-the-art Emergency Training Center, which is a unique asset of MBTA.

**Systems Planning**

Unfortunately, MBTA does not consider changing weather conditions such as climate change within planning activities related to system preservation of transportation networks and infrastructure. However, MBTA has completed a vulnerability analysis to determine which assets are at risk of being impacted by extreme weather and natural disasters. They do this by hiring a general engineering consulting firm issued to engineering and maintenance. Their operations include flooding and storm-related hardening of the system. For example, based on a major flood that impacted the Green Line in 1996, MBTA and the engineering firm worked with the city of Boston to protect subway portals. Studies were conducted to look at elevations system wide, and steps were taken with various locations to prepare for a 100-year flood.

In 2013, a risk analysis was completed to identify critical infrastructure. The focus of the analysis was on four transit lines including heavy rail and light rail and portal systems to support buses, known as the Silver Line. A number of locations within each transit line tend to be vulnerable, depending on the level of event and structures at risk. MBTA is in the process of mapping its assets and infrastructure in terms of vulnerability to natural disasters and extreme weather-related events.

**Asset Management**

In 2013, the MBTA established an asset management plan. Transit asset management is considered the cornerstone on which the MBTA intends to improve system safety and reliability, reduce costs, make better investment decisions, and provide improved service to its customers (3). However, it does not require specific resiliency goals or policies.

MBTA is in the process of completing an infrastructure inventory through its State of Good Repair (SGR) program database. However, it is seven months behind due to funding constraints within the agency. The database includes revenue vehicles, non-revenue vehicles, track/right-of-way, signals, communications, power, fare equipment, stations, elevators and escalators, parking, facilities, bridges, tunnels, and technology. The MBTA Budget Department uses the SGR Database to provide an SGR rating for capital funding requests as well as to establish funding programs for generalized asset categories. The SGR rating is on a 1-5 scale, with 5 representing a new asset, 1 representing a non-functional asset, and 2.5 representing the score at which an asset falls below a state of good repair. The database assesses asset condition, performance and life expectancy. The type of data that the inventory estimates is the SGR Backlog and SGR Rating for each asset category. In addition, the report will analyze three scenarios: how much SGR investment would be needed to eliminate the SGR Backlog over 25 years; how much SGR investment would be needed to maintain the SGR Backlog at its current level in 25 years; and how the planned investment in this and future CIPs affects the projected SGR Backlog (4).

MBTA’s asset management data systems are able to capture disruption-related data; however, due to funding constraints, it has not yet been used. Once operational, it will be done by using remote monitoring of equipment. For example, it will contain a linear track system (support system to the EAM) and takes track geometry and runs an algorithm, looking at potential changes in the pattern. MBTA has
also enlisted front-line operations and maintenance staff to assist with the monitoring of infrastructure condition and environmental and weather-related conditions. This is part of regular day-to-day activity conducted by MBTA.

**Capital Planning, Programming and Finance**

MBTA does have a capital investment program (CIP), and it is updated annually. For the 2016 fiscal year, the Capital Investment Program provides the authorization to reinvest in its transportation infrastructure and to build expansion projects. Various departments in the Authority, with strategic oversight from senior managers, have responsibility for the day-to-day functions of the capital program. The larger principles guiding the programming of funds are based on the MBTA’s enabling legislation and the Authority’s State of Good Repair standards (MBTA, 2014). Though the term ‘resiliency’ is not used, environmental impacts and vulnerabilities are considered when implementing projects.

A vetting process is used to determine the process used to identify new capital projects. All divisions system wide have a listing of capital investment needs. An application must first be produced, the vetting process is initiated, and a public hearing is scheduled. (Public input has some influence in determining priorities). Given the Authority’s vast array of infrastructure and the need for prudent expansion, the number of capital needs identified each year usually exceeds the MBTA’s capacity to provide capital funds. Therefore, the Authority engages in an annual prioritization and selection process to select the highest priority needs for funding and inclusion in the CIP (3).

For new projects, MBTA uses a time horizon of five years and conducts a cost-benefit analysis. Depending on what asset the agency is looking at through the application process, a description relative to the need for resilience may be associated with that particular asset. A software tool used by the capital budget group weighs long-term benefits versus short-term costs. However, the cost-benefit analysis does not deal with uncertainty in the context of vulnerabilities to changing climate conditions. MBTA only adopts resilient-type projects when there is a critical need, such as the $83 million Winter Resilience Plan.

**Project Development, Infrastructure Design and Construction**

The MBTA reevaluates, develops, and regularly updates infrastructure design standards to address changing requirements and needs and has included design standards that are focused on flooding issues and rely on industry standards, relative to system upgrades governed by local, state and federal codes to balance short-term cost versus long-term durability. However, they do not require the use of resilient materials for rehabilitation, reconstruction, or new construction projects.

When considering the location of new facilities and equipment, MBTA does consider potential risks such as extreme weather and flooding. Through risk analysis, MBTA has identified infrastructure that is potentially susceptible to future flooding events, however, due to funding constraints, nothing has been implemented to date.

**Emergency Preparedness**

MBTA has an emergency management plan that addresses all hazards. The plan is coordinated with emergency response plans at the state and local levels. Updates to the plan are circulated and
developed in collaboration with different departments where regular meetings from stakeholders across organizations discuss emergency management preparedness. However, MBTA does not have a Continuity of Operations Plan and has only certain contingency plans in place when a disaster strikes. Also, MBTA does not have a disaster recovery plan. Depending on the assets that need to be addressed, they mobilize the necessary trades (i.e., engineering) to get service restored.

MBTA has experienced two major weather-related disasters that required significant response: the 1996 floods and the 2015 snowfall. In 1996, the Green Line flooded from the Fenway subway portal to Arlington St. Four hundred million gallons of water were pumped out of the line in four days. Service disruption lasted for nearly a week. In 2015, 100 inches of snow was accumulated and there were freezing temperatures over a 30-day period. Service disruption lasted for nearly 60 days.

For both weather-related disasters, an emergency plan was in place. The plan was useful to an extent, but many lessons were learned. In 1996, the flood pointed out shortcomings with regard to signal system and track components. As a result, preventative and corrective maintenance considerations have advanced. In 2015, needs arose for updated equipment to fight snow and removal; for an updated snow management plan; for more streamlined coordination of snow activity; for better interdepartmental communication; procurement of MBTA’s own snow-fighting equipment to lessen dependencies on outside help; and for replacement of right-of-way infrastructure.

References


Metropolitan Atlanta Rapid Transit Authority (MARTA)

Case Study:
Atlanta, GA

**Highlights:** MARTA has successfully integrated resilience into its operations and maintenance (O&M), asset management, safety management, risk management, capital improvement planning and sustainability initiatives. For a number of years, the agency has sought to advance resilience adoption incrementally by building resilience into existing systems over time. Examples include adding weather-related identification codes to maintenance work orders; adding a module to the Enterprise Asset Management System (EAM) for capital projects that specifically references resilience; including risk management as an explicit component of each asset management plan; and modifying the agency’s capital improvement plan checklist to include resilience and sustainability components. MARTA has found that incremental approaches for broad initiatives, such as sustainability and resilience, are more successful than imposing a new, standalone system.

**Key Resiliency Drivers**

- Leadership;
- Emphasis on linkages between safety, asset management and capital planning;
- FTA Asset Management and Adaptation to Climate Change pilot study;
- Emphasis on sustainability programs and bold initiatives; and
- Severe weather events.

**Key Successes**

- Adding O&M work order codes to better track weather impacts
- Adding proactive “check boxes” to CIP forms to support resilience awareness and actions
- Including risk management in asset management templates; fostering widespread adoption of asset management through procedural templates, working groups and committees
- Developing a capital tab module for the TAM system to include environmental factors, climate resilience, and sustainability (developed with FTA assistance, now widely available)
- Working toward ISO 55000 certification before 2017

**Key Lessons Learned**

- A champion is needed near or at the top of the agency
- Great relations among departments are key- culture of collaboration rather than competition
- Show value for the effort- enable “wins” in what is important to the user. Demonstrate how to navigate the system (for those not as adept) to achieve success
- “Don’t mess with work orders”- build on existing systems, don’t impose new ones
- Name is not important- “sustainability” resonates in Atlanta, resilience does not
- Dedicate your best staff leads across divisions to implement a new, broad-based initiative (like the asset management program beginning in 2009). Pays off in delegation/ internal leadership
development and in building internal expertise and fostering ownership (and reducing reliance on consultants for continuity).

### Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Southeast, not coastal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>HR, MB, DR</td>
</tr>
<tr>
<td>Vehicles Operated [all modes][2013]</td>
<td>781</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>129,901,379</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Extreme heat and wider temperature variations, drought, more intense precipitation</td>
</tr>
</tbody>
</table>

**Background:** MARTA was established by a state legislative act in 1965. After organization, planning, and a successful regional referendum, MARTA purchased the previous Atlanta Transit System bus system in 1972, lowered fares from $.40 to $15 in participating jurisdictions, and greatly increased riders. (1) It is primarily supported by that one-cent sales tax, fare revenues, and federal assistance. It has no dedicated state funding.

MARTA began planning, design, land acquisition and construction for a rapid rail system in the early 1970s. The first trains and set of stations began operation on June 30, 1979. MARTA steadily continued its rail system expansion through 2000, when it opened its 38th station, on 48 (route) miles of track. (1) MARTA operates 446 buses, 182 heavy rail cars, and 153 demand response vehicles in maximum service, and carried approximately 130 million passengers in 2013 across the three modes. (1)

MARTA has often been an industry leader. “At the start of 1999, MARTA announced a partnership with BellSouth to create the Lindbergh Transit Oriented Development (TOD), a live, work and play community built around a rail station and the largest multi-use development of its kind in the United States at the time.” (2) MARTA’s sustainability programs include its fleet of compressed natural gas (CNG) buses and the Laredo Bus Garage, which has the largest solar canopy installation in the state of Georgia, and the second largest structure of its kind at a U.S. transit system. (2) MARTA was one of the FTA Transit Climate Change Adaptation Assessment/Asset Management Pilot sites. Since then, MARTA has worked with FTA and its asset management software supplier (Trapeze) to develop modules to better integrate capital planning and resiliency into asset management. MARTA is currently seeking ISO 55000 certification (the ISO standard for asset management systems), and expects to complete the process by the close of 2016.

MARTA is far enough inland that neither sea level rise nor hurricanes pose a direct threat; likewise it is not in the typical path for tornadoes, and is not in an active seismic zone. Its major threats, as noted in the Climate Change pilot study and reinforced in interviews, are extreme heat (higher temperatures and for longer periods of time); drought; and extreme precipitation (higher volumes over shorter periods of time), with occasional winter storm events. As a result of these non-spectacular risk assessments, the region and the agency are more attuned to the language and focus on sustainability, rather than resilience, while implementing monitoring and checks and balances, so resilience is still considered.
Resilience and sustainability are integrated with other systems of safety, asset management, risk management, capital planning, and operations and maintenance,

**Policy and Administration**

**Summary:** MARTA is an independent transit authority established by the Georgia Legislature in 1965. Its Board of Directors is appointed by the Governor. The Board has the authority to appoint the General Manager, approve the budget and approve agency policy. Funding is primarily a combination of a dedicated one percent sales tax, fare revenue, and federal grants. There is no dedicated state funding, although the state does make contributions at times.

MARTA’s basic operating structure consists of three committees headed by a member of the Executive team.

Divisions work well together, the COO is described as a “best buddy;” collaboration in seeking resources is the rule, rather than competition for resources. The committees work to engage staff from the “front lines” up through the ranks in a culture of safety and innovation.

MARTA’s two major clients/partners in terms of the subway system resilience are Georgia Power, the utility company that supplies power to the rail system as well as facilities for all modes; and Norfolk Southern and CSX, who operate alongside much of the subway system’s right-of-way. All are essential in responding to major events. Georgia Power presents a “single point of failure”; not much has been done to date in terms of resiliency, but as noted, the Atlanta region’s risks from natural disasters are fairly predictable and limited, compared to most areas of the country.

**Successes:**

- Setting and maintaining a collaborative tone across all divisions with systems and processes that emphasize safety and interdependence among divisions.
- Providing leadership to promote sustainability initiatives, such as the solar canopy for the Laredo Bus Garage and the CNG bus fleet.
- Building a culture of safety; integrating asset management, risk management, capital planning and resiliency into that safety culture framework.

**Lessons Learned:**

- A champion is needed near or at the top of the agency.
- Terminology is not as important as results. Without dramatic changes anticipated from climate change, Atlanta is more attuned to sustainability than resilience, and has developed major initiatives to support sustainability. Nevertheless, the agency is explicitly including risk assessments and resilience in the CIP and EAM, and incorporating weather-impact tracking measures into its O&M worksheets and procedures.
- Great relations among departments are key—culture of collaboration rather than competition. Building leadership from divisions among the ranks, such as O&M, encouraging collaboration and discouraging competition among divisions, takes time, effort and mutual trust.
- Folding an initiative like resilience into an existing integrated culture is more effective (for an agency like MARTA) than establishing a separate program.
- A culture of forward thinking in many aspects makes pushing new and upcoming priorities such as resiliency or ISO 55000 Certification easier.

**Asset Management**

MARTA defines asset management as a strategic approach to the management of assets that balances the competing needs in an organization and where informed and prioritized decisions are based on reliable data and clear organizational objectives.

The asset management program represented a new way of doing things, when it was first initiated in 2009. MARTA dedicated cross-divisional “A-team” leaders to work together (in physical proximity as well as figuratively) for over a year to figure out how to implement and embed asset management across the organization. They were responsible for thinking through the issues, and troubleshooting any problems that arose. They worked with the contractor, but ultimately understood the overall system better than the contractor, and as such were able to step up to fully manage the system once it was fully implemented. This internal expertise reduces MARTA’s reliance on outside contractors.

Since implementation, one of techniques that have been used to encourage adoption and acceptance of the procedures has been to demonstrate the value: e.g., what’s in it for me? (WIIFM)? For example, the manager for non-revenue vehicles stated that he needed a new truck to replace an old truck. Helping him work through the asset management process for a multiyear period helped him demonstrate that multiple vehicles would be nearing or past their useful lives in the subsequent few years; getting those vehicles into the capital plan helped the manager better manage his assets, and enabled the agency to better plan expenditures.

**Tools:**

- **Asset Management Stakeholder Management Plan (in database).**
  The stakeholder management plan describes how asset management is integrated across agency divisions and practice areas (including a detailed matrix and organization chart). It also describes three separate but related agency forums (with their respective missions) for institutionalizing asset management into everyday practices: the Asset Management Committee; the Asset Management Working Group; and the Enterprise Asset Management Special Interest Group.
- **Asset Management Plan Template**

  The Asset Management Plan template ([located in](#) database- Table of Contents shown below) demonstrates imbedded collaborative practices as well as the “fold-in” approach to resilience (via risk management.)

  **Highlights—**
  - Explicitly requires acknowledgment and documentation of interdependencies with other divisions and outside stakeholders (see item 3.2).
  - Explicitly requires a risk management plan (see item 6).
Table 1. Table of Contents for MARTA Asset Management Template for Office/Branch Use

TABLE OF CONTENTS

1. INTRODUCTION ........................................................................................................................................... 1
   1.1 Goals and Objectives of the Asset Management Plan ........................................................................... 1
   1.2 Scope ....................................................................................................................................................... 2
   1.3 Review ..................................................................................................................................................... 2
   1.4 Applicability ........................................................................................................................................... 2
2. ABBREVIATIONS AND DEFINITIONS ............................................................................................................ 3
3. [OFFICE/Branch NAME] ORGANIZATION, FUNCTION AND RESPONSIBILITIES ............................................. 5
   3.1 [Departmental/Office/Branch] Goals and Objectives ............................................................................. 5
   3.2 Relationship to other MARTA Offices .................................................................................................... 5
      3.2.1 Relationships with Internal Stakeholders ....................................................................................... 5
      3.2.2 Relationships with External Stakeholders ...................................................................................... 6
4. [OFFICE/Branch NAME] ASSET MANAGEMENT PROGRAM ........................................................................... 6
   4.1 Overview of [Office/Branch Name] Assets ............................................................................................ 6
   4.2 Asset Services Levels ............................................................................................................................. 6
   4.3 Inspection and Maintenance .................................................................................................................. 6
   4.4 Asset Condition ...................................................................................................................................... 6
      4.4.1 Condition Assessment .................................................................................................................... 6
5. [ASSET BY EQUIPMENT TYPE] REPLACEMENT PROGRAM ...................................................................... 7
6. RISK MANAGEMENT PLAN ................................................................................................................................ 7
7. NON-CONFORMITIES, INCIDENT AND ACCIDENTS .................................................................................... 7
8. [OFFICE/Branch NAME] ASSET MANAGEMENT GOALS AND OBJECTIVES .................................................. 8
9. IMPLEMENTATION PLAN .................................................................................................................................... 8
   9.1 Action Plan for Implementing the [Office/Branch Name] AMP Objectives ............................................. 8
   9.2 Action Plan for Implementing STAMP Objectives ................................................................................ 8
10. REFERENCE DOCUMENTS ............................................................................................................................. 9

- EAM cross-over to CIP

MARTA has added a tab to its EAM system, with financial support from FTA, in cooperation with the
EAM software provider (Trapeze). The explicit interface between the EAM and the CIP supports the
MARTA culture of “reaching across the aisle”, recognizing the interrelationships between divisions and
processes, and building bridges between divisions, processes and people. In this particular case, both
systems (EAM and CIP) are supported by established legacy systems, with underlying databases and
procedures for maintaining and updating the systems. Their obvious interrelationship led MARTA to
seek FTA funding for a pilot demonstration, building on the Climate Change Adaptation/Asset
Management pilot. As shown in Figure 1, the Capital tab also provides the opportunity to document
Sustainability, Climate Resiliency, and Environmental factors for consideration in the Asset
Management/ Capital interface file.

B-57
Figure 1. Capital Tab for EAM System

Figure 2 illustrates the MARTA workflow and interface between the EAM and CIP systems.
Whole Lifecycle Asset Management

- Enterprise Asset Management (EAM) System
  - Asset Register/Maintenance Module, etc.
  - Candidate Assets
  - EAM Capital Planning Module
  - Candidate Projects
  - Systems Interface
- CIP Decision Software
- Operate & maintain assets
- Evaluate asset data and develop asset related projects
- Evaluate & rehab/replace assets
- Evaluate projects for inclusion in the Capital Improvement Plan
- Close-out
- Asset Life Cycle Cost Tracking
- Initiative
- Project adopted in capital budget
- Lifecycle Management
- Project Delivery/Controls
- Implementation/Construction
- Procurement
- Planning
- Design

Figure 2. MARTA EAM and CIP Interface Workflow
Successes:

- Implementing a rigorous asset management system across diverse divisions and operating organizations (supported by an FTA pilot grant).
- Deliberately developing an asset management “culture” that incorporates risk assessments and cross-disciplinary forums to sustain the effort.
- Developing an add-on tab to “cross walk” between the EAM and CIP that incorporates climate change resilience, sustainability and environmental factors.
- EAM is one of the foundations of ISO 5500; EAM and other agency-wide initiatives have emboldened MARTA to take this next improvement step to certification (not just the checklist/benchmark).

Lessons Learned:

- Developing an “add-on” tab (or check box, or line, depending on the case) is much better for encouraging adoption of a new concept than creating a new standalone system, particularly for overarching concepts such as sustainability or resilience.
- Instituting a new program like asset management works best with a dedicated “A team” representing O&M as well as other divisions at the outset and through implementation.

If a “new” concept, such as asset management is introduced, it must be “baked in” to the organization culture through procedures, people and perceived benefits as in the non-revenue vehicle manager example above—e.g., understand that the process will need some “hand holding” and demonstration of its real benefits to those using it.

Building a company culture that strives for leadership and excellence—in safety, asset management, operations, and more, takes time and dedication, great relations among departments, a champion at or near the top of the agency, and must show value for the effort.

Capital Planning, Programming and Finance/Project Development, Infrastructure Design and Construction

MARTA updates its capital improvement plan (CIP) annually, with quarterly adjustments if needed. The capital plan follows a ten-year cycle. The EAM interfaces with the CIP, as shown in Figure 2, above. The EAM maintains records on asset condition and performance, and is not specifically a business tool for decision making. The Capital tab in the EAM system (see Figure 1, above) facilitates the ad hoc transfer of data between the EAM and CIP systems. The CIP uses an “Expert Choice” support system to facilitate project prioritization.

MARTA does not have a special process in place to plan for resiliency. As noted, their emphasis areas are safety and sustainability. They do have a flagging system in place for review; operations and engineering work well together to foster smart design.

MARTA maintains a contingency fund for disasters or significant events. It is not limited to capital replacement.
Successes:

- Implementing sustainable solutions like the fleet of compressed natural gas (CNG) buses.
- Implementing the innovative and sustainable Laredo Bus Garage, which has the largest solar canopy installation in the state of Georgia, and the second largest structure of its kind at a U.S. transit system.

Creating direct linkages between the CIP and the EAM.

Lessons Learned:

- Successes in different types of innovations make it easier to embrace new challenges and innovations, like the ISO 55000 Certification.

Operations and Maintenance (O&M)

Summary: O&M is critical to virtually every aspect of safety and asset management, insights into service and capital planning, as well as day-to-day operations. One of the cardinal rules at MARTA is “don’t mess with work orders”. In other words, minor tweaks to work orders, such as adding a check box to identify a weather-related event, is okay; but substituting or imposing an entirely new form or procedure would be very challenging.

Operating procedures related to weather events are in place that help the system achieve needed resilience. Example 1: Operators are familiar with roadways, and know which ones typically flood; they are able to quickly alert dispatchers when conditions are poor, so service can be re-routed and customers alerted. Example 2: Operators identified a site this year that has begun flooding in flash rains, that had never flooded before. Trash clogs and other blockages appear to be part of the problem; work orders and other efforts are being used to monitor the situation and determine what additional actions may be needed. Example 3: Rail operating procedures establish the conditions for going from automatic controls to manual controls, such as icy conditions.

Successes:

- O&M personnel take their roles as the eyes and ears of the organization seriously, in general, especially in terms of safety, and alerting about immediate or recurring hazards.
- Maintaining a collaborative tone across all divisions with systems and processes that emphasize safety and interdependence among divisions.

Lessons Learned:

- Great relations among departments are key- culture of collaboration rather than competition. Building leadership from divisions among the ranks, such as O&M, encouraging collaboration and discouraging competition among divisions, takes time, effort and mutual trust.
- “Baking in” a new system like asset management.
- Folding an initiative like sustainability or resilience into an existing integrated culture is more effective (for an agency like MARTA) than establishing a separate program. Incremental approaches work best.
• A culture of forward thinking in many aspects (such as sustainability, asset management, and ISO 55000) makes pushing new and upcoming priorities such as resiliency easier.

References


Nashville Metropolitan Transit Authority (MTA)

Case Study:
Nashville, TN

**Highlights:** Nashville MTA’s interest in resilience stems from flooding that impacted the agency’s assets and services in 2010. In addition, the City’s Mayor has expressed a public commitment to expanding transit services. In this context, most of the agency’s efforts have been on emergency preparedness and rapid recovery of services when disrupted by extreme weather or natural disaster. Nashville MTA is focused on making sure it “can keep services on the street.” Part of achieving this goal has included taking steps to ensure bus storage facilities and administrative offices were moved out of flood prone areas.

**Key Resiliency Drivers**
- New leadership in the agency in Chief Operating Officer, arrived in summer 2015, and city leadership in mayor’s office
- Citywide emphasis on collaborative emergency planning
- Local partnerships with agencies, such as public schools and Housing, whose populations are regularly affected by urgency and emergency in their circumstances
- 2010 anomaly flooding of the Cumberland River, which destroyed approximately a third of the bus fleet, forced boat evacuation of staff from MTA hub facility, interrupted transit service for two weeks, required rebuilding the hub facility, and spurred previously unprecedented preparation and training for flooding events

**Key Successes**
- Consideration of flooding in alternate route planning, siting, operator and staff training
- Increased collaborative planning with regular and new department/agency partners in the city
- Renovation of existing facility and staff move to additional new facility on higher ground
- Capital planning with more preparedness focus (e.g., scissor lifts in future purchasing)
- More readiness in overall planning: “We are looking to reinvent ourselves in terms of emergency responses”
- Development of MOU with water department location on higher ground 2.5 miles from MTA hub to move buses there when high water is forecast

**Key Lessons Learned**
- Importance of training for staff and operators toward emergencies that have not happened before
- Coordination with city departments and other agencies for emergency response and recovery
- Increased potential for flooding due to changing weather patterns
Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Southeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>Metro bus, commuter bus, and paratransit</td>
</tr>
<tr>
<td>System Size</td>
<td>Small</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Summer storms/lightning, tornadoes; winter storms/icy hills, occasional snow; high winds; potential but rare riverine flooding</td>
</tr>
</tbody>
</table>

Background: The Nashville-Davidson, Tennessee metropolitan area has one independent transit agency, the Metropolitan Transit Authority (MTA), which provides service to the city of Nashville and purchased services to the Middle Tennessee Regional Transportation Authority. MTA operates more than 50 routes for 9.8 million riders on an operating budget of approximately $60.5 million. MTA functions as a Nashville municipal department, with 54 percent of its annual budget derived from the metropolitan government, a combined county-city entity in Nashville.

A newly-elected mayor and her appointed Director of Finance have stated ambitious goals for increasing transit in Nashville, so the agency is in the process of several efforts not used in the past, including long-range capital planning and stepped-up emergency management planning, which will likely contribute to resilience and sustainability. These are not terms the agency currently uses for planning — they are more likely to use “preparedness”—but the forecasting work they describe will clearly contribute to future resiliency.

Policy and Administration

The Nashville-Davidson Metropolitan Transit Authority (MTA) provides services to Tennessee’s capital city, the second largest city in the state. City-county (the government structure) population was 644,014 in 2013, about the size of Boston. The 13-county metro area population was 1,757,912. The city is a center for the music, healthcare, publishing, banking and transportation industries, and is home to numerous colleges and universities. In 2015, Business Facilities’ 11th Annual Rankings report named Nashville the number one city for Economic Growth Potential. Economic and population growth is attributed to revised zoning and investment in parks has stimulated real estate development, especially out of state capital investment, toward creating walkable urban neighborhoods mixing retail, residential, commercial and entertainment.

The Nashville-Davidson metropolitan area (combined city and county governmental entity) is one of the fastest growing cities in the country: an average of 82 people move there every day, contributing to an annual growth percentage of 12.7 percent between 2000-2013\(^1\) Resulting traffic woes have increased attention to transit, but Tennessee has no income tax and municipalities depend on sales tax for revenue. The new mayor called out a focus on transit in her 2015 inaugural address, promising to seek federal and state funding for transit projects. Currently, MTA receives 17 percent of its funding from

\(^1\) http://www.theatlantic.com/business/archive/2015/10/nashville-charlotte-public-transit/412741/
federal sources, and six percent from state. MTA is revising its capital planning from annual to longer term, with fuller budget planning expected for 2017.

The MTA provides bus transit within the city, out of a newly built hub station downtown. Approximately 55 routes utilize a hub and spoke method. Expansion plans include use of bus rapid transit for new routes, with the possibility for local rail service at some point in the future. Currently service includes using RTA for Relax and Ride commuter service during a.m. and p.m. rush, under contract with Gray Line to provide buses and operators. Active Ride, MTA’s paratransit services, uses contracted overflow taxi service to provide added capacity beyond what MTA can handle.

The agency does not conduct formal asset management planning and anticipates that future capital spending guidance will be issued from the mayor’s office of budget and finance. MTA’s COO expects that priorities will be “More balancing to be sure that projects that were approved are completed and that right amount of funding was given and that in any shared projects both [collaborating agencies with MTA] agencies are successful.”

The area has a moderate climate, with few enough winter storms that city resources for plowing and salting are scarce. An eight-inch snow in 2015 effectively shut down the city for three days, although some bus routes operated. Occasional winter storm conditions of ice and some snow make transit hazardous because of hilly terrain; black ice is a problem as often as three or four times a year. Summer weather produces some high winds that affect buses and occasionally cause delays, from operators’ pulling to the side of the road to wait out gusts. Little street flooding occurs and has not been a transit issue (with the exception of the 2010 flooding). Tornadoes are seasonal and MTA has emergency procedures in place for these events.

A thousand-year flooding event of the Cumberland River in 2010 brought nearly 50 inches of water into the MTA primary facility and caused complete flooding of bus parking areas, two weeks’ service interruption, and substantial damage to primary office/hub/maintenance facility. The MTA’s hub facility, where most of its vehicles and staff were at the time, was surrounded because the Cumberland River is on one side of the property and two streamways on another side.

The historic event was unexpected and no protocols were in place to respond. When it was clear that the river was overtopping, operators began moving buses to higher ground, but had to give up when water reached the engines. Some staff evacuated by vehicle while they could; others stayed into the night to direct emergency response, as much as possible, but then were evacuated by fire and rescue personnel in boats. The building was severely damaged, and a third of the fleet lost.

The flood triggered more awareness of preparedness, but funding prevented some measures. The hub building was remodeled, not torn down and rebuilt, so some resiliency changes that could have been made in a new building were not. MTA has developed an MOU with the Water Services Department to use the parking lot of their facility 2.5 miles from the bus hub as a place where buses can be moved if flooding threatens.

Most of MTA’s efforts toward resiliency appear to be in collaborative work with other departments and agencies. Interdepartmental cooperation has been required by the metro government’s budgeting approach in the past, but collaborative work has been increased since the flood, especially in shared
emergency planning. This collaborative effort means that administration of the MTA has a shared aspect in some areas that may be unusual for other transit agencies. For example, MTA’s requirements for engagement in the city’s crisis management plan (CMP) dictate some decisions about operations, funding allocation, and staffing.

**Measurement and Reporting on Resilience-Related Efforts**

Because MTA doesn’t specify resilience-related efforts, there is no measurement or reporting as such. There is tracking of increased training for emergencies.

Because of the shocking impact of the 2010 flood on Nashville, communication with the public, policy makers, customers or others about emergency preparedness has been considerable. The agency uses press releases and its web site to get information about conditions out to the public, but also relies on its partner agencies (e.g., police, schools, housing) to reach the public. These agencies share awareness that changing weather circumstances mean increased likelihood that a damaging flood could occur again. Rains in 2015 brought some flooding to the area, but not as a significant emergency.

**Systems Planning and Asset Management**

MTA has not mapped its assets and infrastructure in terms of vulnerability to natural disasters and weather-related events. As capital planning for the agency becomes more sophisticated, other layers of planning, such as asset planning, may be added.

MTA plans for back up routes during disruptions from flooding. Agreements with collaborating agencies are directed toward borrowing assets (e.g., parking space from Water Services) and services (e.g., distribution of bus passes for homeless in acute cold conditions) from sister agencies. The agency plans to evaluate what resiliency goals may be achievable and what makes sense (time for return to service) in the next year.

**Capital Planning, Programming and Finance**

MTA’s capital planning is performed annually to meet the requirements of the city office of budget and finance. For the first time, in 2016, MTA will begin long-term (five-to-ten year) capital planning. The focus of capital planning is assuring funding requests that can be justified by actual expenditures, with planned outcomes. When projected outcomes are shared – such as MTA’s youth programming that provides student bus service, coordinated with schools, after-school programs, police/crime prevention – budgets, including capital expenditures, are coordinated and each agency held responsible for its portion of the funding.

MTA’s life-cycle planning is built into its bus replacement planning. For a typical bus, the average life is 12 years, and MTA tries to get four or five buses every year, through joint purchasing agreements with other transit agencies in Tennessee.

In the past there was no real assessment of buildings, but since the 2010 flood, MTA has moved administrative staff to a new facility (on higher ground) and is considering how to manage the maintenance work still done in the flood plain facility. The agency’s first priority is its vehicles and keeping service on the streets (unless there is a security or safety issue).
Operations and Maintenance

MTA is working on plans/standard operating procedures to temporarily harden infrastructure (e.g., deploy sandbags and other flood proofing), which it had never considered before 2010, and to protect assets (relocate vehicles and other moveable equipment) when extreme weather and/or a natural disaster are anticipated.

Emergency Preparedness

MTA has emergency management and procedures, which are part of its coordinated CMP with other agencies and the city’s overall emergency planning. Communication is central to their approach; in threatening weather, customer care people come in earlier, and the agency uses email, phone calls, and verbal alerts at transfer points. They alert third party operators and news media. The area’s office of emergency management (OEM) is close to downtown and MTA provides a safety or security manager overnight to keep track of weather, when necessary. MTA has participated in tabletop exercises to train personnel regarding the protocols and procedures included in the area’s management preparation.

Current Collaborations

MTA is part of many collaborative efforts for provision of services, and for regional emergency management planning. The agency’s resiliency efforts seems to be shaped in important ways by these collaborations with other metropolitan agencies (fire, police, emergency management, housing) that involve cooperative funding, with each agency responsible for providing budget forecasts, executing planned/budgeted activities, and demonstrating how activities corresponded to requested funds (“how spending matches asking plan”) in cooperation with other agencies sharing the funding. For example, MTA collaborates with the local housing authority for emergency transportation/shelter for the area’s homeless population when the temperature is 32 degrees or below. Bus passes distributed through the housing authority to various agencies are made available to people who will need transportation to shelters. Both MTA and the housing authority must defend to the city finance officer the amount and use of their collaborative funding.

Various youth services provide another example, including the STRIDE program that provides bus passes to get students to and from schools. Not only providing the bus services, MTA also works with crime units, police, and schools to monitor how after-school programs are utilized, as well as on-time performance for students with passes.

While it is beyond the scope of this study to examine an agency’s contribution to overall community resilience, it is worth noting the substantial commitment and achievement MTA makes to resilience in Nashville, in just the two programs named above.
New Jersey Transit Corporation (NJ TRANSIT)

Case Study:
New York – Newark, NY-NJ-CT

**Highlights:** NJ TRANSIT has adopted an enterprise-wide commitment to infrastructure and operational resilience across modes and departments. The agency’s resilience initiatives are being undertaken in the context of Superstorm Sandy recovery and rebuilding. The agency’s infrastructure and rolling stock sustained significant damage during the storm. Long term, NJ TRANSIT is focusing on resilience by incorporating “designs and materials that can resist and survive weather events.” The agency is also in the process of designing and constructing NJ TRANSITGRID, “a first-of-its-kind electrical micro-grid capable of supplying highly-reliable power during storms or other times when the centralized power grid or local power distribution networks are compromised;” and a Coast Storm Surge Emergency Warning System in partnership with NOAA and Stevens Institute of Technology. In the wake of Superstorm Sandy, NJ TRANSIT put in place a very detailed, mode-specific, Comprehensive Emergency Management Plan that is publically available online. NJ TRANSIT utilizes FTA’s Hazard Mitigation Cost Effectiveness Tool to evaluate resilience as part of its capital planning process and adopted new service cessation and rapid recovery procedures.

**Key Resiliency Drivers**

- Events including September 11th, the 2003 Northeast (NE) Blackout, Tropical Storm (TS) Irene and, Superstorm Sandy
- Availability of federal recovery funding to support project implementation
- Leadership
- Availability of models and technology
- National requirements to support safety, reliability, and economy

**Key Successes**

- Robust commitment of the NJT enterprise to resilience
- Implementation of the NJT Comprehensive Emergency Management Plan (CEMP) that is flexible, adaptable, and scalable
- Application of the CEMP, evaluation of results
- Strategic approach to capital planning and programming for resilience, across all modes
- Training across the NJT enterprise in emergency response, and recovery
- Active communication concerning design, progress, and benefits of resilience projects via an interactive web site, public information sessions and stakeholder engagement
- Utilization of models and GIS data to support decisions concerning priorities for actions promoting resilience
- Integrated approach to resilience at two levels: Resilient infrastructure initiatives that have independent utility, while also interdependent (capital projects); and Resilient operations (CEMP)
**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>East Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>MB, CR, LR, CB, DR</td>
</tr>
<tr>
<td>Vehicles Operated (all modes) (2014)</td>
<td>5,019</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2014)</td>
<td>271.0 million</td>
</tr>
<tr>
<td>Hazard Examples</td>
<td>Flood, Winter Storms, Superstorms/Tropical Storms, Extreme Heat, High Winds/Lightning, Storm Surge/Wave Action, Sea Level Rise, Cyber Disruption, Power Failure</td>
</tr>
</tbody>
</table>

**Background**

NJ TRANSIT is the nation's largest statewide public transportation system providing more than 938,500 weekday trips on 257 bus routes, three light rail lines, 12 commuter rail lines and through Access Link paratransit service. It is the third largest transit system in the country with 165 rail stations, 62 light rail stations and more than 19,000 bus stops linking major points in New Jersey, New York and Philadelphia. NJT also administers several publicly funded transit programs for people with disabilities, senior citizens, and people living in the state's rural areas who have no other means of transportation. In addition, the agency provides support and equipment to privately owned contract bus carriers.

New Jersey is a comparatively small state—ranked 47th in terms of total area. However, it is ranked 11th in terms of population. With more than 8.7 million residents, New Jersey is the most densely populated state in the nation with almost 1,200 residents per square mile. New Jersey is bordered by New York State to the north, Pennsylvania to the west, the Atlantic Ocean to the east, and the Delaware River and Bay to the south. NJT provides public transportation services throughout the State, including in urban, suburban and rural areas. The agency has a service area of 5,325 square miles, which covers more than 70 percent of the state’s land area. It provides bus, commuter rail, and light rail transit, linking major points in New Jersey, New York, and Philadelphia. New Jersey’s monthly average temperatures range widely across the different regions of the state, with average summertime highs in the mid to upper eighties to wintertime lows in the single digits to low thirties. New Jersey receives an average of 46.94 inches of precipitation annually.

New Jersey is vulnerable to a number of natural and weather-related hazards, including: high heat days during summer months, significant rain events that cause urban street and riverine flooding, high winds, regular recurring tidal flooding, and coastal storm surges from nor’easters and tropical cyclones. Winter storms can bring significant snowfall coupled with winds as well as icing events that impact both roadways and power lines. The last major storms to impact New Jersey were Tropical Storm Irene in 2011 and Superstorm Sandy in October 2012. In particular, Superstorm Sandy devastated parts of the state; however, both storms caused widespread infrastructure damage. New Jersey has also been subject to localized and regional power failures.

NJT’s current resiliency initiatives are being undertaken in the context of Superstorm Sandy recovery and rebuilding. The agency’s infrastructure and rolling stock sustained significant damage during the
storm. In the immediate aftermath of the storm, NJT’s recovery strategy involved efforts to “identify damaged infrastructure, deploy resources to effect immediate repairs and to make service restoration a priority.” Intermediate recovery efforts focused on protecting vulnerable infrastructure and resources by implementing “near term protection measures.” Long term, the agency is focusing on resiliency by incorporating “designs and materials that can resist and survive weather events.” NJT has programmed $768 million dollars repairing damaged infrastructure in a resilient manner ($625m) and investing in long-term resiliency ($143m). Funding sources for the agency’s resiliency capital program include Sandy Recovery funds from FTA and state transportation trust fund and partially from insurance proceeds.

In addition, in September 2014, it was announced that NJT had been awarded $1.276 billion in resiliency funding as part of a competitive grant program sponsored by the FTA. A portion of these funds will be used to design and construct NJ TRANSITGRID, “a first-of-its-kind electrical micro-grid capable of supplying highly-reliable power during storms or other times when the centralized power grid or local power distribution networks are compromised.” The micro-grid will incorporate renewable energy, distributed generation, and other technologies to provide resilient power to key NJT stations, maintenance facilities, bus garages, and other buildings. Through a micro-grid design, NJTGRID will also provide resilient electric traction power to allow NJT trains on critical corridors, including portions of the Northeast Corridor, to continue to operate even when the traditional grid fails.2

Additional to the NJ TRANSITGRID, this funding will be used to support four other projects that will construct a resilient river crossing; help maintain passenger rail operations before, during and after a weather event; protect communications and safety infrastructure; and, provide for the safe storage and rapid re-deployment of equipment. Although, these projects will be discussed in more detail later, it is important to note that they are each an element in a larger strategy of statewide resilience. The separate utility of each project is obvious, but when viewed from a wider perspective, their interdependencies become clear. A project that can help passenger rail remain in operation longer during a weather event and restore service after one is only possible if rolling stock is stored in a protected location; infrastructure is in place that can weather storms; and, electric power is available even if the regional grid has failed.

Policy and Administration

In the wake of Superstorm Sandy, NJT leadership has been forceful and effective in advancing enterprise-wide resiliency adoption. NJT emergency plan evolved into a strategy based on lessons learned which included the Comprehensive Emergency Management Plan to ensure resilient transit operations. NJT has:

- Established and staffed a new Resilience Program within the NJT Capital Planning and Programs Department.
- Expanded its commitment to emergency preparedness and resilience training and retraining.

Those initiatives emanate from a resilience commitment that is comprehensive and intense, mainstreaming resilience as an integral part of NJT capital planning and operations.

---

The Resilience Program is within the Capital Planning and Programs Department. The staff is responsible for administering federal funds dedicated to resiliency projects. The Resilience Program works with project managers and others across the enterprise, using a matrix management approach.

NJT brings on expertise as needed via staff hires and consultants.

**Metrics to Support Policy and Administration**

To evaluate the success of the Resilience Program, NJT applied the metrics embedded in the Federal Transit Administration’s Hazard Mitigation Cost Effectiveness Tool. The tool estimates potential benefits and costs in terms of damage to fixed structures and rolling stock, costs associated with response and recovery/repairs; and “other” costs such as the projected number of commuter delay hours that are saved per day because of investments being made. Those hours are then multiplied by $19.40 per hour to provide one estimate of the value of an investment.

**Communications of the Resilience Program**

NJT highlights its Resilience Program to the public in several ways, including:

- Periodic updates to the NJT Board of Directors on specific resiliency projects.
- Creation and maintenance of a public website, [www.njtransitresilienceprogram.com](http://www.njtransitresilienceprogram.com). The site includes:
  - The NJT Comprehensive Emergency Management Plan
  - Status reports on the progress of projects that enhance resilience of the system
  - Environmental assessments and impact statements
- Staff presentations at community meetings and at professional forums.

**Cooperation with Other Agencies**

NJT, through its Resilience Program and NJT Police Office of Emergency Management, regularly cooperates with a range of federal, state and local agencies. These include: United States Department of Energy and Sandia National Laboratory on the NJ TRANSITGRID project; the Federal Transit Administration; Federal Emergency Management Administration; the NJ Governor’s Office; NJ Office of Homeland Security and Preparedness; NJ State Police and the NJ Office of Emergency Management; other state agencies as needed and various county and municipal public safety officials, including local offices of emergency management. NJT, along with the NJ Department of Transportation, serve as the co-leads of Emergency Support Function #1 (ESF1) – Transportation, under the State Emergency Operations Plan. As part of its ESF1 responsibilities, NJT provided emergency bus transportation to support the evacuation of critical transportation needs populations living in coastal communities and the transport of first responders during both Tropical Storm Irene and Superstorm Sandy.

**Asset Management**

NJT has an Asset Management Plan/Program and is working on bringing it into compliance with MAP21 requirements. The plan addresses all transit modes. Resilience is being incorporated in state of good repair decision making, especially in terms of flood resiliency. The asset management system utilized separate, mode-specific databases. A unified, enterprise-wide database is currently in development.

NJT already has good information on the location and state of good repair of bus and rail rolling stock, stations and terminals, underground storage tanks, and diesel generators. Enhancements are under
way that will afford NJT visibility of both inventory and state of good repair of all assets and infrastructure.

The agency does maintain a geo-referenced inventory of assets and has mapped the asset in relation to FEMA Flood Rate Insurance Maps (FIRM) and Sea, Lake, and Overland Surges from Superstorms (SLOSH) vulnerability. In addition, the agency continues to assess the vulnerability of its infrastructure, assets and operations to failures in the electric grid or disruptions due to cyber-attacks.

High heat days are already part of NJTs Standard Operating Procedures (SOPs) for LRT and Heavy Rail. Rail inspection protocols are part of regular safety protocols. De-icing is also part of SOPs to avoid sagging catenary. Running trains to prevent icing and clear tracks is a standard practice.

**Capital Planning, Programming and Finance**

NJT continuously maintains or replaces century-old infrastructure – much of it inherited from predecessor railroads – while at the same time trying to make its property resilient to current and future hazards. The costs associated with upgrading/replacing century-old infrastructure components are seen as a barrier to resiliency implementation. Other challenges to resiliency improvements include the fact that many stations and terminals are historic resources and not easily modified or replaced with modern equipment or features. In addition, NJT recognizes that many of the improvements made for the purpose of increasing resilience also have more general benefits for safety, reliability and economics of service.

NJT’s multiyear, multimodal comprehensive capital program of projects is intended to repair Sandy damage and complete system-wide resiliency projects. In particular, NJT is focused on improving the resiliency of its system assets to flooding and storm surge and to ensure power is available to support and maintain key assets before, during and after disasters.

The overall program comprises a variety of projects and programs, including:

- **Construction of Delco Lead Train Safe Haven Service and Inspection Facility.** This project includes construction of a service and inspection facility and storage tracks for trains in County Yard, an existing railroad property adjacent to the Northeast Corridor in New Brunswick, NJ. It also includes improvements to the Delco Lead, which is adjacent to both the County Yard property and the Northeast Corridor between New Brunswick and North Brunswick Township, for storage of NJT equipment during severe weather events.

- **Filling of the Hoboken Long Slip Canal.** Much of the flooding that inundated NJT’s Hoboken rail yard during Sandy was caused by storm surge entering through the Long Slip Canal. As part of an FTA grant, NJT will fill in the Long Slip Canal that runs by the Hoboken Terminal and yards. Six new tracks will be installed on the land created by filling the canal, and a major source of vulnerability will have been eliminated.

- **Replacing the Raritan River Drawbridge.** Recognizing that bridge resiliency is essential to safe and reliable operations along its North Jersey Coast Line (NJCL), NJT is replacing the Raritan River Drawbridge (River Draw), an existing century-old swing bridge that carries almost 10,000 daily NJT customers on NJCL trains over the Raritan River and is a critical link to the employment...
centers of north Jersey and Manhattan and the southern beaches and attractions of the Jersey shore. Taking advantage of structural design approaches and materials that are able to withstand ocean surge forces and saltwater immersion, the new Drawbridge will be significantly less vulnerable to severe weather events. Proposed components to achieve infrastructure resilience include new reinforced concrete piers on piles; new steel superstructure; new drive motor and electrical controls; tie-ins to existing track; vertical adjustment of existing track; and electrical catenary relocation.

- **Projects that will raise vulnerable infrastructure above flood levels.** NJT has completed an analysis of all infrastructure items damaged by Superstorm Sandy (substations, switches, other electronics, etc.) that can be elevated above flood levels and is systematically raising these items to reduce the risk of damage from future flooding. This includes raising an entire electrical substation to the second floor of a building NJT owns. To facilitate this effort, NJT has adopted a design standard for construction that specifies that facilities and equipment be built at an elevation of two and one-half feet above base flood elevation. The general standard in New Jersey is one foot above base flood elevation.

- **Projects designed to protect assets that can't be raised above flood levels.** Many essential components of rail transportation, including fixed facilities and assets such as stations, signals, wiring, and yards cannot be elevated. To protect these assets, NJT has undertaken a systematic effort to flood proof facilities and assets where feasible and where not, to develop procedures that will facilitate rapid repair/recovery of item functionality post event. For example, NJT has designed signal and switch technology and developed a zone-based plan so that it can be rapidly removed when flooding is expected and returned to service after flooding has subsided. In addition, NJT is investing several million dollars to protect and harden its Meadows Maintenance Complex and Yard against inundation and infiltration with raised barriers forming a perimeter wall and, pumps.

- **Development of NJ TRANSITGRID.** NJT is keenly focused on ensuring the availability of power and energy to support its operations and services before, during and after emergency events and natural disaster. Sole reliance on public utilities to provide power is insufficient, and relying on diesel generators for redundant power is not adequate to maintain continuity of public transit operations. After Sandy, NJT participated in the New Jersey State Public Utilities Working Group to develop a comprehensive approach to provide resilient power sources. The idea for developing NJ TRANSITGRID grew out of the working group meeting.

Subsequently, NJT received a grant from the U. S. Department of Energy (USDOE) that included $1 million worth of technical assistance from experts at Sandia National Laboratories who normally work on guaranteeing the resilience of electrical power grids at U. S. military bases. The Sandia consultants worked with NJT for a period of a year and three-part energy resilience strategy that includes:  a) Construction of its own central power plant capable of producing at least 100 megawatts utilizing gas turbines; b) Installation of a resilient power transmission and distribution architecture including redundant substations and distributed generation capabilities at specific facilities including stations, bus garages, and ferry terminals; and, c) Creative methods
of storing power in batteries in non-revenue service vehicles. The power is to be collected during off-peak hours.

All the projects taken as a whole are a package of improvements that will protect assets and operations, and, speed recovery and a more rapid return to full services, including key elements of the bus network and light rail, commuter rail, and paratransit services.

Finance

NJ TRANSIT does not have a separate process for financing resiliency efforts.

Resiliency requirements are considered in the planning, programming, and budgeting of projects.

NJT accumulates the costs of damage due to weather-related events by establishing separate accounts for charging labor and other costs allocated to recovery. Those costs form the basis for insurance claims and for claims to the Federal Transit Administration’s Emergency Relief Program.

System Planning

NJT’s planning for resilience includes all departments of the enterprise. It is also integrated with the activities of the NJ State Police, Office of Emergency Management. NJT uses modeling, including inundation models to assess infrastructure and service vulnerability to flooding and storm surge. In addition, NJT is developing its own in-house modeling capability. In partnership with researchers at Stevens Institute of Technology and its consultant, BEM, NJT is building out a Coastal Storm Surge Emergency Warning System for its Hoboken and Kearny facilities.

The system will use active tide gauge data to model the potential impacts of storm surge in real time. The system will map effects of potential surges on NJT property, including the effects of surges on areas as small as three meters by three meters. When the system is built out, NJT will be able to correlate surge forecasts to specific assets at Hoboken Terminal and Kearny and potential impacts of a surge.

The totality of data collection and modeling tools enable NJT to correlate predictions of storm surges and flooding with the latitude, longitude, and elevation of specific NJT assets. That will, for example, inform the decision to implement the plan for removing components of switching systems to protect from likely flooding.

Operations and Maintenance

NJT evaluates data from regular maintenance inspections to access the condition of its infrastructure upon which the assumptions of the Comprehensive Emergency Management Plan are based. In preparation for a severe weather event, inspections are conducted by operations to identify specific conditions of infrastructure.

Emergency Management Planning

NJT’s emergency management functions are coordinated through the New Jersey Transit Police Office of Emergency Management. Since, 2014, NJT formally promulgates its CEMP annually. Based on an all-hazards, whole-community approach to emergency preparedness, the CEMP includes a Basic Plan that sets an overall concept of operations for managing emergency situations and assigns responsibilities to NJT departments and personnel in terms of their roles during emergency events. In addition to the
Basic Plan, the CEMP includes six annexes that provide guidance on preparedness, response and short-term recovery. A Business Continuity Plan with six similar annexes for operational continuity is under development. Guidance regarding business continuity in terms of NJT’s corporate/administrative functions, the functions of NJT Police as well as the operation of NJT’s commuter rail, light rail, access link, bus services and information technology immediately before, during and after an emergency event is included.

In addition to the CEMP, NJT has also developed redundancy in terms of its emergency operations center with a new mobile emergency operations center. The agency has also upgraded its communications interoperability; and has placed renewed focus on building and sustaining relationships with regional, state and local government agencies/jurisdictions that enhance preparedness and improve outcomes when a disaster occurs. In addition, NJT has undertaken the construction of a new, state-of-the-art Emergency Operations Center.

Finally, NJT maintains a robust enterprise-wide emergency preparedness training program. Annual training on the CEMP and its associated annexes is also conducted. As part of the program NJT personnel from across modes and departments regularly participate in immersive, scenario-driven, tabletop simulations and exercises through the Texas A&M Engineering Extension Service (TEEX). Additional exercises, tabletop through full scale – some of which are FRA-mandated – are held throughout the year. Members whose skills are essential to response and recovery attend more than once.

The winter storm of January 2016 resulted in the activation of the CEMP, including several of its various annexes. Activation of the plan improved outcomes and reduced customer disruptions. Services were shut down for approximately 24 hours and restored on a rolling basis, with all services recovered within 48 hours.

Activation of the plan included a provision for shutting down service to eliminate the risk of bus accidents on snow-covered streets in low-visibility conditions and of stranding passengers in trains or buses in a hazardous environment. Shutting down service also allowed for reserving and allocating resources to protection of the system and recovery. Success of the CEMP operations reflected the fact that operations staff and managers of all transit modes had been trained in CEMP procedures.

After the winter storm of January 2016, NJT Office of Emergency Management facilitated an after-action “hot wash” with management to discuss and detail how NJT operations performed under plan activation and how the CEMP might be changed to improve outcomes even further. The hot wash was supported by hardware and software that records decisions and actions on an active basis during each emergency event. There is also an infrastructure impact assessment during and immediately after the event that assists in understanding what is needed to restore services effectively.

Based on the experience of NJT with the winter storm of January 2016, NJT rated itself well prepared for responding and recovering from winter storm events. They rate themselves as progressing toward becoming “very resilient” overall.
New Orleans Regional Transit Authority (NORTA)

Case Study:
Serving Orleans Parish and Kenner, Louisiana

**Highlights:** Over the past 10 years, the RTA has been aggressively rebuilding its entire system (facilities, vehicles, equipment, track, catenary, electrical substations), which was largely destroyed Hurricane Katrina in 2005. A “philosophy of resilience is woven into all their investment and operational decisions.” RTA has put in place procedures to relocate all moveable assets out of “harm’s way” to remote and safe locations when flooding is expected. Key functions for the system’s operation can be provided “on the fly.” The RTA has a mobile dispatch and communication unit that is now a key player in New Orleans’ City-Assisted Evacuation Plan, which is designed to serve the large carless population in New Orleans. The plan was successfully executed in response to Hurricane Gustav in 2008

**Key Resiliency Drivers**

- Leaders at all levels of government
- Infusion of critical funding by the Federal Government (FEMA, USDOT, FHWA, Corps of Engineers)
- Leadership by the RTA Board of Commissioners and their private management/operational team of Transdev, which oversees the day-to-day functions of the transit authority
- Implementing policies that assure there will be no repeat of the death and destruction caused by Hurricane Katrina
- Strong partnership with the City of New Orleans, the Deputy Mayor for the City’s Office of Homeland Security and Emergency Preparedness, the Regional Planning Commission (MPO) as well as leaders in the region.

**Key Successes**

- “In a mere 32 days, the RTA resumed operations, using its surviving vehicles and a group of 83 buses donated from cities across the country. The RTA’s resilient employees began to cobble together the remains of New Orleans’ 179 year-old transit system” (1).
- Over the past decade, the RTA has rebuilt their system almost completely while instituting an operative philosophy of resilience woven into all their investment and operational decisions.
- While Katrina showed the dysfunction of the City’s and RTA’s evacuation plans, in the ensuing years great strides have been taken to right the wrongs of Katrina-era evacuation policies and procedures: no “shelter of last resort” within the city; no vertical evacuation; no “safe harbors” within the city.
- Strong partnerships with a wide array of federal and state partners as well as the Regional Planning Commission (the New Orleans MPO).
- An aggressive streetcar line expansion program is being constructed along North Rampart Street along the upper French Quarter.
Key Lessons Learned

- Resiliency is a management and operational mandate post-Katrina.
- The unthinkable can happen. Be prepared for the worst.
- Tenacity can persevere over incredible obstacles; it just takes incredible focused vision and the financial resources.
- Anything is possible.
- Aggressive marketing and system expansions have resulted in significant gains in annual ridership: “Last 5 years – ridership up (7.0 million) 60% and service hours up (146,000) 32%. In 2013 – ridership up (2.0 million) 12% and service hours up (75,000) 14%” (2).
- “The RTA in New Orleans has undergone an amazing renaissance and has overcome enormous challenges in the ten years since Hurricane Katrina – challenges never faced by any transit system in American history. Through this process the RTA has emerged as a renewed organization” (3).

Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Gulf Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>Bus, paratransit, historic streetcars, pedestrian ferry</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td>135</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>12,915,657</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Hurricanes, urban flooding, coastal flooding, waves, storm surge,</td>
</tr>
</tbody>
</table>

Background: The RTA began operating as the public transit provider in 1983 for the Greater New Orleans region, however, today, it provides service to only Orleans parish and the suburban city of Kenner. Its Board of Commissioners is appointed by both the Mayor of New Orleans and the President of Jefferson Parish. At its peak its annual ridership was over 18.6 million riders making it the largest transit authority in Louisiana. In 2004, the RTA reported 367 buses, 66 streetcars, and 115 demand response vehicles to the National Transit Database.

The RTA is governed by a Board of Commissioners but day-to-day management and operations are contracted to Transdev, formerly Veolia, who were awarded a 5 year contract in 2009 with a 5 year extension. This is a unique operating model for a public transit authority in the United States. The RTA Board has the overall authority for transit in New Orleans including setting fares, overseeing service and operations, developing operating budgets, approving each year’s annual transportation development plan, and deciding upon capital purchases and expansions.

Background of Hurricane Katrina and New Orleans: When Hurricane Katrina struck New Orleans on August 29, 2005 the massive flooding caused by the storm surge and resultant failures of the federal protection system (flood walls, levees and pump stations) covered over 80% of the city with water, in some places, over 15 feet in depth. As a result, the city was largely abandoned and those who could not leave were taken to a “shelter of last resort”: the Louisiana Superdome. Others sought shelter at the
Ernest N. Morial New Orleans Convention Center. Their plight was broadcast across the country for countless days as the death and destruction in New Orleans became clearer.

The RTA used buses to transport people to the Louisiana Superdome, the city’s designated “shelter of last refuge.” Flooding occurred at all of RTA’s facilities except the Willow Street streetcar barn. Damages included: 85% of its fleet was destroyed or rendered useless and inoperative; 146 buses were visible outdoors (and under water) at the RTA’s 2817 Canal Street facility, while only 22 were at 3900 Desire Parkway. The flooded buses were basically written off.

Katrina was the costliest natural disaster in US history (estimated at $108 billion by the National Oceanic and Atmospheric Administration). It killed over 1,833 people along the Gulf Coast and impacted almost all of New Orleans’ neighborhoods.

**Katrina and the RTA:** “There was no precedent for how to reconstruct a transit system after the kind of devastation that resulted from Hurricane Katrina. More than half of the RTA’s vehicles were destroyed and others severely damaged. Its maintenance and operational facilities, as well as administrative offices in New Orleans East were destroyed. Employees were left devastated by the loss of their homes and way of life...These everyday people...banded together under unprecedented circumstances and extreme challenges, with limited funds, and rebuilt a major transportation system from scratch. The story of how they responded in the aftermath of Katrina is one of reliance, ingenuity, dedication and grit” (1).

**The First Few Months after Katrina Struck:** In testimony before a subcommittee of the US House of Representatives in October 2005, (post-Katrina) RTA General Manager William J. Deville reported “that as a result of Katrina, the RTA lost 30 streetcars, 197 buses, and an undetermined number of LIFT / paratransit vehicles. Administrative offices in New Orleans East, the A. Phillip Randolph Bus Facility on Canal Street, the Canal Streetcar Storage, Inspection and Service Facility and the East New Orleans were all extensively damaged by high winds and floodwaters” (4). The ridership base for the RTA was devastated.

To understand the extent of the RTA’s infrastructure damage and its impact on ridership, I attended all sessions of the Bring New Orleans Back (BNOB) Infrastructure Committee, the Mayoral appointed recovery body, chaired by then RTA-Chairman James Reese. I wondered about the fate of the RTA. Mr. Reese stated in multiple meetings “As far as public transit is concerned, I have no idea. Are the people coming back? To where? How many? At this time, all of these remain unknown” (5). No one had answers to these questions in the waning months of 2005. But the citizens of New Orleans did return, neighborhoods were rebuilt and public transit began a long, painful period of recovery and renewal.

Pre-Katrina, daily ridership averaged 124,000 on the system’s 46 bus routes and 3 streetcar lines or an annual ridership of 45,260,000. According to a local transit advocacy group, Ride New Orleans, whose 2015 publication *The State of Transit in New Orleans, 2015: Ten Years After Katrina:* “Today, 10 years (after Katrina) bus service is down 65% while there are now more streetcars making more trips than were offered in 2005. Ridership gains have slowed in recent years, likely due to the lack of frequent service. While streetcars remain an historic and iconic part of our transit system, they are costly to install and inflexible in providing service. Federal monies and local bond sales have financed a massive
streetcar expansion project which has not been well-integrated into the existing network of bus routes and has worsened commutes for some bus riders by forcing them to transfer to the new streetcar to complete their trip.” (6)

**Policy and Administration**

Relative to RTA’s post-Katrina efforts, they “sought as many external sources of revenue as possible, securing over $320 million in federal funding. Countless hours were expended to provide the exhaustive detail necessary to complete the extensive paperwork and submit proposals to secure each funding source. Examples of the secured funds include:

- A $45 million grant from the TIGER stimulus program
- $17.3 million from the American Recovery and Reinvestment Act federal stimulus program
- $7 million to replace the cross-ties on the St. Charles streetcar line
- Forgiveness of a $47 million community disaster loan
- $130 million in FEMA funds to restore facilities, streetcar electrical wires and track infrastructure and to purchase new bus, streetcar and paratransit vehicles

The above actions, plus the ongoing rigorous management of finances, budgets, and costs have improved the RTA’s credit rating and its financial stability. With careful management, the RTA has recovered financially from the many challenges presented by Hurricane Katrina” (1).

“In 2008, with about 30% of the transit system restored, the RTA recognized that more transit service was needed to get the people of New Orleans to and from jobs, retail, universities, healthcare, and other locations...(Consequently) The RTA Board of Commissioners, through a competitive solicitation process, requested proposals from private-sector companies with expertise in transit operations and management. The RTA selected Veolia Transportation, now Transdev, to serve as its transit operator under a five year agreement with a five year extension...Under an agreement signed in the fall of 2009, Transdev manages and operates all aspects of the transit agency with supervision from the RTA. The Board maintains policy control, including service levels and fares, as well as ownership of all assets, vehicles, and facilities. This arrangement is common in Europe and Asia, but was the first-of-its-kind in the U.S...The RTA Board directed Transdev to build upon what the RTA had already accomplished since 2006. After an extensive analysis, bus routes were redesigned in 2010 to serve as many people as possible, address the greatest needs, and match new settlement and travel patterns in the city with the equipment the RTA had at the time...Since 2008, as operations became more normalized and the focus on efficiency paid off, RTA costs per revenue hour have decreased significantly every year...Total RTA cost per revenue hour is approaching pre-Katrina levels, an accomplishment of which the RTA Board and Transdev are deservedly proud....The combination of decreased costs plus significant growth in ridership means the RTA is providing more trips for less cost per trip” (1).

With the infusion of federal monies and bond revenues, the RTA has steadily rebuilt their facilities and service fleet. However, since Katrina, the operative philosophy at RTA is resilience and recovery. Toward those ends, fixed route services have returned to most neighborhoods. During the repopulation period,
Lil Easy demand response vehicles provided service to neighborhoods “slowly repopulating” including Gentilly, Lakeview and the Lower Ninth Ward.

Tools:
- Used a variety of federal, state and city funds for disaster recovery and reconstruction as well as bond monies
- Operative policy of resiliency adopted post-Katrina for all reconstruction and new capital projects

Successes:
- Substantially rebuilt system and facilities after Katrina
- Active participation in the CAEP which was used successfully during Hurricane Gustav

Lessons Learned:
- Previous policies and procedures applied during Hurricane Katrina were abandoned.
- New policies and procedures were adopted that changed the foundations of disaster evacuation in New Orleans.

**Systems Planning**

All policies and procedures adopted by the RTA have resiliency at their core. This includes the reconstruction of facilities, vehicle rebuilds, support infrastructure, maintenance programs, etc. Key support utilities (generators, substations, etc.) have been elevated to avoid future flood damage. Remote safe houses for moveable equipment (buses and paratransit vehicles) have a pre-arranged “safe” destination “out of region”. A mobile control and dispatch unit has been purchased which accommodates eight key personnel for management of equipment during disasters.

Tools:
- Core policy in all planning, operational and management decision making is resiliency
- Closely coordinate their system with the Deputy Mayor for Homeland Security and Disaster Preparedness and his core staff as well as state and federal partners

Lessons Learned:
- Plan for the worst but prey for the best because the worst can and did happen during Hurricane Katrina
- Proactively plan and manage for a resilient system: physical facilities, vehicle fleet, critical infrastructure
- Safe locations for vehicle storage “out of region” have been secured for future hurricane events
- The CAEP works. This was shown by the successful evacuation during Hurricane Gustav. Details are described below.
**Post-Katrina Evacuation Policies Rethought: The City-Assisted Evacuation Plan**

The City’s evacuation plan for hurricane events include some significant changes from their pre-Katrina policies: no vertical evacuations are allowed; no “shelter of last resort” is used in disaster evacuations; proactive partnership with the RTA to pick-up carless evacuees by public transit at 17 designated pick-up points throughout the city; uses the New Orleans Union Passenger Station (used by Amtrak, Greyhound and Mega-Bus) as a staging area for evacuation out of the city to “safe havens” at state or federal shelters.

The City’s Office of Homeland Protection and Emergency Preparedness in association with Evacuteer, a local not-for-profit (dedicated to the safe evacuation of the city’s carless population both residents and tourists), and the RTA have joined with other affected agencies in the region to form a standing committee on emergency preparedness and evacuation. An interesting outgrowth of this partnership was a recent project coordinated with the Arts Council of New Orleans. Funded by the city’s Percent for Art program, identifiers (large symbolic structures) were installed at the designated evacuee pick-up spots for carless evacuees. They have also prepared graphic materials as part of the City Assisted Evacuation Plan (CAEP) and have a procedure in case of an approaching hurricane. The RTA is an active participant in the CAEP and has a “seat at the table”.

The RTA, with federal assistance, purchased a Backup Mobile Command Center, which is on ready-alert with onboard systems including satellite communications, GPS tracking, dispatch and control capabilities for its eight person crew. Equipment safe havens have been secured at the Baton Rouge Airport for “out of region” relocation of equipment storage. All RTA facilities have been flood proofed as much as feasible. A remote operating facility is on hand in case of a future disaster. A comprehensive fleet / equipment replacement and upgrade program continues. Finally, the New Orleans Union Passenger Terminal is now being converted to a multimodal transportation that includes Greyhound, Amtrak and RTA services (the newly built Loyola Avenue Streetcar connecting to Canal Street).

**Capital Planning, Programming and Finance**

Post-Katrina the RTA was tasked to restore their pre-Katrina system (all modes, all flooded facilities, critical infrastructure) as quickly and effectively as possible. This required the RTA to pursue all available sources of finance, including their own bond indebtedness, to rebuild their entire system. They were fortunate to obtain a $45M (100% federal) TIGER grant for the Loyola Streetcar extension, $17.3M from the American Recovery and Reinvestment Act stimulus program, forgiveness for a $47M community disaster loan, and $130M in FEMA funds to restore facilities, catenary and track for the streetcar lines, and to purchase new bus, streetcar, and paratransit vehicles.

**Project Development, Infrastructure Design, and Construction**

**Summary:** In terms of new project development, infrastructure design, and construction the emphasis post-Katrina has been system restoration as well as new streetcar line development. The rationale for new streetcar lines is described below.
A New Emphasis on Streetcar Line Expansions

Special mention must be made for the streetcar vehicle replacement and expansion program. According to RTA “Of what was left of (our) infrastructure in the aftermath of Hurricane Katrina, the streetcars were in the best position to be quickly repaired and restored to service. Streetcar line reconstruction was made possible by federal funds, which by law could only be used to restore streetcar track, electrical systems, and the red (Riverfront line) streetcars. Thanks to these funds, streetcar lines now feature new infrastructure including underground cabling, track beds, catenary poles, electrification and substations. Streetcars were essential to mobility during the recovery years...Today, the streetcar system continues to provide over 7.3 million passenger trips for local residents and tourists each year, and it connects with all but two of the RTA’s bus lines. The agency is in the process of expanding streetcar service to additional areas and continues to connect streetcars to bus routes for travel crosstown, downtown, and to key commercial centers. The first phase of streetcar expansion was Loyola Avenue, which opened in 2013. The second phase will be Rampart to Elysian Fields which began construction in January 2015” (1).

Tools:
- Special federal funds (TIGER grant and the American Recovery and Reinvestment Act) were secured by the RTA to implement projects that had been on the drawing boards for over 15 years. With these funds, the RTA ventured into unknown territory: the Loyola Avenue Streetcar line (finished in 2012) and the North Rampart Streetcar Line (currently under construction). These projects have served as economic development stimuli for a number of projects along their route: the South Market District mixed use neighborhood adjacent to the Loyola Streetcar line ($400M) as well as the Pythian mixed use project under construction and a new hotel project along Rampart Street, the first new lodging facility under taken in decades along the North Rampart corridor.

Operations and Maintenance

Summary: From an operations and maintenance perspective, RTA has been actively pursuing reliance-oriented thinking and activities for the past decade: i.e. post-Katrina. They have had no choice. Their survival was dependent on this core philosophy. It was imperative to make this the core for all activities of the RTA.

Post-Katrina Growth and Development

Looking back over the past decade, the transformation of New Orleans as a city and the RTA as a public transit provider is nothing short of remarkable. We now have over 600 more restaurants than pre-Katrina, our schools are now a national example for the charter school movement, and the RTA is back with expanding streetcar service serving the upper Vieux Carre’ along North Rampart Street and is planning for its extension down St. Claude Avenue. This project has been on the table for consideration by the affected neighborhoods for over 15 years. The RTA is now making historic strides with an operative goal of resiliency in policy, procedures, operations, and construction.
References

San Francisco Bay Area Rapid Transit (BART)

Case Study:
San Francisco, CA

**Highlights:** BART’s resilience efforts date back several decades to the Northridge Earthquake (1994). More recently the agency has begun to broaden its focus to include resilience to extreme weather and climate change. Research over the past several years—including as part of the FTA Climate Change Adaptation pilot program—regarding vulnerability of BART assets and infrastructure to natural hazards and sea level rise provided a basis for obtaining the support of senior management at the agency to pursue strategies aimed at extreme weather resilience in addition to earthquake safety. The agency’s 20 years of experience retrofitting existing and building new infrastructure to withstand seismic threats is providing a strong foundation for its climate adaptation efforts and consideration of weather-related resilience in its policies, planning, capital programming, project design and construction activities. BART is also an active participant in regional planning efforts aimed at addressing the threat of sea level rise in the San Francisco Bay Area.

**Key Resiliency Drivers**

- State and local emphasis on resiliency;
- FTA Pilot Study’s identification of vulnerabilities;
- Extreme weather events; and
- Local, regional and state resiliency activities.

**Key Successes**

**Earthquake Safety Program**

- Obtaining public support to seek approval of bond issuance to pay for earthquake safety upgrades.
- Implementation of a complete earthquake resiliency program including a comprehensive vulnerability assessment, development and evaluation of adaptation strategies, and full implementation of a capital improvement program to retrofit the transit system to increase resiliency against the hazard.
- Establishing a process to allow for variances from seismic design criteria that does not compromise infrastructure performance during an earthquake.
- Incorporation of earthquake resiliency into agency through seismic design standards.

**Climate Adaptation**

- Obtaining leadership support on current and future climate adaptation and resiliency efforts.
- Effectively communicated risks to executive leadership to drive resiliency funding decisions.
Key Lessons Learned

- There is a need for a robust understanding of risk through understanding asset vulnerability to and impact from hazards to be able to incorporate policies and promote projects within an agency. Agencies will rely on the best available science provided at the local or regional level.
- Regional coordination will be key in addressing sea level rise flooding issues where adaptations can occur beyond the transit agency’s property boundary.
- Public outreach and education may improve public support for resiliency programs.

### Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>HR</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td>534</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>126,546,495</td>
</tr>
<tr>
<td>Hazards</td>
<td>Earthquake, Sea Level Rise, Flooding, High Winds, Tsunami, Landslides, Wildfire, Drought, Heat</td>
</tr>
</tbody>
</table>

**Background:** Established through the State Legislature in 1951, plans were developed for the original BART system between 1957 and 1961. After plan changes and challenges, construction began in 1964 with first rail service beginning in 1972. As part of the original system, BART completed the Transbay Tube in 1969, which saw revenue service begin in 1974.

In 1989, the San Francisco area was hit by the Loma Prieta earthquake. Major damage to BART’s infrastructure was avoided, resulting in an influx of BART commuters. The month following the earthquake, BART hit new ridership records providing a critical service link during the closure of the Bay Bridge. With the passing of each earthquake, including those outside of the greater San Francisco Bay Area such as the Northridge Earthquake in 1994, many changes to the seismic design and subsequent building codes occurred. As knowledge and technology advances, the need for continual updates to resiliency efforts should as well. In the 1990’s, a series of studies were conducted identifying that aerial structures were at risk to a major earthquake. The USGS predicted at least one more major earthquake will hit the region in the next 30 years. It was at this point a seismic retrofit program was proposed.

In 2000, the Earthquake Safety Program was established and continues today focusing on retrofitting the system with updated design standards to increase resiliency. San Francisco itself has been at the forefront of addressing climate change, specifically sea level rise. In 2010, local, state and federal agencies were brought together to collaborate and understand the effects of flooding along the coast in the San Francisco Bay Area. The program, Adapting to Rising Tides (ART) continues to provide tools and support for resiliency planning in the region (1).

In 2011, the agency was one of eight transit systems to be funded through the FTA to conduct a climate change adaptation pilot study. This study allowed BART to evaluate its infrastructure against the risk and threats to the system, develop adaptation strategies to address at risk infrastructure, and link those
strategies to the organizational structure and activities. Today, BART is continuing their efforts to address both seismic resiliency and climate change resiliency.

In a follow-up study to the FTA Pilot Project, BART participated and supported the development of the “Climate Change and Extreme Weather Adaptation Options for Transportation Assets in the Bay Area Pilot Project: Technical Report (6).” Outlined within the report is guidance for conducting an assessment of infrastructure in the Bay Area as well as guidance on mainstreaming climate change within transportation decision making. This guidance may support transit agencies as they fully integrated resiliency into their organization. Beginning in 2015, San Mateo County began the process of conducting a vulnerability study, which BART has engaged the county on.

**Policy and Administration**

**Climate Adaptation**

The State of California along with regional stakeholders has been and continues to be proponents of resiliency and climate change adaptation. This state and local level emphasis on resiliency has allowed BART and its leadership to respond in-kind and begin to support efforts in addressing resiliency. After completion of the FTA Pilot Study, staff was able to effectively communicate the findings of the study to department leads and executive management. As a result, senior level staff recognized the importance to expand on the original study to include additional vulnerability assessments and other work. This recognition led senior management and the BART Board of Directors to approve agency funding for FY15-16 to continue work on resiliency and adaptation.

Internal efforts are currently focused on continued assessment and work around flooding vulnerabilities from the agency’s train control system. The train control system will be modernized in the coming years and the additional funding will look at best adaptation strategies to protect the capital investment. Additionally, BART is directing efforts to incorporate climate change impacts, and more specifically sea level rise, into the update of the Local Hazard Mitigation Plan (LHMP) (1) [Note: The 2016 draft plan is available (2)].

Related, BART is also working to solidify its sustainability program. Further highlighting the agency’s leadership in support of future resiliency work, the sustainability program will be built with input and direction from top leadership. Although a specific policy has not been adopted by BART on resiliency and/or climate change adaptation, it is fully anticipated that this will become one area of focus for the sustainability program.

Externally, the San Francisco Bay Conservation and Development Commission (BCDC) has adopted policies that require sea level rise risk assessments to be completed when planning within shoreline areas. Projects must be designed to cope with expected sea level rise impacts for the lifetime of the design. (3) BCDC provides guidance to increase resilience to sea level rise and storm events through a collaborative project with Bay Area communities called “Adapting to Rising Tides” that may assist transit agencies. (4) In addition to these local and regional actions that can impact an agency’s effort to improve resiliency, state and federal agencies can drive efforts and policy. At the state level, California has worked to develop a statewide climate adaptation plan. This includes CalTrans, the State
Department of Transportation. As part of this state effort CalTrans has developed guidance for Incorporating Sea Level Rise into future projects and planning. (5)

**Earthquake Safety Program**

BART is recognized as a leader in earthquake resiliency. Following the 1989 earthquake, extensive studies were conducted highlighting the seismic risk BART was susceptible to. As a result, BART established the Earthquake Safety Program (ESP) in 2000. The program is expected to end when infrastructure upgrades are completed in 2022. The program may serve as a model for other transit agencies, which seek to implement a retrofitting program to address a particular type of hazard. BART’s program recognized that it is neither practical nor cost effective to protect everything against every hazard, so choices were made about the level of retrofit to be pursued. It should be noted that each hazard is unique therefore the adaptation approach can differ. BART’s earthquake retrofit program primarily focuses on the agency’s infrastructure whereas a program to address flooding may require more regional coordination. For example, the Port of Oakland’s constructed levees and implemented pump stations resulting in protection for both Port of Oakland as well as BART assets.

**Tools:**

- **Adapting to Rising Tides (ART) (4)**
  
  **Description:** The ART Program is focused on incorporating adaptation into local and regional planning in the San Francisco Bay Area. There are a number of tools and guidance, which may be tailored to agencies outside of the region for incorporating adaptation into projects. Guidance and tools from the website includes but not limited to:
  
  - Stakeholder and Public Engagement
  - Selecting Scenarios
  - Vulnerability Assessments and Analysis
  - Identification of Key Planning Issues
  - Developing Adaptation Response
  - Adaptation Response Evaluation

- **Climate Change and Extreme Weather Adaptation Options for Transportation Assets in the Bay Area Pilot Project: Technical Report (6)**
  
  **Description:** The technical report provides extensive guidance that may be adapted to another agency to work through a process of collecting data, assessing vulnerability, and the development and selection of adaptation strategies. It also outlines guidance for incorporating climate change into a transportation agency.

**Successes:**

- Obtaining leadership support to back current and future climate adaptation and resiliency efforts.
- Effectively communicated risks to executive leadership to drive future resiliency funding decisions.
**Lessons Learned:**

- Regional coordination will be key in addressing sea level rise flooding issues where adaptations can occur beyond the transit agency’s property boundary.
- There is a need for a robust understanding of risk through understanding asset vulnerability to and impact from hazards to be able to incorporate policies and promote projects within an agency. Agencies will rely on the best available science provided at the local or regional level.
- The LHMP process broadly solidified BART’s understanding natural hazards and helps to inform emergency preparedness planning.

**Capital Planning, Programming and Finance**

**Earthquake Safety Program**

Although partially supported by BART, the ESP is now funded through a number of sources which leadership actively sought to enhance the transit systems resiliency. Funding is currently provided by the following sources:

- $125 million from California Department of Transportation Local Seismic Safety Retrofit Program
- $93 million from Regional Measure 2 (RM2), State Transportation Improvement Program (STIP), Prop 1B
- $11.5 million from Transportation Congestion Relief Program (TCRP)
- $3 million from FEMA Pre-Disaster Mitigation Program
- $60 million from other Funds

In addition, BART sought public approval for issuance of general obligation bonds in the amount of $980 million. Although the measure failed to pass during the first attempt, BART conducted extensive outreach to local interest groups and other public agencies. This included a number of educational presentations to citizens. During a second vote, voters approved Regional Measure AA, authorizing BART to issue the bonds. The measure also requires BART to establish a Citizen Oversight Committee to ensure the money is spent as promised.

**Successes:**

- Obtaining public support to seek approval of bond issuance to pay for earthquake resiliency retrofit upgrades.

**Lessons Learned:**

- Public outreach and education may improve public support for resiliency programs.

**Project Development, Infrastructure Design and Construction**

**Earthquake Safety Program**

As part of the ESP, the first step was an extensive vulnerability assessment of BART’s entire infrastructure prior to recommending a retrofit program. The approach used by BART is considered
state-of-the-art for seismic evaluations. With input from the California Seismic Safety Commission and a BART Peer Review Panel, the assessment consisted of:

- Defining levels of performance, including service disruptions from an earthquake;
- Scenario development and the evaluation of system vulnerability to those earthquake scenarios to include considerations of costs associated with system repair, and impacts to both commuting and non-commuting populations; and
- Developing and evaluating a series of retrofit/resiliency packages. (7)

An outline of this process, which is adaptable to other agencies, is available online at the Northern California Chapter of the Earthquake Engineering Research Institute. (7) The website also references other potential resources to support an agency in their development of a retrofit program. A copy of the vulnerability study conducted by BART may be requested directly from the agency (8).

Once this assessment was completed, the Board approved the most cost-effective package. The program outlined retrofits for a “core” portion of the system that meets operational standards. Other areas of the system received upgrades to address safety. As part of this assessment, the ESP identified not only the aerial structures also identified in the 1990’s studies as vulnerable but issues with the Transbay Tube, stations and equipment. Projects were prioritized and included demolition of the Lake Merritt Administration building. Other major seismic retrofits included six parking structures.

The efforts to retrofit facilities considered two design events. For the safety upgrades, BART used what they called the ‘Design Basis Earthquake’, which is defined as the greater of the probabilistic 500-year return period event, or deterministic median plus ½ standard deviation. For most faults in the Bay Area, this is not the same as the Maximum Credible Earthquake (MCE). For operability retrofits, there is the Lower Design Basis Earthquake or LDBE, which is the deterministic median. (For the Transbay Tube, both of these criteria are higher than for the rest of the system due to the Tube’s criticality for system operation and safety.) Infrastructure was evaluated on a site-specific basis and BART believes the new design standards are robust for a retrofitting program.

Due to the many unknowns at the start of the ESP, BART established a variance process to allow designers to request relief from established seismic design criteria when it could be shown that earthquake performance was not affected and money could be saved. The process was extensively employed. Various government bodies have established seismic design procedures, some of which are incorporated into national and local codes. BART only employed code approaches for secondary structures such as parking garages, shop buildings, etc.

As the program progressed, the ESP activities have affected seismic design standards for new structures, due to staff knowledge of the state-of-the-art in seismic design. ESP staff has also recommended extensive changes to BART’s specifications and standard drawings and to BART’s earthquake emergency response based on the programs findings. In general, BART updates its Facilities Standards periodically, and as such has a standard procedure for commenting on the Standards. Staff utilizes this process to make their recommendations. The comments are considered by stakeholder committees for incorporation into future revisions to the standards.
In support of furthering earthquake resiliency BART has invested in an Earthquake Event Reaction System:

The BART Earthquake Event Reaction System receives data from the more than 160 seismic stations of the California Integrated Seismic Network throughout Northern California. If the messages from the seismic network indicate ground motion above a certain threshold, the BART central computers, which supervise train performance, institute a normal service braking to slow trains down to 26 miles per hour. An automatic system-wide “hold” is put in place such that no train will depart a station without manual intervention. With the automated braking in place, BART Train Controllers, reacting to the same alert, instruct Train Operators to maintain 26 miles per hour or brake to a stop depending on the specific operational situation for each train. The system software is running on a pair of redundant servers in BART’s central computer room, connected over the internet to a pair of redundant servers at the University of California, Berkeley Datacenter in Berkeley (9).

Climate Adaptation

BART is also considering adaptation strategies through design and construction changes. The current review of the train control system has highlighted some initial problems and strategies that may be considered. These include:

- Reconstructing control room roofs so they are pitched to allow water runoff;
- Incorporation of drip loops along cables to reduce water impacts at conduit locations; and
- Replacement of rubber gaskets at doors.

One pilot project that BART successfully implemented was the construction of head houses at a single entrance to an underground station. The result was successful protection of the entrance elevator from water thus reducing the number of times it is in disrepair.

Tools:

- Earthquake Event Reaction System
  Description: Early warning earthquake system developed out of the University of California, Berkeley that pulls data from seismic monitoring locations to provide warnings of an imminent earthquake. Warnings are just a few seconds to tens of seconds but can allow for immediate and automated responses by transit staff and systems.

Successes:

- Implementation of a complete earthquake resiliency program including a comprehensive vulnerability assessment, development and evaluation of adaptation strategies, and full implementation of a capital improvement program to retrofit the transit system to increase resiliency against the hazard.
- Establishing a process for the allowance for variances to established agency building criteria and code, which does not compromise infrastructure performance during an earthquake.
- Incorporation of earthquake resiliency into agency procedures for updating design standards.
Participating BART Personnel (For Internal Notes Only - To Be Removed Prior to Publication)

- Norman Wong, Environmental Engineer
- Tian Feng, District Architect
- Thomas Horton, Group Manager (Earthquake Safety Program)

References


SFMTA/MUNI: San Francisco Municipal Railway

Case Study:
San Francisco – Oakland, CA

Highlights: Muni public transit service is managed by the San Francisco Municipal Transportation Agency (SFMTA), a unit of city government. The City and County of San Francisco has initiated efforts to incorporate climate risk into an array of planning and policy initiatives including the city’s capital planning process. As a city department, SFMTA will follow the approved Capital Planning Committee’s policies for projects, which meet certain criteria. The Guidelines and Checklist includes an 18 question checklist ensuring capital projects account for: future sea level rise and flood vulnerability, sensitivity to sea level rise, adaptive capacity, planning horizons, costs and other details. SFMTA staff has initiated a pilot project that aims to build upon this citywide effort and will integrate resilience and sustainability features into the agency’s capital planning process. This work may serve as a model for other agencies to use in their climate resiliency and hazard/risk management programs.

Key Resiliency Drivers
- City and state policy/executive leadership;
- Emphasis on sustainability and sustainability programs; and
- Disasters and the agency’s awareness of threats.

Key Successes
- Incorporation of climate risks into capital planning process;
- Obtaining leadership and organizational support throughout City;
- Building capacity to address hazards and climate impacts;
- Integrating resiliency across agency-wide efforts from emergency management and capital planning to long-term planning;
- Maintaining a Climate Action Strategy;
- Integrating resiliency into hazard specific operations and maintenance plans;
- El Niño/ Winter Weather Plan; and
- Scoping a future Vulnerability Assessment.

Key Lessons Learned
- A culture of forward-thinking personnel makes pushing new and upcoming priorities such as resiliency easier.
- There needs to be clear linkages between various planning efforts to understand how each fit together and affect others.
- Develop a strategy that integrates resilience across an agency’s operations and plans.
- Sea level rise projections need to be agreed upon and approved for use within the planning process.
- Coordination with external agencies is necessary to understand how their actions impact the agency’s risks and vulnerabilities.
• Documentation of impacts is an important exercise as it helps to catalog impacts and incidents and supports the development of operational and incident specific plans.

**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>MB, LR, DR, Other</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td>2,373</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>223,851,332</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Earthquake, sea level rise, urban flooding, coastal flooding, waves, storm surge</td>
</tr>
</tbody>
</table>

**Background:** The San Francisco Municipal Railway (Muni) was established in 1912 in the wake of the 1906 earthquake and subsequent fires. Muni public transit service is managed by the San Francisco Municipal Transportation Agency (SFMTA), which serves as the managing and operating agency for the city’s surface transportation network as it has expanded over the past century.

The SFMTA plans, designs, builds, operates, regulates, and maintains one of the most diverse transportation networks in the world. In addition to the four modes of transportation (transit, walking, bicycling and driving, which includes private vehicles, taxis, car sharing, on-and off-street parking and commercial vehicles), the Agency directly oversees five transit modes (bus, trolley bus, light rail, historic streetcar, and cable car), in addition to overseeing paratransit service, which serves individuals unable to use fixed route transit service.

In 1989, the San Francisco area was hit by the Loma Prieta earthquake. Although major damage to SFMTA’s infrastructure was avoided, the earthquake highlighted the immediate need to consider resiliency. With the passing of each major quake, including those outside of the greater San Francisco Bay Area such as the Northridge Earthquake in 1994, many changes to the seismic design and subsequent building codes occur. As knowledge and technology advances, the need for continual updates to resiliency efforts should as well. For example, new constructions built to code as recently as 20 years ago are now considered to be structurally deficient in their resiliency to earthquakes. (1)

As years progress, planning for earthquakes has become incorporated into the city and thus SFMTA’s culture whereas today, securing and retrofitting existing infrastructure is a citywide priority. The agency also has public support as voters have passed obligation bonds to address retrofitting infrastructure around the area. The actions and commitment by the city and its stakeholders show the commitment to address this hazard.

San Francisco is once again at the forefront of increasing resiliency citywide. The city and the state have been working on addressing resiliency through a series of efforts such as updates to coastal plans and local master plans. As a result, the SFMTA has benefitted from city and state initiatives that support the agency’s resilient efforts. Specific to SFMTA, the agency is currently building its sustainability program to expand upon city initiatives to address resiliency. This includes incorporating resiliency into capital planning processes and conducting vulnerability assessments. Though this initiative is just beginning,
staff is involved with city and regional resiliency efforts, which have already produced applicable and beneficial tools to transit agencies.

**Policy and Administration**

**Summary:** The SFMTA is a public department under the City and County of San Francisco and is governed by an agency-specific Board of Directors appointed by the Mayor. This board has the authority to appoint the Executive Director, approve the budget and set agency policy.

**City Level**

At the city level, San Francisco has participated and completed a number of resiliency related projects and plans and continues to be involved in resiliency planning. This demonstration from leadership highlights the support for continued work toward building resilience. Although no formal definition of resilience has been adopted by the city or SFMTA, it has participated in the Rockefeller Foundation’s 100 Resilient Cities Program. The foundation defines resilience as “the capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience.” (2)

In addition to this program, the city’s Department of the Environment has developed a Climate Action Strategy (3). In 2007, voters approved the requirement that the Climate Action Strategy be updated continually. SFMTA supports this plan and its updates through the development of a SFMTA Climate Action Strategy for the transportation sector (4). SFMTA plans to include an adaptation section in the future update. Related, the city, with participation from SFMTA, has established a Sea Level Rise Committee to support development of a Sea Level Rise Action Plan. This guidance document will be broadly focused on the need for agencies to conduct vulnerability assessments. These assessments are intended to be rolled up into a single document for the city to drive adaptation strategy development and the development of an adaptation plan. A related city committee, the Sea Level Rise Technical Committee, has developed the Guidance for Incorporating Sea Level Risk into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaptation (5) which was updated by the CPC in December of 2015.

The CPC is chaired by the City Administrator and is responsible for making recommendations to the Mayor and Board of Supervisors on capital expenditures. The CPC is represented by department heads including SFMTA representation.

Finally, the city also participates in regional efforts. For example, staff from the City and County of San Francisco and local, state and federal partners, in coordination with the San Francisco Bay Area Planning and Urban Research Association (SPUR), have developed an Ocean Beach Master Plan. (6) SF Planning is updating the Local Coastal Plan as part of the city’s Local Coastal Program (7) and may integrate recommendations from the Master Plan into the LCP policies.

**SFMTA Agency Level**

The SFMTA approaches resilience through a balanced approach of looking at near-term needs with long-term planning. In 2007, voters passed a measure requiring SFMTA to develop and maintain a Climate Action Strategy. Future updates will include strategic resilience measures with a planning horizon of
2050. Additionally, the agency is also scoping future vulnerability assessments. Immediate efforts include the development of operational and maintenance weather response plans such as the El Niño Preparation and Response Plan for the 2015-16 El Niño season. Other near-term efforts include the implementation of a resiliency and sustainability pilot project. This initiative is focused on SFMTA working to incorporate sea level rise into agency level capital planning decisions. This work would expand upon the city’s efforts resulting in more projects being required to consider sea level rise resiliency and adaptation.

Successes:

- Incorporation of sea level rise projections and vulnerability assessments into capital planning decisions and establishing an agency level pilot project to expand the city’s policies and apply them to SFMTA’s capital planning process.
- Maintaining a Climate Action Strategy.
- Obtaining leadership and organizational support throughout City.
- Building capacity to address hazards and climate impacts.
- Integrating resiliency across agency-wide efforts from emergency management and capital planning to long-term planning.

Lessons Learned:

- A culture of forward-thinking personnel makes pushing new and upcoming priorities such as resiliency easier.
- There needs to be clear linkages between various planning efforts to understand how each fit together and affect others.
- Develop a strategy that integrates resilience across an agency’s operations and plans.

**Capital Planning, Programming and Finance**

**City Level**

The CPC is chaired by the City Administrator and is responsible for making recommendations to the Mayor and Board of Supervisors on capital expenditures. The CPC is represented by department heads, including SFMTA representation, and is responsible for reviewing projects and making recommendations to the Mayor. In December of 2015, the CPC updated its CPC Guidance and Checklist. Prior to the submission of a project to the Capital Planning Committee (CPC) for review and recommendation, all capital projects must now follow this guidance and checklist if the proposed project meets the following conditions:

- The project has a location identified;
- The project is within the SLR Vulnerability Zone; and
- The total anticipated costs of the project equal or exceed $5 million.

The guidance document does not outline specific adaptation approaches but is intended to be sure a project determines the risks and vulnerability to a capital project.

The vulnerability assessment and checklist accounts for project location, matching it against sea level rise, flood plain and surge predications to determine a projects exposure to sea level rise. Therefore,
the checklist requires use of agreed upon sea level rise projections that were approved by the CPC. These projections are provided in ranges defined as likely sea level rise estimates and an upper bound sea level rise estimates. In addition, the checklist accounts for project lifespan and planning horizon. The project lifespan is defined as the likely use and not intended use. For example, a pump station may be designed for a lifespan of 30 years but may be expected to be used for 75 years. The lifespan is then 75 years for the project. The planning horizon for the project is the lifespan plus the anticipated year of completion. Therefore a pump station built in 2020 with a lifespan of 75 years has a planning horizon of 2095. The horizon then correlates to specific projected tide level calculations for each year, in this example 2095. These tide design calculations and subsequent guidance on its use are all part of this sea level rise guidance for projects.

Given that the guidance and requirement to complete this checklist is a recent development, no projects have gone through this new capital planning process. Therefore, there are no details on how the process works and how it will impact other aspects including project development, infrastructure design and construction as well as maintenance and emergency management aspects to projects.

**SFMTA Agency Level**

As part of a resilience and sustainability pilot project, SFMTA’s sustainability program has begun developing a similar process within the agency for projects that do not meet the criteria for CPC review. This SFMTA capital planning process will utilize the CPC process as an informative process as well as much of the guidance already developed. This initiative is intended to be a collaborative effort across agency units and will seek to expand the considerations of the vulnerability checklist the CPC uses. For example, SFMTA would like to consider the importance of a project from a system criticality perspective. A criticality component would recognize projects that maintain service and continuity of operations will have higher priorities and importance than those that do not. For example, the process may weight projects that may result in increasing the system’s ability to reduce rail service disruptions from urban street flooding over projects that perhaps simply reduce flooding of non-critical areas. As a result, the more critical project may have a higher likelihood of immediately considering the incorporation of adaptation measures during project development, design and construction. These resiliency measures may include but are not limited to zoning approaches, engineering and design measures, and use of green infrastructure.

As part of any process, there is a need for coordination among regional partners and stakeholders. To highlight just one example of this importance, one of the potential issues facing agencies that impact implementation of adaptation strategies are the impacts external agencies have on vulnerability through their actions. This can be both positive and negative. For example, an agency such as the Army Corps of Engineer may seek to construct a sea wall around vulnerable infrastructure. This poses the question of whether or not adaptive efforts are needed to some infrastructure if another project mitigates the vulnerability. However, even if this project was identified as a priority, it may be decades before it’s fully constructed. How should an agency such as SFMTA address the risk between now and the time a project such as that is completed?
Tools:

- Guidance for Incorporating Sea Level Risk into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaptation (5)
  - Guidance for Incorporating Sea Level Risk into Capital Planning in San Francisco: Sea Level Rise Scenario Selection and Design Tide Calculation (8)

Description: The guidance document outlines the background and purpose of the new planning requirement. As part of the guidance document, multiple appendices provide a tool to SFMTA planners seeking investment into a larger capital project that meets specific criteria. This tool requires project developers to consider a project’s vulnerability to flooding and sea level rise in an effort to determine whether the project needs to immediately incorporate adaptation measures or not. The tool is an extensive set of questions in a checklist format to help project organizers determine if they meet this requirement or not by determining the adaptive capacity of the project, sensitivity to sea level rise and the subsequent impacts to operations and cost of potential damage.

Successes:

- Incorporation of sea level rise considerations into the capital planning process resulting in adaptation design to be considered as part of project development, infrastructure design and construction.

Lessons Learned:

- Sea level rise projections need to be agreed upon and approved for use within the planning process.
- Coordination with external agencies is necessary to understand how their actions impact your agency’s risks and vulnerabilities.

Operations and Maintenance

As part of SFMTA’s effort to build operational resiliency, the agency developed an El Niño Preparation and Response Plan (9) to address potential impacts from the 2015-16 El Niño season. El Niño can lead to coastal flooding, extreme tides and urban flooding. The Plan aims to increase SFMTA preparedness in the face of these coastal impacts and hazards. A plan of this nature can be part of the broader adaptation strategy but is focused on addressing ongoing and near-term impacts. The following content outlines some highlighted specific measures and actions SFMTA addresses and outlines within this plan.

During the El Niño season, overhead wires, parking lots, etc. are assessed. Tree incursion to these facilities are photographed and submitted to public works for trimming. Additionally, parking departments are to compile a list of drains that backup consistently and develop a response plan to those drains for flood events per the plan. Finally, during the El Niño season, SFMTA has implemented a preventative maintenance schedule for all modes. Motor coaches and trolleys have a specific
maintenance schedule that also includes random checks to ensure reliability. Light rail and paratransit fleets will:

- Conduct water intrusion test;
- Inspect, and possibly replace, HVAC gaskets on light rail fleet;
- Inspect and clear out roof water drains;
- Verify all rail vehicle sanding systems are functioning and supplied;
- Verify the water integrity of all rail service vehicles; and
- Replacement of propulsion and APSE blower filters;

In preparing for an event, the SFMTA increased maintenance efforts by assessing various pieces of mitigation equipment, such as generators and sump pumps, to ensure they are appropriately located, tested, and fully equipped to operate when necessary. Personnel assignments to maintenance activities are also increased ensuring drainage areas are clear from debris. One technique used is the allocation of staff on-site during weather events to conduct monitoring and quick response activities as needed to keep right-of-ways clear and report problems. This includes staffing parking lots, cable car turntables and sheave pits, among other locations identified in the plan. Should staff not be available for permanent assignment, frequent checks are conducted on infrastructure (e.g. fuel storage tank).

To support resiliency and response to potential flooding events, the SFMTA has identified efforts to help reduce impacts from an event. These include, but are not limited to:

- Storage of 10,000 sand bags for use to protect infrastructure from flooding;
- Movement of vehicles to higher ground at assigned locations;
- Deployment of portable sump pumps to areas with localized flooding;
- Closure of subway system air vents to prevent water backup;
- Acquisition of supplies to support quick restoration or replacement of signal infrastructure;
- Ensuring additional rescue vehicles are activated during the event to quickly respond to vehicles experiencing problems; and
- Deployment of mobile response units to address mechanical issues as they arise in the field.

SFMTA maintenance also addresses reoccurring flooding on an ad hoc basis beyond this particular operational plan. One example of this is the implementation of minor infrastructure changes to divert water through a transformer vault and relay room to eliminate the collection of water and subsequently flooding of equipment within the room.

The plan also outlined responsibilities agency-wide recognizing the important of internal communication between operational units. All modal operators have the ability to communicate to an operations center. Operators and staff in the field are to report all instances of downed trees, downed wires, standing water, potential sink holes, debris, drainage backups, etc. which may impact service. Some non-operators are encouraged to establish a communications plan by coordinating with various city departments.

Any issue deemed severe enough to change service is discussed and addressed. Within the plan, operations personnel are assigned to conduct service planning and be available for developing service
plans upon disruption to service. The service plans outlined within the El Niño plan are for scenarios where the number of operators available was limited and service needed to be prioritized.

Impacts to the system also require information to be passed along to the public. The plan outlines an extensive list of mitigation activities related to public information and internal staff communication. The plan addresses outreach to the public through websites, social media, community leaders, media, etc. Messages are to be drafted ahead of an event and available for quick editing and release addressing commuting, everyday travel, as well as essential and non-essential agency personnel. Electronic signage such as NextBus and subway signage is addressed to remove predicted service to display messages related to alternative service. Finally, customers with disabilities or other access needs are addressed separately ensuring service changes and public information reaches this specific population. Efforts include similar activities such as updating websites and answering services, but it also includes proactively reaching out to customers with scheduled rides.

Tools:
- El Niño Preparation and Response Plan (9)

Key Successes:
- Integrating resiliency into hazard specific operations and maintenance plan.
- SFMTA outlined an effective communication process throughout agency within the El Niño plan.

Key Lessons Learned:
- Documentation of impacts is an important exercise as it helps to catalog impacts and incidents and supports the development of operational and incident specific plans.

References


Southeastern Pennsylvania Transportation Authority (SEPTA)

Case Study:
Philadelphia, PA-NJ-DE-MD

**Highlights:** Resilience and sustainability are part of SEPTA’s corporate culture, which is evident in how the agency approaches extreme weather response, safety, project development, and overall day-to-day operations. Primary hazards include flooding, high heat, winter storms and power loss due to extreme weather. SEPTA is particularly focused on “event readiness” and restoration of service after weather-related service disruptions. They are investing in infrastructure protection where feasible and cost effective (flood proofing, bank stabilization, bridge scour protection), as part of maintenance and capital project construction. SEPTA regularly engages front-line workers to collect data and information on system vulnerabilities and performance and uses its asset management systems to flag preventative maintenance needs/requirements/issues that contribute to improved resilience.

**Key Resiliency Drivers**

- Past disaster experience.
- Executive Leadership: SEPTA’s General Manager, Jeffery D. Knueppel: Chief Engineer for 13 years with progressive responsibilities in asset management, engineering, infrastructure maintenance, and capital construction; then Deputy General Manager for 3 years with broader responsibilities also including operations; now General Manager since October of 2015.
- Board Leadership: SEPTA’s Board emphasized safety, sustainability programs and customer satisfaction and communications.
- MPO, DVRPC, the City of Philadelphia, state and service counties, and the Commonwealth of Pennsylvania, including Penn DOT: Key to providing support for strategic goal, capital funding and project priorities, strategic importance to investments, emergency communications, training and coordination.

**Key Successes**

- Board support for emergency management: through the adoption of safety, sustainability, asset management and event readiness goals, policies, measures and funding support. After safety, the key performance measure is event readiness.
- Consistent support and commitment from executive management.
- Continuous engagement of front-line employees through efforts to engage shop personnel, supervisors, drivers, maintenance, engineers, etc. to articulate and define areas of success, problems and concerns with respect to weather-related emergency operations in the SEPTA service areas.
- Scalability through ensuring developing multiyear capital investments designed and planned to address problem areas in safety, sustainability and event readiness during weather emergency events.
• Building a cross-functional team with committed executive support, recognizing that all of the SEPTA family has a stake in ensuring the safety, event readiness, vigilance of SEPTA in severe weather events.
• Regional support from other partners in emergency management
• Communications with timely, effective outreach and listening to customers, SEPTA employees, federal, state and local partners, press, legislature, Mayor’s and Governor’s offices, Penn DOT, unions, public emergency management offices, etc.
• Building a culture to be event-ready and sustainable, which includes training, building on and celebrating success, development of plans and policies designed to be implemented to achieve event readiness.
• Building linkages between various partners in planning, funding, operations and communications to ensure each player understands their role and function and to understand how each fit together and affect others.
• Additional adequate funding to finance the multiyear capital program to improve SEPTA’s ability to safely meet severe weather events.

**Key Lessons Learned**

• Use the federal environmental review process that encourages the evaluation of future disasters or climatic events as part of the analysis. Look at sustainability in those future conditions and make determinations of risk and vulnerability to address and mitigate issues.
• “Fix and fortify” approach works.
• It is critical to have the public’s trust when dealing with financial and emergency issues or problems, so communication is key.
• Define corporate priorities and processes before shopping for software solutions for asset management or other functions.
• Remember Transit Asset Management (TAM) is a tool and not the end.
• Developing the program is iterative and time consuming.
• Information and assistance from other transit agencies can be very helpful.
• For addressing new and uncertain weather events, and considering various designs, materials and approaches to protect against or mitigate risks, shared “war stories” among public agencies as to the effectiveness and value of such materials or designs would be helpful.

• Be prepared with projects if new funding were to materialize.
• Be transparent and accurate when sharing large capital needs numbers, so as to not overwhelm the public decision makers and public that the number is too large to be able to get things done.
• Communicate and celebrate successes that demonstrate solutions to problems/issues.
• Recognize that severe weather events are part of the new operating environment.
Agency Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Northeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>Bus, heavy rail, commuter rail, streetcar, trolley bus, demand response</td>
</tr>
<tr>
<td>System Size</td>
<td>Large</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Heavy rain, riverine flooding, blizzards, extreme heat, high winds, extreme cold and ice; earthquakes</td>
</tr>
</tbody>
</table>

The Southeastern Pennsylvania Transit Authority (SEPTA) is the sixth largest transit system in the United States. In the mid-Atlantic region, SEPTA serves Bucks, Chester, Delaware, Montgomery, and Philadelphia Counties in Pennsylvania, with services to Newark, Delaware and Trenton, New Jersey, and interfaces with Amtrak on the Northeast Corridor. The 2013-2014 annual ridership was:

- Bus: 184 million passenger trips
- Heavy Rail: 101 million trips
- Commuter Rail: 37 million trips
- Street Car Rail: 27 million trips
- Trolley Buses: 6 million trips
- Demand Response: 1.7 million trips

SEPTA is a Commonwealth-chartered authority charged with funding and operating public transportation in the city of Philadelphia and Pennsylvania counties of Bucks, Chester, Delaware, and Montgomery. Its organizational mission is “dedicated to delivering safe, reliable, sustainable, accessible and customer focused public transit services, contributing to the region’s economic vitality and enhanced quality of life.” It is governed by a 15-member board of directors: two members appointed by the City of Philadelphia, five from the state, eight from the suburban counties. SEPTA’s internal management team is led by the General Manager, a dedicated director, and an interdisciplinary SEPTA team. SEPTA is part of and works throughout the year with the state and city offices of emergency management and the regional MPO-DVRPC. Given the multistate transit service, SEPTA also coordinates with other transit systems, such as New Jersey Transit, PATCO, DART and Amtrak.
SEPTA as part of FTA’s “Transit Climate Change Adaptation Assessment Pilot” (2013)

SEPTA does not emphasize the term “resiliency,” but rather prefers to talk about the sub-components that lead to a resilient system, including event preparedness, response, and recovery. The National Academy definition of resilience is broad enough to encompass their goal of event readiness, asset management and infrastructure sustainability. SEPTA’s approach was pragmatic. SEPTA understands the vulnerabilities of the aged infrastructure and the impacts of decades of weather-related service issues. For the past 12 years, the Deputy General Manager (now the General Manager) has led agency efforts to create a practical and sustainable transit service that meet core values and performance, based on getting service returned as quickly as possible. These efforts include addressing capital, operating, maintenance, and administrative strategies and investments to vulnerable, aging systems to upgrade assets and improve resilience against future extreme weather events.

Because of the early leadership in identifying, planning and investing in weather-related emergencies, SEPTA already had a system and decision-making process in place for the FTA Pilot. Consequently, SEPTA did not need to undertake a systems wide approach and modeling, but could focus the study on their particularly vulnerable service that fully contained all the weather-related issues found in the other service areas: SEPTA’s Manayunk/Norristown Regional Rail line. This route is a more than 100-year-old line whose geographical location cannot be altered without extensive dislocation and a route that experiences all the severe weather events noted above. It is a route that is one of the most challenging to SEPTA; and addressing weather-related problems here assists SEPTA in several ways: extrapolations of solutions or approaches to other system routes/services; minimizing weather-related service disruptions to their customers; and establishing resiliency measures that meet SEPTA’s major performance objective (after safety): getting service back quickly.

Recent climate-related events that affected SEPTA 2010-2015:

- The Philadelphia region has experienced four FEMA major disaster declarations since 2010, including Philadelphia’s first and second snowiest winters ever, its wettest year ever, and its warmest year ever recorded.
- Hurricane Sandy, in 2012, had severe winds that knocked out power for more than 1.3 million Pennsylvania electricity customers. The majority of those outages were focused in SEPTA’s service area of Philadelphia and its surrounding suburbs. The service region also experienced significant flooding.
- Along the Manayunk/Norristown Line, 13 (62 percent) of the 21 recorded floods in Schuylkill River history have occurred since 2003.
- The winter of 2013-2014, for Philadelphia and the Leigh Valley, was the second snowiest winter recorded, with a total over 67.4 inches.
- The northeast United States has experienced a 67 percent increase in heavy rain since the mid-20th century.

Consequences of these severe weather events 2010-2015 included:

- Stranded customers, particularly on the rail system.
- Suspension or disruption of service due to flooding such as severe rain event or hurricanes, such as Sandy; blizzards or significant ice and snow storms; extreme heat; wind; and mud slides.
• Downed catenary and power lines due to high winds and ice that disrupted service, with challenging conditions for customers and employees.

• **Damaged infrastructure** from ice jams against rail bridges, or scouring of rail bridges due to high water or flooding conditions; repair or replacement of catenary power lines due to falling trees/tree limbs, high winds, extreme heat, ice and sleet; rail switches and signals, retaining walls, SEPTA building, shelters, and equipment. **Extreme heat** that buckled rail tracks.

• **Significant costs to harden maintain and repair facilities and systems** to severe weather events, such as slope retaining walls, building raised signal huts; turn back track areas outside flood zones; emergency generators, redesigned and high subway ventwells.

• **Improved maintenance and operations**, such as aggressive tree trimming, sandbagging ventwells, staging fleet to higher ground; improved emergency tracking, enhanced customer communications.

**Working through the risk assessment, events, recovery and rebuilding-focused planning. Today SEPTA’s key severe weather emergency goals and strategies are:**

• Ensuring the safety of customers and SEPTA employees during an extreme weather event;

• Event readiness;

• Effective and timely communications with customers and employees on what SEPTA is and will be doing during the event;

• Planned service suspensions;

• Informed and frequent interagency coordination;

• Undertaking continuous monitoring and risk assessments;

• Prioritized capital investments;

• Securing sufficient financial resources to implement the capital investment program;

• Putting the core system first: for an event affecting all service areas, the approach is to start at the center of their service, which is in the City, and meet those needs first and then proceed out to other service areas.

These goals and strategies anchor planning to address the weather-related events that SEPTA anticipates occurring through mid-century.
Policy and Administration

SEPTA is actively engaged in policies, planning, financing and funding their operations and capital investments. The term “resiliency” is part of larger program efforts, such as safety, sustainability, asset management and delivering services and projects that are efficient, effective, provide the long haul, and are prudent.

For more than a decade, the General Manager and executive staffs have been invested in meeting and addressing disasters and severe weather events. They have worked consistently within the organization and with their partners to develop a culture that includes safety and event readiness for all of SEPTA’s services.

“Resiliency” is an integral part of SEPTA’s strategic planning in terms of asset management and safety. Within those elements is the need to address how severe weather events and natural disasters affect SEPTA’s ability to provide mobility and economic opportunities to the region and state. A key policy and performance measure for SEPTA is event readiness. This requires organizational commitment and funding. SEPTA has been successful in bouncing back from severe weather events due to preplanning and positioning of equipment and staff; and by the ability to quickly respond to unexpected problems, such as a tree falling onto the catenary lines, by providing information to customers and getting alternative bus service to customers.

For anticipated storm events, SEPTA has established procedures and protocols for suspension of services that are coordinated with the with emergency management partners. The agency uses a wide variety of
social media tools, TV announcements, public presentations, and radio shows to inform their customers and the public. Transparency is a key element in the agency’s communication.

**Systems Planning**

Both asset management and the sustainability units in conjunction with operations look at system planning to assess what is working and what needs analysis; what climate threats are affecting service and how can they be addressed. SEPTA has considerable inherent historic and current knowledge about service operations and how weather affects those services, and, using that knowledge, has developed strategic investment decisions and changes to operations. For example, in rail corridors prone to flooding and disrupted service and increasing safety concerns of wash outs or slope slides, SEPTA has invested in turn backs before flood zones to ensure the safety of the customers, employees and equipment. The determination of this type of investment is based on vulnerability and risk analyses, with projects prioritized in terms of safety, probability of the event, cost impacts of service delays on the route and the system, within a matrix of options and projected costs.

The vulnerability and risk assessment informs the asset management and sustainability planning, both short and long term. These plans are critical components to capital investment and programming projects and systems decisions. Climate conditions in the near and longer term are considered by sustainability analysis.

At this time, SEPTA has not mapped the agency’s infrastructure and services in terms of vulnerability to natural disasters and weather-related events or engaged in interagency mapping. Consequently SEPTA has not engaged with other system providers on systems interdependencies. (NOTE: Vulnerability is addressed systematically as State of Good Repair initiatives. No specific interagency projects or cost estimates have been analyzed.)

SEPTA system vulnerabilities have and will continue to be identified and analyzed in terms of their transit impacts and costs. These analyses have been communicated to SEPTA’s decision makers in the form of vulnerability assessments, capital and emergency planning, and capital programming. **The critical measure for system performance is: how fast can a service be safely restored? Event readiness and restoration are the major performance measures for SEPTA’s system performance in weather-related events and disasters.**

SEPTA uses buses to provide service on rail corridors that have been suspended from severe climate events, such as heavy rains and flooding. SEPTA does not have partnerships with other agencies or companies to provide redundant services. However, because safety is a critical path in determining weather vulnerabilities, SEPTA makes redundant power decisions for operational facilities. Many operational personnel are cross-trained to meet emergency situations.

Event readiness and the measure of how fast can service be restored are important to decisions that also balance safety, sustainability, asset management, resiliency and state of good repair (SGR). These factors, coupled with costs, are the bases for investment decisions.

**Asset Management**
SEPTA is in the process of developing an asset management program, which will include projects that mitigate the effects of natural disasters and severe weather events. The Transportation Asset Management program (TAM) involves three elements:

- Vehicle and infrastructure maintenance management systems with inventories, life cycle and maintenance management
- A decision-support tool
- Asset management plan that includes policies on how assets are to be maintained through the assets’ life cycle

The TAM has identified seven major high risk/vulnerabilities that are being addressed; a key one is flooding.

SEPTA is building its inventory system that is based on conversations with front-line staff and the chief engineering officers responsible for maintenance and renewal; the inventory is structured by critical areas. Inventory is updated as needed. The database includes categories for critical areas, such as rail with sub classification tracks, or signals or switches.

SEPTA’s severe weather protocol, as well as the asset management program, identifies vulnerabilities and risks, where individual assets and systems are impacted by disasters and severe weather issues. SEPTA does not have an Office of Resiliency; that concept is incorporated into the organization’s strategic business processes. Adaptation to climate is one of the several parameters that are evaluated as part of the capital decision-making process.

SEPTA’s capital improvement program is funded through federal and state sources. In 2013, the Pennsylvania State Legislature signed Act 89, which significantly increased the size of SEPTA’s capital improvement program. SEPTA also received an FTA grant to harden core infrastructure in 2014. SEPTA is now able to advance several programs to both address state of good repair needs, as well as bolster resiliency to extreme weather events. Examples of such projects include: soil and rock stabilization on the Regional Rail; flood mitigation on both the Regional Rail and the trolley lines, and the construction of an ancillary control center. SEPTA is also experimenting with technology pilots for advanced flood warnings, with information sent to the control center, which captures disruption occurrences.

**Capital Planning, Programming and Finance**

Funding for SEPTA, as with all transit agencies, is limited and requires a commitment to target resources to high priorities. SEPTA’s 12-year capital program plans have critical projects and investments to provide SEPTA with sustainable capabilities. Resiliency is incorporated into the sustainability assessment and program from which projects or systems are prioritized, using APTA’s sustainability guidance.

SEPTA’s approach to weather resiliency and capital investments can be summarized by two key points: 1) Incorporate resilience thinking into project development; 2) Know your system’s criticalities and vulnerabilities and invest strategically.
KEY ENGINEERING TAKEAWAYS:  
RESILIENCE IS THE NEW REALITY

INCORPORATE INTO PROJECT DEVELOPMENT:

- Severe weather events are happening with increasing frequency.
- Consider whether design codes are adequate for a given project.
- Evaluate need for back-up power.
- Think worst case and advise clients of vulnerabilities and the range of possible solutions.

Figure 2. Resilience Lessons for Project Development

SEPTA’s Funded Resiliency Projects
SEPTA’s asset management program is one of the key factors for moving a new capital project forward. Asset management includes assessments for weather resiliency and sustainability. SEPTA’s Capital Planning Committee uses a variety of factors to prioritize capital investments and new projects, and criticality is a consideration. For example, a key SEPTA goal is keep the Broad Street Line operating in severe weather events. Investments that provide for that goal would be viewed as critical. The time horizon for new projects is from 12 years to 50 years, with 15 years for buses. Cost-benefit analyses are not used to prioritize new projects, but event readiness is.

Disasters and severe weather events, while challenging and devastating, can also provide capital funding opportunities. SEPTA received $86.8 million from the Federal Transit Administration (FTA) Emergency Relief Program (the federal 75 percent match) for resilience projects in response to Hurricane Sandy. SEPTA’s asset management and sustainability analyses and programs had identified projects that, if done, would provide a safer and more sustainable transit system. The $86.8 million funded the following projects:

**Railroad Embankment and Slope Stabilization Project**: $18.7 million to stabilize and harden soil and rock slopes along a series of vulnerable 19th century railroad cuts; **Sharon Hill Line Flood Mitigation Project**: $3.8 million to construct a pumped drainage system that will mitigate flooding on the Sharon Hill Line in Delaware County; **Railroad Signal Power Reinforcement Project**: $32.0 million to reinforce signal power across the Regional; **Ancillary Control Center Project**: $9.0 million to construct a back-up control center facility at a strategic location outside of Center City of Philadelphia to allow for remote dispatching of transit service in the event of an emergency; **Subway Pump Room Emergency Power Project**: $3.7 million to install an integrated series of emergency power systems for pump rooms throughout SEPTA’s subway tunnels across the City of Philadelphia; **Jenkintown Area Flood Mitigation Project**: $15.0 million to study and implement improvements to the Hydrologic conditions at Jenkintown, a key hub in SEPTA’s Regional Rail network in Montgomery County; **Manayunk/Norristown Line Shoreline Stabilization Project**: $4.5 million to stabilize 2.45 miles of railroad right-of-way adjacent to the Schuylkill River in Montgomery County. (See database attachment entitled FTA FUNDING FOR SEPTA INFRASTRUCTURE RESILIENCE PROGRAM)

**Project Development, Infrastructure Design and Construction**

Within the asset management and sustainability framework, SEPTA regularly updates infrastructure design standards and how they operate, emphasizing practical processes and learning from other transit, transportation and environmental entities. Sharing what works is helpful. Current and forecasted weather conditions indicate that heavy rainfalls and flooding are likely to continue and be more frequent. Slope retention and raising signal huts will reduce and possibly prevent service disruptions from failed signals or track wash outs.

New projects or replacement projects are evaluated through the asset management and sustainability programs. These programs evaluate projects on the basis of improving the life cycle of the investment
and its ability to resist service failure/disruptions. New materials are considered to the extent that their use will enhance safety or the investments’ life cycle and/or limit/prevent service disruption, or is more cost effective.

Environmental review analyses consider sustainability, which includes severe weather events and disasters. This includes the location of new facilities and equipment as an element of assessment.

SEPTA explores opportunities when repairing or replacing existing infrastructure to consider making the investment more sustainable. Knowing where risks and vulnerabilities are provides SEPTA with critical information on the consequences for safety and service disruptions caused by severe weather events; this in turn helps make the investment decision on whether to mitigate the problem or not. Examples of action are the slope stabilization and raising the signal huts to resolve operational and safety problems. Plans are to continue to elevate infrastructure above future flood levels where beneficial and where SEPTA deems it is prudent. In cases where rail tracks cannot be elevated, SEPTA investigates alternative approaches that include track turn around investment before the flood zone.

For drainage systems and pumping, SEPTA has made and will continue to make these types of investments when prudent. With respect to bridge scour FHWA and FTA have a strong set of regulations and protocols for bridge scour and their remediation. SEPTA follows those regulations and procedures.

To the extent that green infrastructure solutions work and prove to be more cost effective for the useful life of the investment SEPTA will make such investments.

**Operations and Maintenance (O&M)**

SEPTA has in place plans and procedures for temporarily hardening assets, re-routing contingency plans during an event, redundant communications, and some redundant power. Communication with customers is considered critical to readiness, and SEPTA uses available communication tools (social media, press releases to TV and radio outlets, text messages and emails) to inform customers about service disruptions, service delays or service cancelations in severe weather emergencies.

In SEPTA’s asset management program, the asset management database includes information on previous maintenance and issues, manufacturer’s warranties and service schedules, front-line staff observations and reports, calculations for when the next maintenance service is needed and scheduled. The asset management plan also includes activities that are preventative such as tree trimming, embankment assessments and tree stability, cleaning critical drains, etc. in advance of normal weather events, like heavy rains or winter.

**Emergency Preparedness**

SEPTA has developed the following emergency preparedness documents, housed in SEPTA’s System Safety Division:

- Emergency Management Plan
- Emergency Operations Plans (Mode-Specific)
- Emergency Response Plans (Mode-Specific)
SEPTA also has developed emergency weather plans that address preparedness, response and recovery for extreme weather events. In the context of these emergency weather plans, SEPTA works with its partner agencies to inform them of what to expect from SEPTA in the case of a weather emergency; and, to coordinate preparedness, response and recovery.

SEPTA’s Continuity of Operations Plan (COOP) identifies essential management and staff and identifies clear lines of succession for decision making. The plan has specific protocols for canceling service(s) and informing customers, identifying and broadcasting service disruptions and estimated service recovery; prioritized recovery of service (from the center out), including track and bridge inspections; emergency power and refueling sites. Managers and essential personnel annual emergency training are expected to attend and to review the EMP.

References


3. Southeastern Pennsylvania Transportation Authority. FTA Funding for SEPTA Infrastructure Resilience Program (one page summary provided by SEPTA).


Swedish Transportation Administration (STA)

Case Study:
Borlänge, Sweden

**Highlights:** While not a direct provider of urban transit services, as the national transportation authority for the country of Sweden, STA is actively engaged in a variety of activities related to resilience planning, engineering, maintenance, and operations across a range of transportation modes. The agency is primarily concerned with flooding, coastal storm surge and sea level rise, and ensuring the “robustness” of transit operations and infrastructure. Awareness of the impacts of natural hazard related threats, the needs for practice adaptation, and the benefits of creating culture of resilience within the STA started with planners and engineers working in the middle-tier maintenance divisions of the administration. A key area of the STA’s resilience efforts was the development of agency-wide Climate Change Adaptation Strategy and Climate Change Adaptation Action Plan.

**Key Resiliency Drivers**
- Recognition by field-level staff that natural hazard related restoration, repair, and reconstruction projects were growing large and more common;
- Acceptance that global climate change is real and is already effecting the country in numerous ways and, most notably to the STA, carrying out of their daily mission; and
- European Union – wide efforts to raise awareness of a need to adapt to climate change.

**Key Successes**
- Development of an administration-wide Climate Change Adaptation Strategy and Climate Change Adaptation Action Plan;
- These two documents give the STA a structured approach to understand, evaluate, and manage the needs and activities related to climate change within their organization; and
- Achieving executive and leadership–level support to address and incorporate resiliency needs more widely throughout the organization.

**Key Lessons Learned**
- There needs to be coordination between all jurisdictional levels of government that take climate change adaption into account during the planning, design, and construction of transportation projects;
- Climate change leaders need to exist at all level of transportation agencies;
- If there are no specific resources (money and people) allocated to the climate change adaptation work it is difficult to actually work efficiently. The STA is still struggling with this issue and this is also the reason the strategy and the action plan development has been a lengthy process. Theses policy documents could have been prepared much earlier if dedicated funding was available to create them. In fact the STA still lacks funds for actually carry out the activities in the Action Plan (17 such activities are planned for 2016);
• Awareness, understanding, and realization of the threats of climate change and how they affected the organization are key in the development of administration-wide climate change adaptation strategies; and
• Official strategic and action plan documents give a structured approach to understand, evaluate, and manage the needs and activities related to climate change within their organization.

### Administration Details

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>International (Northern Europe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>HR, CR, FB, Other (highway, civil aviation)</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td></td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td></td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Flood, Winter Storms, Extreme Cold, Strom Surge/Wave Action, Sea Level Rise, Other (landslides, dam failures)</td>
</tr>
</tbody>
</table>

### Background:

Although it is a national transportation administration, the Swedish Transport Administration operates similar to a State-level Department of Transportation in the United States. The STA was founded in April 2010 by combining the operations of the Swedish Road Administration and the Swedish Rail Administration, as well as parts of the Swedish Maritime Administration, Swedish Civil Aviation Administration (or Luftfartsverket (LFV)) and the Swedish Institute for Communications Analysis. Some operational responsibilities were also transferred to new commercial companies, particularly for road and railway construction and maintenance as well as the management of airport operations.

The size and activities of the STA reflect the geography and population of the country. The land area of Sweden encompasses about 174,000 square miles (450,295 square kilometers), somewhat larger than the State of California, and has a population of about 9.6 million people, about the population of the State of Michigan. Much of the country is rural and heavily (about 70 percent) forested with somewhat less than 10 percent of the landmass used for agriculture. About 90 percent of Swedish population lives in the southern half of the country with about 85 percent living in city areas. This results in the vast percentage of travel activity being concentrated in the major cities of Stockholm, Gothenburg, and Malmo in the southern half of the country. Sweden is also divided into 21 counties with an Administrative Board appointed by the national government.

The STA’s purview extends over all state owned roads, rail, air and shipping modes in Sweden. As such, it maintains a wide multimodal authority in the country. The STA is also responsible for the planning, construction, operation, and maintenance of state roads and railways. As part of its infrastructure responsibilities the STA maintains, about 7,400 miles (11,900 kilometers) of railway tracks; 40 ferry lines; 16,000 bridges (including 3,781 railway bridges), and 61,000 miles (98,400 kilometers) of state roads (a third of which are unpaved gravel roads) with and employee work force of approximately 6,500 people. It does not, however, have jurisdiction over any local or regional public transportation or municipal transit systems.
In terms of hazard vulnerability, the STA is generally concerned with all hazards. However, the focus of the majority of their resilience effort is centered on natural hazards, most specifically those associated with water-related conditions such as torrential rainfall, river, lake, and coastal flooding; as well as avalanches, mud flows, and various implications from sea level rise in coastal areas, particularly in the southern part of the country. Based on history and experience, other concerns include landslides and winter weather and with respect to climate change, the thawing of permafrost in the northern part of the country which is leading to soil stability issues.

The information collected and reviewed for this Case Study was gathered from several sources, most notably from a phone interview Dr. Eva Liljegren, who works both for the STA Maintenance and Planning Divisions. Dr. Liljegren is responsible for coordinating climate change adaptation, which includes the creation of policies, strategies, and action plans for the administration. Links and citations to additional documents reviewed and used to support the development of this Case Study can also be found in the “References” section of this case description.

**Policy and Administration**

**Summary:** The STA is the national transportation administration under the Swedish Ministry of Enterprise and Innovation. The organization has five major “Business Areas” (although they are often referred to as “Divisions” in English, “Business Areas” is the correct term) organized as “drainpipes.” This in effect means that authority goes from the top of the STA down to the field, with different levels. The director for each Business Area reports directly to the General Director but each Area is then organized in different levels, from the top to the bottom. In terms of Maintenance, there are six regional districts. The districts are responsible for the tendering process with contractors. Each District also has project leaders who work as the contractor’s counterparts, although all actual work is carried out by contractors.

The first division to recognize and react to climate change issues at Trafikverket were people working in the Maintenance Divisions. These included, for example, geotechnical engineers, hydrologists and maintenance experts whose duties were most frequently and directly affected by the impacts of natural hazards. Recent experience has shown, however, that many of these individuals were not enough high up in the organization to be able to influence or take important decisions. Interestingly, these staff members were also not far enough down the chain of activities to make direct and appreciable differences in the work carried actually out by the contractor. This paradigm is viewed as a primary reason that it has been (and still is) difficult to work with climate change at Trafikverket.

The STA does not have an official definition of “resilience.” In fact, the word “resilience” is not used in the STA policy documentation because they feel the term is too vague, broad, and its concepts not well understood. Rather, the administration couches the concept of resilience within the ideas of “climate change adaptation” and “robustness” because these terms are clearer and their meanings better understood. Thus, although STA terminology differs from the National Academies definition of resiliency, it could be suggested the key ideas are largely similar. A noted shortcoming of the robustness definition, however, was that the STA’s thinking with a narrower focus may be inhibiting their ability to take advantage of the “learning aspects” of resiliency in which infrastructure is improved and “built back better” to be more resistant to hazards as lessons are learned over time.
Although the STA does not have a policy that addresses “resilience,” it has formed an administration-wide policy to more specifically address “climate change adaptation.” The policy is documented in “Strategy for Climate Change Adaptation” (STA 2014). As its title suggests, the policy focuses exclusively on natural hazards and not man-made disasters or hazard conditions. These are addressed separately in security-related policies. To support the implementation of the policies outlined in this Strategy, the STA is about to publish an Action Plan. The Action Plan is a key document for the administration because it breaks down the conceptual vagueness of the Strategy into tangible activities.

The Ministry of Enterprise and Innovation, the parent agency of the STA, sets the direction for resilience prioritization, although again, they also use the term robustness. Although, neither agency has a formal division, committee, or individual designated as being responsible for resiliency, there is a prevailing view that all individuals within the organization should have a stake and an interest in robustness.

Currently, there is an effort to establish a distributed set or loose network of robustness “experts” throughout the organization rather than creating a single centralized authority within the administration. These individual experts would maintain their traditional job functions (planning, maintenance, bridges, etc.) within the organization, but when called upon, would serve as the designated domain-specific counterparts to the STA Coordinator of Climate Change Adaption (currently Dr. Liljegren). In addition to this informal group of experts, located within or close to its headquarters, the STA is also establishing a network of regional climate change adaptation leaders who will reside in their current locations (one in each of the six STA regions) and lead and coordinate climate change adaptation activities in addition to their regular job duties.

Similar to most agencies throughout the world, the most significant barrier to implementing resiliency policies, performance, and/or standards within the STA is a lack of funding. Perhaps just as important, however, it was pointed out that resilience thinking also lacked a formal “place” within the structure of the administration. This means that, historically, there has been no designated leader to champion for the needs and issues related to climate change adaptation and ask related questions, particularly at a high level. It was suggested that this came from a lack of awareness, understanding, and/or realization of the threats of climate change – which are now already being felt in Sweden - and how they effected the organization. There was also a fundamental misunderstanding of the difference between “climate mitigation” and “climate adaptation” and the needs for and roles of each.

---

**CALLOUTBOX/SPOTLIGHT:** There are differences between the ideas of “climate mitigation” and “climate adaptation.” Each responds to the threats posed by climate change in distinctly different ways. Broadly defined, climate mitigation includes activities and actions that seek to eliminate or reduce the long-term risk and hazards of climate change to property and human life, health, and safety. In contrast, climate adaptation encompasses and range of activities that seek to adjust systems to mitigate the effects of climate change (including climate variability and extremes). These may include activities that moderate potential damage and take advantage of opportunities, but may also require and/or coping with the consequences.

---

Although these types of issues have begun to change with the recently created half–time Climate Change Adaption Coordinator position in the administration, other issues remain, particularly between
the regional/municipal levels and the nation level. When local projects involve climate change-related issues, there is not a designated coordinator for the STA. And despite having adaption-specific expertise, the lack of knowledge of local conditions often precludes involvement. It is expected that in the future, national policies on key issues (amount of expected sea level rise, for example) can be used to establish design parameters in local areas. These are top priorities in the Action Plan which is (or will soon be) the most important tool to measure or report resilience-related efforts.

The Action Plan will cover many areas, including what data and information are required, prioritizing what needs to be done, and communicate these activities and their results with the policy makers and the public. While this is currently under development, the STA uses internal methods like distributing articles through their intranet and HR training to update its employees on resiliency-related issues. To communicate with the broader public, the STA also uses traditional web based tools like web pages as well as social media. Another important communication platform for the STA is its involvement with the national climate change adaptation committee, which includes high level representatives from key administrations (constructions, geology, etc.) who meet twice a year to discuss needs and concerns.

**Tools:**
- STA Climate Change Adaptation Strategy
- STA Climate Change Adaptation Action Plan

**Successes:**
- Strategy and Action Plan will give a structured approach to understand, evaluate, and manage the needs and activities related to climate change within their organization

**Lessons Learned:**
- When local projects involve climate change related issues, there is not a designated coordinator for the STA
- Lack of STA local knowledge of local conditions often precludes involvement.

**Asset Management**

**Summary:** Although the STA estimates that the infrastructure under their jurisdiction includes 100,000 kilometers (km) of roads, 12,000 km of railroads, 25,000 bridges, and about 300,000 culverts spread over a vast geographic area, they do not currently maintain a centralized comprehensive asset management and inventory system. Thus, assets for the various modes and components (such as pavements, railways, etc.) are managed mainly as separate systems. Among the most advanced of these are the asset management plans for bridges and tunnels. Known as the Bridges and Tunnels Management system or (BaTMan), the tool focuses on management, inspection, and planning of bridges and other structures


Inventories are typically conducted at different time cycles and what specifically they include ranges widely and depends on the specific system. Included in this are resilience-related activities like
vulnerability assessments, the specifics of which are covered in the strategic Action Plan. However, the STA maintains a range of systems for location-specific monitoring of hazards. These include systems for monitoring and providing warnings for landslides as well as to warning of railroad track switch freezing and warming systems for the switching mechanism. In addition to routine weather forecasts the STA also maintains a network of about 600 local monitoring stations throughout the country to collect weather data and provide warnings of snowfall, fog, and rain conditions.

A newer system (AnDa) is used to inventory culverts under STA authority [http://iug.buildingsmart.org/resources/itm-and-iug-meetings-2013-munich/infra-room/bim-in-swedish-transport-administration]. As part of the inspections using this system, it is possible to make dimension measurements to assess adequacy under various storm conditions.

Maintenance on STA roads is performed exclusively by contractors. These groups are also tasked with monitoring conditions and reporting conditions back to the STA as part of their daily inspections.

Tools:

- Bridges and Tunnels Management (BaTMan) system is used for the management, inspection, and planning of bridges and other structures
- STA maintains a range of systems for location-specific monitoring of hazards, including systems for monitoring and providing warnings for landslides and railroad track switch freezing
- AnDa system is used to inventory culverts under STA authority and using dimension measurements from field inspections determine their adequacy under various storm conditions

Lessons Learned:

- STA does not maintain a centralized comprehensive asset management and inventory system. Assets for the various modes and components are managed as separate systems.

Project Development, Infrastructure Design, and Construction

Summary: In terms of capital project development, infrastructure design, and construction, the STA has been updating infrastructure design standards to address changing climate-related requirements and needs. These are primarily related to water events more than other hazards. For example, the administration has recently updated their standards with regard to hydraulic design for bridges and culverts. This has not, however, required any change in the types of materials or methods used in construction.

Although the STA does not operate transit rail systems, it does operate heavy rail for intercity passenger and freight rail networks. The planning and design of high-speed railways was noted, in particular, as requiring climate change to be taken into consideration. Resilient design of high-speed rail systems has garnered high initial interest for a variety of reasons. Most notably because it is more sophisticated and constructed to higher design standards than those used for heavy rail and highway modes because the nature of the high-speed rail operation brings potentially higher levels of risk. Since several lines currently exist or are being planned very near coastal areas of the country, they are also susceptible to storms and sea level rise. Thus, any high-speed rail construction or improvement project involves major financial investments.
In terms of the environmental review, project development process, and consideration of locations for new facilities and equipment; practices vary someone within the STA. As policies are continuing to evolve, the specifics of individual projects are varying with respect to these changing considerations. Often, how much climate adaptation related features are included in a project depends on the people involved in the projects and their familiarity and awareness of climate change and the need to consider its impact in project development.

In terms of longer-term planning to resist climate effect effects, the STA does not currently have programs to elevate and harden infrastructure to withstand greater or more frequently occurring flooding. However, it was noted that the administration is involved in a project in a southern coastal community where the roads are being elevated to permit the road embankment to provide levee-like protection from flooding. This project, a first for the STA, will create roads similar of those seen in Holland and south Louisiana where road serve a dual, transportation-flood protection, purpose.

**Tools:**
- Roads elevated to permit the road embankment to provide levee-like protection from flooding similar of those in Holland and south Louisiana.

**Key Successes:**
- Infrastructure design and construction the STA has been updated infrastructure design standards to address changing requirements and needs

**Operations and Maintenance**

**Summary:** From an operations and maintenance perspective, the STA has been active for some time in resilience-oriented thinking and activities. As it was pointed out earlier, much of the initial integration of resiliency practice come from the lower levels of the maintenance divisions. As such, the STA has numerous plans and procedures in place to rapidly and temporarily reconstruct damaged infrastructure. Among their most effective tools are the use “Bailey bridges” to temporarily span washed out sections of road. These are portable, pre-fabricated, truss bridges originally developed by for military use. Similarly, the STA uses temporary power stations, ferries, and trucks passed down to them from the military.

The STA also uses and has plans to construct more alternative railroads and roadways to temporarily carry travelers while damaged systems are restored. It has been recognized that difficulties can occur when temporary and detour roads are not designed to accommodate heavy vehicles and/or hazardous cargo. Detour roads can also be susceptible to the same hazardous conditions (floods) if they are close by the originally damaged road. As a result, planning is beginning to take these types of considerations into account.

Emergency communication and power systems are used during times of need, but they are generally similar to those of routine periods and they tend to have limited capabilities. For example, temporary power generation systems are only meant to be used on temporary bases; operating for several hours until full or partially services are restored. Communication systems span a number of different systems
including broadcast channels, especially emergency radio broadcasts that preempt routine content, as well as web pages and social media applications.

The STA uses regular maintenance and inspection activities to monitor the condition of potentially vulnerable infrastructure and assets. This is especially so for bridges and tunnels because of their criticality within the system and the capabilities made possible by the BatMan system (described earlier). While these inspections include functions and needs associated with resilience concepts, for the most part, these review and assessment activities are part of routine practice and are not necessarily aimed at resilience, specifically. It is notable that contractors play large role in the inspection efforts of the STA during the performance of their unrelated (though overlapping) contracted maintenance duties. Unfortunately, however, they are not perceived to be of as high quality or thorough as inspections carried out directly by the STA.

A noted problem area of inspection was for roadway culverts, which are often in poor condition but not always noted in inspection reporting. Railways are viewed to be generally better inspected then roadways because of more structured, mandated, and regulated maintenance programs. In general, all inspections programs, for road, rail, or other modes, are typically limited to intervals of the year outside of winter and summer when either snow and ice or overgrown vegetation do not hamper visual inspections.

As a final note related to inspection efforts, the STA seeks input from front-line operations and maintenance staff and managers regarding system performance during extreme weather and emergency events to help inform resiliency decisions. However, it is generally not formally organized. While there is input from the practice leaders, maintenance staff, and contractors; work currently being conducted as part of a doctoral dissertation research project has shown that there are no systematic approaches or databases on specifics of response activities. Thus, it makes it difficult for the STA to assess how they investigate disasters and natural hazards and if they are improving responses and learn from past difficulties.

**Tools:**

- Bailey bridges are used to temporarily span washed out sections of roads and railways.
- The STA uses temporary power stations, ferries, and trucks, some of which has passed down to them from the military.
- Emergency communication and power systems are used during times of need, but are only meant to be used on short-term, temporary bases until full or partially services are restored.
- Doctoral dissertation research on effects and benefits gained from emergency related improvement projects.

**Key Lessons Learned:**

- Difficulties can occur when temporary and detour roads are not designed to accommodate heavy vehicles and/or hazardous cargo.
- Detour roads can be susceptible to the same hazardous conditions (floods) if they are close by the originally damaged road.
- Contractors play large role in inspection, however, they are not perceived to the level of quality or thoroughness as inspections carried out directly by the STA.
- Railways are better inspected than roadway because of more structured, mandated, and regulated maintenance programs.
- It is difficult for the STA to assess how/if natural hazard improvement response because there are no systematic approaches or databases on specifics of response activities. This makes it difficult to learn from past events.

References


Transport for London (TfL)

Case Study: London, England

Highlights: Transport for London (TfL) is one of the largest multimodal transportation agencies in the world. The agency faces a range of weather-related and climate threats including floods, extreme heat, and sea level rise. TfL made significant strides toward improved transit system resilience in preparing for the 2012 Olympics. The centerpiece of policy and plan making for resilience is the London Resilience Forum (LRF), which includes more than 170 organizations. The London Climate Change Partnership (LCCP) is a separate but related forum that also addresses transportation to prepare the region for extreme weather and climate change. TfL infrastructure planning standards require a 120-year design life that takes into consideration climate change and mitigation strategies. TfL is a leader in asset management and regularly collects and analyzes performance data as part of operations and maintenance activities and makes this information available to the public. According to the agency, with past incidents and the ongoing threat of terrorism, TfL is focused on a constant state of operational preparedness, which includes ensuring infrastructure is safe from various threats and resilient to climate change.

Key Resiliency Drivers

- Preparing for the 2012 Olympics and preparedness for terrorism in general
- Seeking to meet the Mayor’s carbon reduction targets with large population growth
- Preparing for climate change, particularly increasing flood and extreme heat risk
- Aging of the infrastructure, particularly the Underground is a key concern

Key Successes

- Creating a culture of resilience across many related agencies to prepare for climate change
- Providing online data to the public that has resulted in innovative apps for the public to use, which have been developed at no cost to TfL
- Standardization of asset management processes using a framework
- Innovative use of financing mechanisms such as value capture to coordinate new rail expansion and growth of housing in TODs near future stations
- Designing new infrastructure to be resistant to impacts of climate change with a long-term time horizon (100+ years)
- Working across 14 modes to encourage multi-modalism and redundancy across rail, bus, non-motorized transportation and using congestion pricing in Central London and parking charges to achieve desired outcomes
- Coordinating with various agencies to ensure emergency preparedness
**Key Lessons Learned**

- Because TfL manages all major modes of travel in London, including major streets, they have the ability to use many policy levers to achieve desired outcomes. Other cities should consider consolidating transportation modes into a single agency that can work in unison to promote resilience.

- London has created a culture of resilience that addresses many aspects, including climate change, population growth, and affordable housing through systems planning, asset management, project planning, operations and maintenance, and emergency preparedness.

- TfL provides all data to the public, which has resulted in innovative apps that the public use to obtain better information about their travel options. Such innovation would have never been possible if TfL kept the data confidential and tried to develop apps in-house. By providing the data to the public, they achieved better results at no cost to the agency.

**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>International (Northern Europe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>14 modes</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2013">all modes</a></td>
<td>20,000+ vehicles (8,500 buses; 530 Tube trains; 100 commuter trains; 150 light rail vehicles; 11,000 bikes)</td>
</tr>
<tr>
<td>Annual Unlinked Trips (2013)</td>
<td>3.806 billion trips on bus, heavy rail and commuter rail</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Flood, Extreme Heat, Winter Storms, Extreme Cold, Strom Surge/Wave Action, Sea Level Rise, Other</td>
</tr>
</tbody>
</table>

**Background:** Transport for London (TfL) is one of the largest and most comprehensive multimodal transportation agencies in the world. TfL is an agency within the Greater London Authority (GLA). Boris Johnson is currently the Mayor of London (head of the GLA).

The GLA region has an estimated population of more than 8.5 million people and is one of the largest urbanized regions in Europe. TfL provided nearly 4 billion transit trips in 2013/2014 on three of its major modes, including bus, the Tube and the London Overground. Detailed and the most up-to-date information about transportation patters in London can be found in *Travel in London* (Transport for London, 2015a).

TfL’s website lists over 14 modes that the agency provides and/or regulates, including buses, the Tube (London Underground), Docklands Light Rail, Emirates Air Line (gondola lift across the River Thames), Coaches, TfL Rail, driving, bicycling, London Overground (commuter rail), taxis and minicabs, River (ferries), Dial-a-Ride and walking. TfL operates a public bike-sharing scheme, known formally as Santander Cycles and informally as Boris bikes, which is named for the Mayor of London, Boris Johnson who launched the system in 2010. The bike share system is available 24 hours per day, 365 days per year and includes over 11,000 bikes across 750 docking stations.
TfL has broad and consolidated powers across London. They manage the roadway network, which includes an innovative congestion pricing zone, which charges a toll for driving on the streets of Central London. Congestion charge tolls are then used to encourage non-driving in London.

The Mayor of London takes the lead role in planning for the region as the GLA works with the 33 boroughs that operate under the GLA. Major strides were achieved toward resiliency efforts in collaborating across agencies in preparing for the 2012 London Olympics, given the expected surge in transit ridership during the games. However, since then London’s population continues to grow and in 2015 more people were transported on an average weekday than during the peak of the Olympics. This fact underpins the need for TfL to remain in a constant state of preparedness for operational disturbances, which could include terrorism, weather-related events, or employment strikes.

Over the years, terrorist bombs and changing weather patterns including flooding and extreme heat have pushed TfL toward resiliency planning, especially given that much of the infrastructure is very old and is in constant need of repair and upgrading.

The information collected and reviewed for this case study was gathered from several sources, including interviews with Professor David Banister of Oxford University, Reader Robin Hickman of University College London, and Robert di Cani, Planning Director of TfL. Links and citations to additional documents reviewed and used to support the development of this case study can also be found in the Bibliography section of this case description.

**Policy and Administration**

**Summary:** TfL has a robust set of policy and administration mechanisms in place to advance resilience. The efforts are coordinated with all levels of government, including the national government, GLA and the local boroughs. The centerpiece of policy- and plan making for resilience is the London Resilience Forum (LRF) (Mayor of London, 2016a), which was established in 2002, but a multi-agency team worked on these issues dating back to 1996. The LRF provides a collaborative environment for coordinating the planning for all types of emergencies. More than 170 organizations are involved in the LRF. Since 2010, the Mayor of London appoints the Chair. Figure 1 depicts the organizational structure of the LRF.
The London Resilience Team supports the work of the LRP in both planning for and responding to multi-agency emergencies. Their work includes:

**Planning:**
- Coordinating development of multi-agency capability
- Providing the secretariat for the London Local Resilience Forum and London Resilience Programme Board
- Providing a liaison point between London responders and central government, other Local Resilience Forum areas and internationally
- Ensuring consistency in the development and maintenance of London’s plans
- Promoting preparedness and raise awareness of risks
- Developing and maintain a weekly Common Recognized Information Picture for London (based on input from partners)
- Facilitating London Resilience Partnership meetings to share information.

**Response:**
- Providing 24/7 point of contact for the Partnership
- Coordinating the sharing of information between partners and maintenance of a shared Common Recognized Information Picture
- Facilitating London Resilience Partnership meetings where a SCG is not called
- Providing strategic advice on London’s plans to the Mayor of London, Gold Commanders or Strategic Coordinating Group members (London Resilience Forum, 2013, pp. 6-7).

*Figure 1: London Resilience Forum Structure* (London Resilience Partnership, 2013).
The London Climate Change Partnership (LCCP) also provides a forum for topics related to transportation, with involvement from the GLA and TfL, along with other public, private and community sectors to prepare London for extreme weather today and climate change. Their vision states, “London will become the most climate-resilient city in the world. London’s people, infrastructure and systems are adapting dynamically to its changing climate, and its economy is reaping the rewards of being a world leader in this field.” LCCP’s project, “Understanding the Ripple Effect – Anytown” examines transportation and infrastructure, including disruptions to electricity, which powers much of the transport system.

A recent report, *Providing Transport Services Resilient to Extreme Weather and Climate Change* (Transport for London, 2015b) identifies the risks London faces, which include the following weather changes by 2050 (these are the medium predictions scenario of the 2009 United Kingdom Climate Projections, as noted in the report):

- Higher summer temperatures – average summer days are 2.7°C hotter and very hot days 6.5°C hotter than the baseline average
- Warmer winters – average winter day being 2.2°C hotter and very warm winter days 3.5°C hotter than the baseline
- Drier summers – average summers will be 19% dryer and the driest summer will be 39% drier than the baseline average
- Wetter winters – the average winter will be 15% wetter and the wettest winter will be 33% wetter than the average baseline
- Sea level rise – sea levels are projected to be up to 96 cm by 2011

The most likely impacts to TfL based on climate change will be the provision of transit services on the Tube, rail, bus and river services, and roadway functions. The report provides matrices comparing the likelihood and impact of various risks for various risks for each of the following: London Rail, London Underground and the surface transport system (see Figure 2).
Figure 2: Example of Extreme Weather and Climate Risk Map  
(Transport for London, 2015b)

Tools/Partnerships:
- London Resilience Forum
- London Climate Change Partnership
- Extreme Weather and Climate Risk Mapping

Successes:
- London has created a “culture of resilience” among policy and administration within TfL and across other sectors that relates to public transportation

Lessons Learned:
- Planning for the Olympics was noted as a major catalyst to bring stakeholders together with a focus on resilience

Systems Planning
A major factor impacting systems planning within the context of resilience at TfL is the Mayor’s carbon reduction targets of 60% of 1990 levels by 2025. Achieving these carbon reduction targets is a major challenge, especially if air travel is included in the carbon budget (Hickman and Banister, 2014). TfL Director of Planning, Richard di Cani, confirmed that these goals, also combined with growing population, are a major challenge. Because housing affordability is a major quality-of-life concern for the region, new transportation investments will focus on expanding rail infrastructure to create new housing in transit-oriented development locations to allow future residents to minimize automobile use.

The London Infrastructure Plan 2050 “is the first ever attempt to identify, prioritize and cost London’s future infrastructure. It considers how we might deliver and fund it, in order to support future growth” (Mayor of London, 2016b). As shown in Figure 3, the plan includes an innovative mapping application
that integrates online data. This allows for the planning process to be open and supports infrastructure providers, developers, local government (London boroughs), training providers and colleges and investors.

![London Infrastructure Planning, Mapping and Online Data](image)

**Figure 3: London Infrastructure Planning, Mapping and Online Data**

The Mayor’s office released a specific supporting paper on transport, which identifies key challenges and opportunities and requirements of a world-class system. The report identifies a number of proposed capital projects, including a description, timescale, passenger’s impacts, qualitative benefits, capital cost and other information (Mayor of London, 2016b).

**Tools:**

- London Infrastructure Plan 2050 Mapping Application
- Cost estimating future infrastructure needs

**Successes:**

- Provides data online for various stakeholder to use and analyze
- Creates dialogue about how to plan the future transit system
Lessons Learned:

- Providing data online can help inform discussions about which infrastructure to invest in and/or when such infrastructure is needed

Asset Management

TfL is a leader in asset management, especially since as noted above the age of their infrastructure can result in increased vulnerabilities. The London rail systems (Tube and Overground) are some of the oldest in the world and in need on continual maintenance. Upgrading the Underground is very costly and difficult for the agency, which makes asset management so important. Moreover, continual population growth in the London region has even strained their infrastructure. For example, average weekday ridership in 2015 was greater than the peak during the Olympic Games in 2012.

Figure 4 shows a graphic of TfL’s asset management framework. The overarching vision for TfL informs the strategic framework for each mode, in this case the Underground system. Asset management policy, strategy, and line asset network plans guide the implementation of the plan.

*The Asset Management Policy sets out the high level principles for asset management for staff to manage our assets. It provides the links and line of sight from our vision, down to the asset strategies in the different business units, through to planning, delivery and monitoring of our work banks and processes.*

*The Asset Management Strategy sets out the detailed strategies for each asset group to the end of the current business plan. These determine the performance and condition required in each asset group, the maintenance strategy (preventative and reactive), and the major capital interventions.*

*The London Underground Line Asset Network Plan is produced annually as part of the business planning cycle and sets out the project and maintenance activity that is funded in the business plan. The Asset Control Report is an annual summary of the condition of our assets. The report uses data that is collected throughout the year from condition assessments and summaries from daily operational issues. It classifies the condition of assets by residual life and condition related risks.*  (Transport for London, 2015b, p. 9)

Below these three levels overarching the implementation including planning, then acquiring, refurbishing and replacing equipment, followed by operating, maintaining and disposing. This process is informed by the organization and people, asset information and systems, performance and condition monitoring, safety and risk management, and decision-making processes. Performance measurement and improvement and management review feeds back into the policy, strategy and planning process (Transport for London, 2015b).

TfL has taken strides to ensure that they are in sync with international standards. They note:

*There is a structured asset management process that has been developed in line with PAS 55 and is now being certified to ISO 55000 – the standard for physical asset management. Asset management is the way assets (such as trains, signals, stations and tunnels) are managed throughout their life to achieve the right balance of cost, performance and risk for the organization and follows a 'plan, do, check, act' process* (Transport for London, 2015b, p. 9).
Figure 4: TfL Asset Management Framework

Tools:

- Asset Management Framework

Successes:

- Working to standardize asset management process with international standards (ISO 55000)

Lessons Learned:

- London has some of the oldest transportation infrastructure in the world and it needs to be continually monitored and updated to reduce the system to disruptions. This is occurring at a time when population is growing and demands on the infrastructure are becoming more acute.

Capital Planning, Programming and Finance

Given significant population growth in London, which puts a strain on both the transportation system and housing affordability, the expansion of rail in the region is seen as major factor to encourage resilience. The TfL Planning Director noted that Crossrail and Crossrail 2 will serve multiple benefits to promote sustainability and resilience, including economic expansion, environmental stewardship and social equity. The projects are not just viewed as transportation mobility projects, but economic development generators to create new housing that can provide affordable locations for the working class through transit-oriented development (TOD). London has one of the most expensive housing markets in the world, and leaders fear that if they do not provide adequate affordable housing industry might choose other regions to locate future job growth.
Historically, the vast majority of the funding (approximately 90%) for new infrastructure came from the national government, but in recent years the national government has reduced funding commitments and are placing a larger burden of capital planning, programming and finance on the GLA. The TfL Planning Director noted that because of these changes, the agency is looking at using alternative value capture financing mechanisms, such as Tax Increment Financing (TIF) to cover a larger share of the costs for expansion. Moreover, the national government charges a stamp duty tax on all real estate transactions. TfL believes that new housing sales would not be possible unless TfL is able to construct the new rail corridor, thus they are in discussions with the national government to seek some devolution of funding from these tax receipts to assist with financing the infrastructure that makes new housing possible.

**Tools:**

- Coordination of rail expansion with TOD and new housing
- Use of innovative financing mechanisms such as value capture and TIF

**Successes:**

- Coordinating transportation and land use helps to encourage new city patterns that are more sustainable and resilient compared to automobile-oriented patterns
- Innovative financing tools, such as TIF create new revenue streams to finance infrastructure

**Lessons Learned:**

- In an era of shrinking national resources, local and regional governments need to be more creative in viewing transportation projects not just for the sake of mobility, but to serve multiple factors, including economic, environmental and social goals that can promote sustainable and resilient outcomes

**Project Development, Infrastructure, Design and Construction**

Crossrail is one of Europe’s largest public works projects at an estimated cost of nearly £15 billion. The project is 117 kilometers (73 miles) and includes 40 stations with 10 new stations that connect existing services together to create better regional transit accessibility. The construction includes tunneling under Central London and is scheduled to open in 2018.

The project promotes resilience in a number of ways, including new mobility options for transit. From an infrastructure design and construction perspective, Crossrail includes a 120-year design life in order to ensure long-term resilience based on climate change. A recent FTA report highlighted some of the features of Crossrail and the Docklands Light Rail that incorporate climate change adaptation into the design and construction:

*Transport for London incorporated climate change projections into the design for its major new rail project, Crossrail, with a 120-year design life. Adaptation measures were built into the design and remained through pressure to reduce the budget. The main adaptation is flood prevention in the tunnels, which will traverse a floodplain predicted to be more subject to flooding as the climate changes. The design includes “passive” flood protection such as raising entry and egress levels, raising track levels, and extending portal walls. Where these measures do not suffice (above 0.4m), active flood protection measures have been identified such as floodgates and stop*
logs. Design standards for all tunnel entrances are set to withstand a 1-in-200-year flood. Anticipating higher temperatures, the trains and platforms will have air conditioning (8).

Another major new project, the Docklands Light Railway extension, also included climate adaptation considerations in the design. Future potential flood levels were analyzed and the elevation of the light rail adjusted accordingly (9). (FTA 2011).

According to Professor David Banister, TfL is working to ensure more resilience within the electrical power system, given that much of the rail system is powered by electricity and some power stations are located in flooding-prone areas. Banister noted that the design of power substations, Crossrail station and tunnels are all being designed to minimize risk of impact to infrastructure based on flooding. TfL Planning Director di Cani also noted that not only is TfL designing to address increased flood risk, they are also working to mitigate impacts of extreme heat.

Successes:

- Designing new infrastructure with long-term (100+ year) climate change goals

Operations and Maintenance

TfL has invested a lot of time and resources toward improving operations and maintenance with the goal of improving resilience. As noted earlier, di Cani believes that the 2012 Olympic Games helped the agency to focus on operations and maintenance. He noted that the agency has become smarter about using data from previous events to make decisions for the future.

On the operations side, TfL has integrated their traffic control systems, which has resulted in less delay. Mayor Boris Johnson was elected based on a platform of improving the performance of operations. Poor on-time performance was resulting in public frustration. Di Cani noted that improving operations was not easy and required a detailed assessment using a variety of metrics and data.

One of the major decisions TfL made that di Cani credits with improving resilience efforts on the operations side was to make all data publicly available on an integrated website called the London Data Store. At first, this decision was not easy for TfL but di Cani noted that it was the best decision the agency has ever made. He noted that providing data to the public allows for many programmers to develop innovative apps that TfL riders use to give them better information about how to move around the region. “We put the data out there. We could never have developed the apps that the professional developers create,” di Cani noted.

According to di Cani, the concept of resilience in operations can lead to smarter travel. TfL is trying to get people out of their cars and onto transit in the suburbs but in Central London, transit is congested so the strategy is to get people off transit and encourage them to walk and bicycle more. The London Tube map is iconic but fails to depict distance between stations. Many people, especially tourists not familiar with the geography, will choose to ride the Tube several stations when in fact walking or using a public bicycle could be much faster. TfL is working on new advertising and educational schemes to encourage short trips on non-motorized modes in Central London, which di Cani noted also has better public health benefits.
The last element of operations resilience relates to a large increase of freight on roads. Di Cani noted that during morning peak hours, 30% of vehicles on the roads are “white vans” delivering small packages. TfL uses congestion charging and parking restrictions to incentivize freight delivery during non-peak times.

**Tools:**
- Making data publicly available
- Congestion pricing and parking restrictions to incentivize freight to deliver during non-peak times and for people to drive less, use transit and non-motorized modes more

**Successes:**
- App developers utilize TfL data to create innovative apps that customers use to more efficiently navigate the transportation system in London, which is fully integrated across modes

**Lessons Learned:**
- Public transportation agencies can harness the power of mobile technology without having to invest much. All they need to do is make the data publicly available and the app developers will create new tools that significantly benefits the public’s accessibility and mobility

**Emergency Preparedness**

Emergency preparedness has been an important topic for TfL, especially due to a series of bomb attacks in the recent past, the Olympics in 2012, and the high-level terrorist concerns following the Paris attacks in the fall of 2015. David Banister and Robin Hickman noted that the bus system aids in the resilience of the transport system, especially when the rail system becomes unavailable.

The United Kingdom has a detailed set of emergency preparedness policies, which is overseen by the Civil Contingencies Secretariat of the UK Parliament. The Emergency Planning College (EPC), which is a government contractor, provides many training opportunities targeted to government agencies to become more prepared. Emergency preparedness has become a major sector that brings together police, fire brigades and other first responders with transportation planners at TfL and the UK Department for Transport. The Emergency Planning College maintains a number of resources related to resilience at: [http://www.epcresilience.com/](http://www.epcresilience.com/)

**Tools:**
- EPC has online library of resources for emergency preparedness
- EPC offers a variety of training courses targeted to public agencies
- TfL collaborates more frequently with police, fire and other first responders in emergency preparedness, which was spurred from the Olympic preparations

**Successes:**
- Collaboration and preparation from the Olympics resulted in permanent increased collaboration for emergency preparedness for TfL
Lessons Learned:

- Major events, such as the Olympics, can create long-term benefits for increasing collaboration and emergency preparedness efforts.

References


Additional Resources:


Utah Transit Authority (UTA)

Case Study:
Salt Lake City, Utah

Highlights: UTA’s resilience efforts are focused in the area of emergency management, safety and asset management. The agency uses FEMA’s Threat Hazard Identification and Risk Assessment framework to identify system vulnerabilities and a hazard mitigation approach to address risk. UTA has identified earthquakes and flooding as the primary threats facing transit assets and infrastructure. In that regard, capital project infrastructure designs must meet seismic standards. In the area of asset management, UTA follows a “fix before failure” approach that requires a very proactive inspection program. Tracks are inspected twice a week. Other items must be inspected at least once a month. Inspections data is collected using computer tablets that store inspection checklists. All inputs are automatically uploaded to a database. UTA uses the large quantity of data gathered to continually monitor asset condition and performance.

Key Resiliency Drivers

• The agency’s focus is on emergency management.
• Resilience is not at the forefront of the agency’s priorities.
• The agency conducted a hazard assessment using the Threat Hazard Identification and Risk Assessment (THIRA) process to draft their hazard mitigation plan.
• UTA coordinates their emergency planning with state, local and county emergency management, health departments at state and local levels, local first responders, VOADs (Voluntary Organizations Active in Disasters), and county Office of Emergency Management (OEM), as well as private-sector entities (e.g. hospitals, airport).
• Climate change is not being addressed by the agency presently, but may be soon.
• The agency has no planning or programming that specifically addresses resiliency at this point.
• The agency’s operational and planning emphasis has been on asset management and emergency preparation.
• Other key areas of effort include customer and employee safety, agency accountability to stakeholders, sustainability, and customer and financial performance.

Key Successes

• Comprehensive asset management program.
• Completion of last budgeted capital management program for infrastructure – light rail.
• Emergency management initiative focused on assurance of safety and recovery from disruption of operations, primarily from natural events, such as extreme weather, accidents, and earthquakes. (Emergencies caused by violent human activity are managed by non-UTA agencies.)
• Adoption of seismic standards in the design and construction of all UTA facilities.
Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies

- Incorporation of strategies to protect riders from extreme weather conditions, and limited redundancy to protect operational assets.
- Regularized asset inspection system that enables front-line supervisors to effectively reduce life-cycle costs through a “fix before failure” maintenance program.

**Key Lessons Learned**

- Strong stakeholder outreach and support is critical to further funding and service development success.
- Invest proactively. Delayed investment is likely to be more costly.
- Some transit agencies may have pursued “resiliency thinking” without calling it that, and they can build on their past practices in that regard to conduct more generalized resiliency actions. Application of seismic standards to new construction is an example.
- Well-trained staff ensures superior emergency response.
- Close communication and collaboration between the agency and the wide variety of local and state agencies that have a role in emergency response ensures greater transparency and uniform response to emergency situations.

**Agency Details**

<table>
<thead>
<tr>
<th>Geographic Location</th>
<th>Western United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modes Operated</td>
<td>MB, CR, LR, CB, DR, Other</td>
</tr>
<tr>
<td>Vehicles Operated <a href="2014">all modes</a></td>
<td>776</td>
</tr>
<tr>
<td>Annual Boardings (2014)</td>
<td>45,078,458</td>
</tr>
<tr>
<td>Typical Hazards</td>
<td>Earthquake, Flooding, Extreme Temperatures (both Heat and Cold), High Winds, Heavy Snowfall</td>
</tr>
</tbody>
</table>

**Background:** Salt Lake City lies in a mountain valley with the Wasatch Mountains to the east and north. The Oquirrh Mountains border the western edge of the valley. Salt Lake's official elevation is 4,330 feet/1,320 meters above sea level. The city is situated on land once covered by the prehistoric Lake Bonneville. This ancient lake existed within portions of Utah, Nevada, and Idaho, with an elevation rising from 4,200 feet to 5,200 feet (1,280 meters to 1,585 meters) at some points. The eastern and northern portions of the city are located on a series of terraces, or former beaches, which are known locally as "the benches." Average daily temperatures range from 29°F during January to 77°F during July. The city lies above the Wasatch fault line increasing vulnerability of the city and transit system to earthquake activity (http://www.visitsaltlake.com/about-salt-lake/facts/).

UTA was established on March 3, 1970, and was formed from several smaller transportation providers serving various communities along the Wasatch Valley of Utah. It is governed by a 16-member board of trustees appointed by local elected officials. The agency employs 2,302 personnel and provides service over 1,400 square miles to 80 percent of Utah’s population. UTA is a four-time recipient of the American Public Transportation Association’s Outstanding Public Transportation System award, more than any other transit agency. The agency maintains both ISO 9001 certification for quality management and ISO 14001 certification for environmental management.
Utah Transit Authority (UTA) provides over 100 bus routes throughout a 1,400 square mile area. UTA transit system provides commuter rail (90 miles), light rail (93.9 miles), bus and commuter bus, as well as BRT and demand response.

In 1999, UTA opened its first light rail transit line, TRAX. As of August 2013, 140 miles of rail operation provided a means of transportation for a growing number of Utah residents (Foy, P., UTA debuts $235M rail service to SLC airport, http://www.standard.net/stories/2013/04/13/uta-debuts-235m-rail-service-slc-airport). From visioning in the late 1980s, to taking action in the 1990s, to the successful system that currently exists and is expanding across the Salt Lake City region, UTA set a high standard for transportation expansion programs. With unconventional planning processes and fortuitous partnerships, UTA was able to transcend public skepticism of light rail and transit expansion, modeling a new approach for transit providers (Eno Transportation Center, Lessons learned from the Utah Transit Authority Expansion, November 2013).

In 2015, UTA completed its first full year of operating all five commuter lines that were a part of its FrontLines 2015 program. The agency was named the Outstanding Public Transportation System of the Year for 2014 by the American Public Transportation Association (APTA). Additionally, the agency experienced the highest ridership in its history with 45 million boardings, a 2.17 percent increase over 2013 and a growth rate of more than twice the national average. FrontRunner ridership, in particular, was strong with a 15 percent increase in weekday boardings. The authority also focused on adding bus service to Hill Air Force Base, increasing frequency on key commuter routes and offering campus shuttle services at Utah Valley University.

UTA is a government special service district overseen by a board of trustees. Special service districts are usually smaller than a state agency but serve an area larger than traditional city or county borders. UTA serves the residents of Salt Lake, Weber, Davis and Utah counties and select cities within Box Elder and Tooele counties. UTA’s funding comes primarily from the municipalities within its service area. This funding is primarily local sales taxes matched with available federal funding. Additionally, UTA does raise additional funding from advertising and other non-operational business activities. UTA’s budgeting is done annually.

In addition to the bus and paratransit services provided by UTA from its outset, UTA launched light rail service in 1999, and commuter rail service in 2008. Future service developments include bus rapid transit (BRT), corridor and connector services, a downtown streetcar, and a regional accord to make long-term decisions on the future of the central Wasatch Mountains, including transportation, environment, economy and recreation (Utah Transit Authority Year in Review 2014).

Policy and Administration

UTA is a government special service district overseen by a board of trustees. Special service districts are usually smaller than a state agency but serve an area larger than traditional city or county borders. UTA serves the residents of Salt Lake, Weber, Davis and Utah counties and select cities within Box Elder and Tooele counties. UTA’s funding comes primarily from the municipalities within its service area.

The UTA Board of Trustees provides broad direction, governs the Authority, and sets policies and goals on issues such as ridership, services and financial responsibilities. Members of the board are generally
appointed by the city and county governments within UTA’s service area that support the agency with a local-option sales tax, with some members appointed by the state. Board members serve four-year terms with no term limits. The size and structure of the board and the procedures for appointing its members are determined by the Utah State Legislature (Utah Transit Authority Year in Review 2014).

UTA runs light rail, buses, commuter rail called Frontrunner, and 400 vanpool and par transit vehicles.

The Frontrunner is UTA’s commuter rail service. It operates over 90 miles from Provo to Ogden. It runs every 30 minutes at peak hours and every 60 minutes at other times. Frontrunner runs on track that UTA bought from Union Pacific. UTA owns 200 miles of track.

Since 1983/4, the system has suffered no major natural disasters, but is very conscience of the potential for earthquakes, given Salt Lake’s location along a fault line at the base of the Wasatch mountain range. Except for earthquake, natural threats are ongoing and include extreme weather, both very hot and very cold. Freeze-thaw sun kinks are a problem for UTA’s various rail services. Because of high altitude (4,500 feet in the central valley of Utah), intense sunlight is also a concern for passenger safety. UTA works to provide shade for people waiting for buses and trains in the summer. On high heat days, UTA makes frequent road calls to repair air conditioning equipment and must be vigilant for sun kinks in rail.

During winter, UTA experiences an average of four or five large snow events, each dumping one to two feet of snow. Maintaining service requires a lot of snow removal and the use of salt to keep the tracks free of ice. This has an adverse effect on life of the agency’s rolling stock. Since 1984, there have also been significant flooding events in the Wasatch Valley.

Earthquakes are the only other major natural concern for UTA. As noted earlier, Salt Lake City is just above Wasatch fault line. As a result, all construction standards in Utah take that fault into account. UTA makes bridges and structures conform to most up-to-date seismic codes.

Safety and Security policy is set by a committee of executive leadership including:

- Development Department Chief Development Officer
- Asset Management
- State of Good Repair
- Safety and Security Department, Chief Safety Officer
- Planning Department, Chief Planning Officer
- Communications, Chief Communications Officer
- Finance, Chief Financial Officer
- Technology, Chief Technology Officer
- Operations, Chief Operating Officer. Meet weekly.

This committee meets weekly to advance goals that are set twice a year, and the work of the committee is reported to the UTA Board of Directors. Visioning and goal setting is done in several retreats each year; one includes the board. There is community input at the board retreat, and some mayors come to that retreat. The executive committee has its own retreat and each department has a retreat. Advisory committee of citizens (20 members) meets three to four times a year to provide input about conditions and policy concerns.
UTA considers its customers to include both riders and taxpayers who don’t ride: the community served. UTA is committed to retaining its focus on riders while broadening and deepening its concern for non-riding public. To the extent that there is a notion of resilience at UTA, it is reflected in the creation, three years ago, of the position of Chief Safety Officer. The catalyst for that action was an accident during the testing of a rail line in which a young woman was killed. Culture of safety (resilience) is now in the mainstream of UTA’s daily operations.

As UTA looks ahead, the agency will continue to lead many of the region’s transit-oriented development efforts, which are designed to encourage the use of public transportation rather than driving. UTA will also continue its pursuit of operational excellence and work to improve its current 90 percent on-time reliability. In addition, the authority will maintain its focus on safety by continuing its educational outreach efforts and by implementing state-of-the-art safety measures system wide (Utah Transit Authority Year in Review 2014).

**Capital Planning, Programming and Finance**

UTA has a 30-year capital plan that is updated every four years. For the last 15 years, the capital plan has focused on large infrastructure projects to support their light rail and commuter rail programs and university transportation systems. Now the focus is shifting to support operations and maintenance of their systems.

UTA plans their investments using a regional travel demand model. Near-term investments are driven by the needs of state of good repair and system performance. In the future, but not yet considered in plans, is the possibility that UTA service area may be extended to the mountains east of the current operational area. UTA performs cost-benefit analyses based on estimates of capital cost per mile, operational cost per mile, and ridership generation. UTA applies FTA standards and guidelines to evaluate feasibility. UTA’s rail systems generate an estimated 1,000 to 1,500 riders per day. A single bus line is estimated to generate 300 to 500 riders per day.

UTA has not invested in resilience or considered resilience specifically in its capital planning. However, new facilities have been built to conform to seismic standards. Although climate change is not a specific concern of capital planning, UTA has recognized that weather has a significant influence on ridership. Currently, UTA is participating in a study to measure the effects of inclement weather on ridership.

UTA recognizes that the cost of designing and building system assets below standard and risking an event is greater that building to or above standard and experiencing no event during the life cycle of the asset. Although UTA has not addressed resiliency specifically, that perspective seems to be one of semantics. In actual practice, UTA’s application of seismic standards is almost the definition of resilience thinking. Investments in construction that take seismic ratings into account proceed with the hope that an earthquake will not occur and with no certainty that a dangerous temblor will occur. Still, the investments recognize the probability that an earthquake will occur, and that the results would be catastrophic. Given those premises, UTA spends whatever extra is needed in construction.

Likewise, the term “no regrets” is not used in UTA’s planning. Yet, as is hoped, there is no powerful earthquake during the life of the structure, there are “no regrets.” Although UTA does not systematically
apply the “resilience” thinking pattern about earthquakes or other threats, such as floods, they are veterans in using the “protection” and “mitigation” parts of the resilience concept.

**Asset Management, Project Development, Infrastructure Design and Construction, and Operations and Maintenance**

UTA has not given extensive consideration to effects of climate change, but preservation of asset value is an ongoing concern, especially through preventative maintenance. UTA has not evaluated the vulnerability of their systems to disaster. Recently, UTA received a FEMA estimate of likely hazards from a 7.0 magnitude earthquake, and UTA will evaluate the implications of that study. UTA recently completed a hazard assessment using the Hazus model from FEMA that evaluates the vulnerability of our rail lines, platforms, and facilities to dam inundation, flooding and geological events both earthquake and liquefaction. This assessment provided information on both the approximate damage and losses to the system.

UTA did conduct a study of consistent failures of catenary in the UTA light rail system. Analysis showed that connectors were probably going to fail, so all connectors were replaced.

Vulnerabilities of operations have been considered without regard for disaster. The UTA light rail system operates on one track. So if a switch or signal fails or a non-rail traffic accident occurs, major delays result. Back up systems provide a bypass to add redundancy when such delays occur, but a massive event that affected the back up system would close the system down. No funds are available to provide a larger capability.

Performance planning does not include consideration of potential climate change impacts. UTA conducts performance reviews similar to those done by other transit agencies. UTA takes a detailed look at on-time performance and other variables such as ridership metrics, special event ridership, miles between road calls, interruptions, accident rates, and internal or external causes of failures. Reports of performance go monthly to the board. Reports are online at [www.rideuta.com](http://www.rideuta.com).

UTA achieves redundancy in bus operations by re-routing around bottlenecks and breakdowns. There is little redundancy in the commuter rail system, which has declined in reliability. The commuter rail runs on mostly single track. Breakdowns can wreak havoc, causing domino effects down the line. UTA’s approach is basically to fix each problem and run late. At times, UTA does run shuttle buses as bridges around breakdowns. The bus bridge is well established.

UTA has installed a major asset management program that tracks between 16,000 and 17,000 items. Management focuses on “normal” expected life cycle and the costs of non-routine maintenance, rehabilitation, and replacement, with a life-cycle plan for each asset. The philosophy of the asset management program is “fix before failure.”

Asset management does not include resilience as a specific consideration. Criticality and vulnerability are viewed in the context of the effects of loss of an asset’s function on the transit system’s scheduled revenue operations. UTA has not addressed the vulnerability of a facility or equipment to specific kinds of the threats. Rather, it is generally understood that a major earthquake or very unusual flood would render the light rail system inoperable for an extended period. That is true even though newer
structures were built with seismic ratings in mind. Rail, because its routes are more constrained than those of buses, is more vulnerable.

UTA also recognizes that they are dependent on the integrity and continuing operation of the electrical grid.

The asset management program is used for capital, safety, and systems planning considerations, taking into account construction, operations, rehabilitation and enhancement. UTA’s Development Office works as part of a committee that also includes leaders of other departments:

- Information technology
- Bus program
- Rail maintenance of way
- Rail operations
- Vehicles
- Electrification

The committee operates effectively because they have front-line ability to detect deterioration of assets as it occurs.

Front-line supervisors are responsible for frequent inspections to maintain operations. For example, tracks are inspected twice a week. Other items must be inspected at least once a month. Notable in that process is the innovation of an inspection system based on use of computer tablets. The tablets store the inspection checklists, and the results of completing the work on the lists, including photographs of the items inspected. All inputs are automatically uploaded to a database. UTA uses the large quantity of data gathered in those inspections to discern the need for action that allows realization of their “fix before failure” or continuous condition assessment approach. For example, examination of a series of inspections of the same item might document deterioration of an asset.

With the front-line observations and the tablet-based database, UTA can modify generalized life-cycle estimates, such as those cited by manufacturers, to reflect deterioration curves that are peculiar to the UTA region and the “real expected life” of assets. For example, UTA has to deal with over 100 freeze-thaw cycles and heavy salting to melt snow and ice. The effects of such stresses shorten the life cycle of some assets. Analysis of actual data on deterioration allows UTA to build locally adjusted estimates into its asset management plans. Using that approach, they have shortened several projections of life cycles. Data have never justified lengthening of a cycle.

The biggest concern of the Development Director is the potential for destruction, as in an earthquake, of multiple long-lead items. Many items on the rails systems are manufactured or build in unique ways, and replacing even one has a long-lead time. The UTA General Manager has a contingency account that can be used to support recovery from damage.

UTA does re-evaluate its design standards. For example, UTA does not have sufficient personnel to manually remove snow on all the platform surfaces that must be safe over the system, which are about 100 miles long and 20 miles wide. For that reason, UTA invested in installation of electrical snowmelt systems on platforms to increase the safe, clean walking path for riders during snow events. Those systems are expensive to install and operate, but they improve overall safety. The UTA light rail system
is 16 years old and affords some protection from a flood like the one that occurred in 1983 because of the elevation of the tracks and extra drainage.

Operations and maintenance deal with emergencies well, coordinating well with outside agencies, such as police and activating a telephone tree of emergency response with maintenance teams from UTA. An example is response to bridge hits that result when the height of a truck’s load is measured incorrectly and the truck strikes a bridge supporting rail tracks. UTA has provided law enforcement organizations, because they are usually the first responders at incident sites, with photographs that show the kinds of damage that justify the following decisions:

- Stop rail traffic over the bridge immediately
- Allow rail traffic to run at reduced speed
- Continue rail traffic at normal speed

Depending on the observations reported by law enforcement, UTA repair personnel take appropriate action to ensure safe rail service. UTA operates its commuter rail system on tracks that are also used by Union Pacific (UP) Railroad. UP movement occurs only at night, however, so there is none during UTA’s hours of revenue service.

**Lessons Learned:**

- The life cycle of an asset is often shorter than it is advertised to be.
- UTA is vitally dependent on the integrity and continuous operation of the electrical grid.
- UTA has the ability to redress the failure or destruction of discrete elements of its system, but the lead time and cost for replacing major elements of their system due to failure or destruction would probably cause broad scale system interruption.

**Emergency Preparedness**

UTA has an emergency management plan as required by CFR 659 [Chapter 6]. The plan has a draft annex that covers continuity of operations. As part of the plan, each UTA facility has its own plan specific to the facility. There is also a plan for operations of a family assistance center that would operate in case of an incident that involved fatalities. The emergence preparedness plan focuses on dealing with threats to UTA from natural or technological forces. Separate security and police forces have plans for threats from terrorism or other human motives.

UTA has only recently received from the state an assessment using FEMA’s Hazus toolkit the probability of hazards from an earthquake of 7.0 magnitude in UTA’s area of operations, liquefaction, landslides, flooding, and dam inundation. They will review the study to determine if they need to adjust their emergency preparedness plan.

UTA has established a well-tested emergency response program that provides for continuity of operation and high-levels of customer service in cases of natural and man-made events. The agency will be incorporating results of their Hazus assessment into the UTA emergency preparedness program. UTA runs several simulation exercises per year to evaluate its emergency management plans. Twice a year, the emergency operations center (EOC) is activated to test its operations. Twice a year, “full-scale” exercises of the whole plan focus on the light rail system and the commuter rail system. Full-scale tests
involve as many elements of UTA as are included in the emergency preparedness plan as possible. Those events include deploying participants to the site that is the focus of the emergency in the exercise scenario.

Evacuation of the UTA system depends on a decision of the effected local jurisdiction(s) in the UTA service area. In case of such a decision, UTA makes sure that riders are safely removed from the UTA property and moved to the care of appropriate county authority. Because the light rail system’s right-of-way includes a segment that could be flooded, UTA has prepared a response plan, a requirement that is levied by UTA’s insurance company.

The agency’s emergency preparedness plan has worked well, and the possibilities for improvement have been noted. One event, a derailment, required opening the agency’s emergency operations center (EOC). UTA has established a bus bridge back up program for its rail system, and UTA personnel deploy to platforms to actively engage riders to reassure them that the system will provide for their travel.

The emergency preparedness plan includes redundancy of control centers, power, offices, and communications. Meals ready to eat (MRE) and water are stored at several locations. Appropriate UTA personnel keep “go bags” with items such as flashlights and first aid kits to facilitate their response to emergencies.

UTA’s emergency preparedness program is coordinated with:

- Local police
- Sheriff’s departments
- Fire and EMS departments
- Hospitals
- Local and state health departments state medical examiner
- Red Cross
- Medical Reserve Corps
- Local and county emergency management
- Utah Department of Emergency Management

UTA has a seat in the state EOC of the Utah Department of Emergency Management. UTA’s emergency preparedness planning has not addressed threats that may result from climate change.
References


10. Utah Transit Authority. 2014. Year in Review.