ASSESSING PUBLIC TRANSPORTATION AGENCIES' CLIMATE CHANGE ADAPTATION ACTIVITIES AND NEEDS

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ABSTRACT

Climates are changing throughout the world, including on a regional level in North America. It is likely that changes to four aspects of the climate will cause the greatest impacts to transit infrastructure and operations: intense precipitation, very hot days and heat waves, rising sea levels, and storm (e.g., hurricane) intensity. Climate changes will affect the way transportation professionals manage their multimodal transportation infrastructure. A region or city’s ability to adapt their vulnerable transportation infrastructure and operations to climate-related impacts will determine the resilience of that community’s transportation system.

Federal agencies have led the way in adapting many transportation modes to climate changes. A literature review and analysis of current activities and a survey of 300 transit agencies found that focus at the transit agency level was on mitigation of climate change by reducing greenhouse gas emissions. However, transit agencies are facing impacts caused by current weather conditions and by future climate change. The review highlights 17 agencies conducting climate adaptation activities, mostly as part of federally-funded pilot projects. The online survey focused on gathering information such as whether the agencies were involved in climate change adaptation activities, which activities they have or are currently engaged in to assess potential impacts of weather and climate change on their facilities and operations and the relative importance of different resources to effectively assess these impacts. The most common barriers to conducting activities seems to be a lack of funding, lack of access to information and tools (including regional-scale data) and lack of organizational priority.

KEYWORDS: Climate Change, Transit, Adaptation, Vulnerability
INTRODUCTION

Climates are changing throughout the world, including on a regional level in North America, and impacts associated with the climate changes are expected to continue and intensify (1, 2, 3). In most of North America, summer temperatures are expected to increase by up to nine degrees Fahrenheit by 2100 (1), while annual mean precipitation is very likely to increase in the northeast United States, and likely to decrease in the southwest United States (1).

Though changes to the mean temperature and precipitation in the United States will surely affect much of the nation’s transportation infrastructure and facilities, public transit will likely be most affected by region-specific climate changes, including changes to seasonality and increased frequency of extreme events. It is likely that changes to four aspects of the climate will cause the greatest impacts to transit infrastructure and operations:

- Intense precipitation,
- Very hot days and heat waves,
- Rising sea levels, and
- Storm (e.g., hurricane) intensity (4).

In the short term (the next 30 years), heat and precipitation will likely pose the most challenges nationally. Heat waves and regional droughts have become more frequent and intense during the past 40 to 50 years (1, 4). Urban areas, which are the base of most transit systems, tend to be hotter than surrounding areas due to the urban heat island effect. These urban heat islands will likely compound the effects from heat waves. Rain that occur only once every 20 years are projected to increase in frequency to every four to 15 years (depending on location) and drop 10 to 25 percent more rain (1). In the northeast United States, the duration of extreme rain events (defined as more than two inches per day) is projected to increase by one to 1.5 days by 2040-2070, putting some of the nation’s oldest and largest transit systems at an increased risk of the effects of these rain events (4, 5).

For coastal transit systems, sea-level rise (SLR) could outweigh the issues of increasing heat and precipitation, especially in the long term. It is likely that the rate of SLR will increase, with sea levels rising up to 24 inches by the end of this century (6, 7). An average of almost 10 percent of the land in the 180 largest US coastal municipalities lies at or below one meter of elevation above sea level (4, 8). Sea levels will continue to rise even if climate change mitigation efforts prove successful, and the effects of SLR will be felt differently by region, depending on elevation and whether the area is experiencing any subsequent uplifting or subsiding. San Francisco Bay and Miami are two examples of particularly vulnerable areas (4). Climate models also project more intense tropical cyclones (e.g., hurricanes) with related increases in wind, rain, and storm surges (1, 4), and this increasing intensity coupled with SLR could lead to rising storm surge levels and increasing damage.

There are many ways that transit agencies are recognizing or addressing climate change. Many agencies, national and local, acknowledge the role that transit could play in mitigation of climate change. An analysis of current climate activities found that focus at the transit agency level was on mitigation of climate change by reducing greenhouse gas emissions through new bus technologies or encouraging transit ridership. However, even with a strong mitigation movement,
there are already climate changes in motion for which the nation’s transit systems will need to be prepared (4).

The National Research Council defines climate change adaptation, vulnerability, and resilience as follows: Adaptation refers to adjustments in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Resilience is 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 (3). This paper focuses on transit climate change adaptation activities and baselining the state of the practice within transit agencies.

CLIMATE IMPACTS ON TRANSPORTATION AND TRANSIT

The climate changes described in the previous section will cause impacts – social, economic, and physical – that will affect (or may already be affecting) the way transportation professionals manage their multimodal transportation infrastructure. A region or city’s ability to adapt their vulnerable transportation infrastructure and operations to climate-related impacts will determine the resilience of that community’s transportation system. Though several countries have undertaken fairly extensive studies to prepare their transportation systems for likely climate changes, the United States is only beginning the process (9).

The Transportation Research Board’s (TRB) 2008 publication “Special Report 290: Potential Impacts of Climate Change on U.S. Transportation” led the way in examining the impacts to transportation facilities in the U.S. There has been a growing focus on the topic at a national and local level, including within state and regional departments of transportation (DOTs) (10, 11, 12, 13).

Policies and research have not only focused on assessing the impacts to transportation, but also on potential ways to adapt transportation infrastructure and operations to these impacts (14, 15, 16, 17). The United States Department of Transportation (USDOT) Policy Statement on Climate Change Adaptation expresses the USDOT’s intent to incorporate consideration of climate adaptation into their planning processes and investment decisions, and encourages state, regional, and local transportation agencies to consider climate change impacts in their decision-making (18).

The literature and policies that are aimed at addressing the impacts of climate change on transportation in general can be applicable to transit, but the lack of transit-focused climate adaptation literature is problematic because climate change has many negative impacts that are particular to public transportation, such as impacts to catenary wires, subway tunnels, electrical equipment, and passenger comfort (Table 1). There is also a possibility of climate change impacts that will have positive effects on transit, such as a decreased number of very cold days, later onset of seasonal freeze, and earlier onset of seasonal thaw. These climate changes could lead to reductions in snow/ice removal costs, fewer cold-related restrictions for maintenance workers, and improved mobility and safety (4).
It is possible that one reason for the lack of literature on transit-specific climate change impacts is that transit agencies may have been brought into the conversation primarily as a road user. Larger-scale infrastructure sectors, such as highways, are usually overseen by bigger agencies with more funding to put towards researching, analyzing, and adapting to the impacts of climate change. According to the 2010 National Transit Database, 93% of transit route miles are on non-rail mixed traffic roads, which are owned and maintained by other state and local agencies (19). All road users will experience impacts that are similar, such as flooding or debris blockage of roads. However, non-bus forms of public transportation, such as light rail, will be impacted differently from bus transit. Though these rail transit modes only constitute about 5% of transit route miles (12,363 miles), they make up approximately 55% (29.3 billion) of annual passenger miles (19), and their rights of way are operated by the transit agencies, and thus significant attention should be given to the climate impacts that are unique to rail transit.

To begin to address the lack of transit specific information, the Federal Transit Administration (FTA) released a policy statement, which included plans for addressing the challenges associated with climate change and to analyze the impact on FTA’s mission and operations (20). In December 2011, FTA announced selections for seven climate change adaptation pilot projects at local transit agencies (21). The selected projects will assess the vulnerability of transit agency assets and services to climate change hazards such as heat waves and flooding. More information on these pilot projects can be found in the next section of this paper.

The FTA’s 2011 publication “Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation” was the first major publication to take an in-depth look at transit climate adaptation. The document examines projected climate impacts on U.S. transit, climate change adaptation efforts by domestic and foreign transit agencies, transit adaptation strategies, risk management tools, and incorporation of adaptation into transit agency organizational structures and processes (4).
<table>
<thead>
<tr>
<th>Climate Change</th>
<th>Possible Impacts on Transit Infrastructure</th>
<th>Possible Impacts on Transit Operations</th>
</tr>
</thead>
</table>
| Increased number of very hot days and heat waves | • Buckling of track, possibly leading to derailment  
• Overhead catenary wires could lengthen, lose tension, and fail, causing the vehicle to lose power  
• Limitation on construction periods during summer, leading to delays to improvements  
• Reduction of asset life  
• Vehicle overheating and tire deterioration | • Reduced/variable speed limits (e.g., due to slow orders)  
• Health, safety, and comfort concerns for workers and passengers  
• Overheating of electrical train control, monitoring, electrical equipment, or communications systems; damage to catenary lines  
• Brownouts could disrupt street traffic signals, slowing bus operations and affecting electric rail transit |
| Rising sea levels | • Subway tunnels, busways, rail tracks, lots, and maintenance facilities vulnerable to increased flooding  
• Erosion and inundation of coastal facilities  
• Higher groundwater level could flood tunnels | • Inundation of roads and rail lines in coastal areas leading to disruption of service from road closures or diversions, or power outages |
| Increased number and intensity of extreme precipitation events | • Increased erosion of track/road bases (scouring)  
• Impacts on soil moisture levels, affecting structural integrity of roads, bridges, and tunnels  
• Flooding of subway tunnels, busways, rail tracks, lots, and maintenance facilities  
• Flooding of signals, lights, and electrical equipment (switches, signals, and gates) | • Increased weather-related delays, diversions, and disruptions  
• Decreased visibility  
• Overloading of drainage systems, causing backups and street flooding  
• Possibility of increased bus accident rates  
• Possibility of increased landslides/embankment failures  
• Road closures |
| Increasing drought conditions in some regions | • Increased susceptibility to wildfires that threaten transportation infrastructure directly | • Increased susceptibility to wildfires, causing road closures due to fire threat or reduced visibility |
| Changes in seasonal precipitation and hydrologic patterns | • Increased risk of floods from runoff, landslides, sinkholes, slope failures, and damage to roads if precipitation changes from snow to rain in winter and spring thaws | • Floods could cause delays, route changes, increase in maintenance and inspections |
| More frequent strong storms (including hurricanes, storm surge, and tornadoes) | • More frequent and potentially more extensive emergency evacuations  
• Greater probability of infrastructure failures  
• Flooding of subway tunnels, busways, rail tracks, lots, and maintenance facilities  
• Increased damage to signs, lighting fixtures, and supports | • Contraflow lane operations  
• Winds could cause more debris (e.g., tree branches) that blocks rail lines, bus routes, and access to stations and bus stops  
• Power outages (e.g., due to loss of high voltage power lines) may disrupt service and communication |

Compiled from multiple sources: 4, 10, 12, 15, 22, 23
Other transit-focused organizations are also recognizing the need to encourage transit agencies to investigate the potential impacts of climate change. American Public Transportation Association (APTA) published “Guidelines for Climate Action Planning” in 2011. Though these guidelines focus mainly on mitigation, the guide does mention that “understanding the potential of these [climate] changes and planning accordingly can help agencies reduce future costs of adaptation while ensuring their ability to continue to provide service,” (24).

Prior to the release of their statement on adaptation, the U.S. DOT began the Gulf Coast Study, which includes a study of climate adaptation needs for transportation agencies, including transit agencies. The Gulf Coast region under study contains 13 major providers of public transit, and the study identifies ways in which these agencies may be affected by increased storm intensity, storm surge, and SLR (13).

The Gulf Coast study is split into three phases. Phase I of the Gulf Coast Study concluded with multiple findings about impacts, many of which are similar or related to those identified in Table 1. For instance, the study found that relative SLR is expected to affect the level of service for both bus and rail, but will likely cause more loss of infrastructure to light rail than bus systems, since the latter can presumably be rerouted to higher areas more easily (13). The second phase of the study is underway, and will develop a risk assessment methodology and identify techniques to incorporate environmental and climate data in transportation decisions. A report has been published under Task 1 for Phase II, and it identifies critical infrastructure in Mobile, Alabama, including the local transit agency’s assets (27). This agency’s (Wave Transit) assets, including fleets, terminals, and other facilities, were analyzed qualitatively using socioeconomic, operational, and health/safety factors (27). Phase III of the Gulf Coast Study will identify and analyze adaptation and response strategies and develop tools to assess these strategies, and enumerate future research needs (13).

In addition to the Gulf Coast Study, there has been additional research around climate impacts on transportation as a whole but which incorporates substantial information about transit vulnerabilities and associated climate change adaptation measures. For example, a U.S. DOT Federal Research Partnership Workshop included discussions of threats to transit, including flooding (28). Peterson found that the greatest impact of climate change for North America’s transportation systems could potentially be flooding of coastal infrastructure, including transit systems, because of global rising sea levels coupled with storm surges and (in some locations) land subsidence (29). Zimmerman focused on impacts and adaptation challenges for major urban infrastructure sectors and notes the difficulties that cities and agencies may encounter as they work towards addressing climate change impacts. The paper gives the example of New York City’s transit sector and roadways, which have multiple owners and complex sharing arrangements that pose challenges to introducing adaptation (30). In addition, Zimmerman notes other potential difficulties that must be considered when identifying vulnerabilities and planning for climate change adaptation, including: the size and density of the city’s transit sector; the fact that many of the facilities are located underground and/or either in coastal or river floodplains; the difficulty and considerable expense that would be incurred to retrofit or to relocate vulnerable portions of the system; and the need to keep the system operational (30).
LOCAL TRANSIT AGENCY CLIMATE CHANGE ADAPTATION ACTIVITIES

While much of the local transit agency focus has been on the role of transit in mitigation of climate change through reduction of greenhouse gases, there has been a response to the need for climate adaptation. The analysis described here began with a review of literature and other readily-available documents (including workshop proceedings and other presentations) to see how often United States transit agencies were cited as conducting these activities, and to gather information on the types of activities being conducted.

The next step in the analysis was a high-level review of transit agency websites to find any readily-available documents or web pages that discussed climate change activities, especially those related to adaptation. In choosing the agencies to review, several factors were taken into account, including size of service area, location, and mode. The list includes the transit agencies for the 50 largest cities in the United States, at least one agency from each state, and all agencies that have regional/commuter rail and light rail systems alone or in addition to bus lines, in order to get information pertaining to a variety of modes. In total, 150 agencies were reviewed. Based on the review, 17 agencies were participating in or conducting activities explicitly related to one climate change adaptation, and several different climate impacts are being addressed (Table 2). All of these transit agencies have at least a local or state plan or report related to climate change or adaptation, and most of the cities had both, which could be indicative of a driving force behind the agency’s actions or the mindset of the local community. In addition, many of the activities take place at agencies located near the coast (Figure 1).
### TABLE 2 - Agency Climate Adaptation Action Analysis

<table>
<thead>
<tr>
<th>Transit Agency</th>
<th>Adaptation (or need for adaptation) included in agency...</th>
<th>Climate impacts highlighted</th>
<th>City/Region or State Climate Action Plan or Report</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plan</td>
<td>Project</td>
<td>Pilot</td>
</tr>
<tr>
<td>BART (San Francisco Bay)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Cape Cod RTA</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTA (Chicago)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Island Transit (Galveston)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Hillsborough Area Regional Transit (HART), Houston Metro</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Los Angeles MTA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MARTA (Atlanta)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>NJ TRANSIT</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>NYC MTA</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oahu Transit Services</td>
<td>✗</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEPTA (PA)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>SFMTA (San Francisco)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMART project (San Raphael, CA)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound Transit (Seattle)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TriMet (Portland, OR)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Transit (Mobile, AL)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- = climate action plan without adaptation language
FIGURE 1 - Map of United States Transit Agencies Taking Climate Adaptation Actions
Though there were many agencies addressing mitigation and general sustainability through transit, there were four transit agencies that explicitly addressed climate change adaptation in their planning, or had explicitly evaluated the need for a transit adaptation plan.

- **Central Puget Sound Regional Transit Authority** (Sound Transit) in Seattle, Washington has a sustainability plan that incorporates adaptation considerations into planning processes by setting an initiative to “ensure climate change impacts are addressed in Risk Management, Safety and Security Plans” (31).

- **Los Angeles County Metropolitan Transportation Authority** (LACMTA) has taken a multi-pronged strategy for addressing climate change. The agency’s long-term plan mentions the need to partner with other agencies to craft an adaptation and mitigation plan for the region (32). The agency is developing a plan that will address both service disruptions that occur now during periods of extreme heat and heavy precipitation, and it will ensure the reliability and safety of future and planned infrastructure projects, using LACMTA’s Environmental Management System (33).

- A report which focused specifically on climate impacts on transit was produced for **New York Metropolitan Transportation Authority** (MTA). The report examines a variety of potential climate changes and identifies the main threats as temperature rise, changes in precipitation, SLR, and coastal storm surge (34). The process for identifying the need for adaptation included identifying facilities and programs subject to risk; applying climate change scenarios; screening adaptation options for feasibility and linking options to capital replacement and rehabilitation cycles; benefit/cost analyses and environmental impacts; implementation plans; and monitoring/reassessing strategies according to observations and enhancement of existing climate science (34).

- **San Francisco Municipal Transportation Authority**’s (SFMTA) draft 2011 Transportation System Climate Action Strategy notes that mitigation is only the first major step in climate action planning that will include adapting to changes in storm severity, drought, SLR, and transportation system reliability. Development of an adaptation plan is described as an “immediate next step” (35).

Seven current FTA pilot projects will advance the state of practice for adapting transit systems to the impacts of climate change. At the end of the 15-month pilot, each recipient will submit a final report on the activities conducted, main findings, and applicability to other transit agencies (21).

- **Chicago Transit Authority**’s (CTA) project will leverage the City of Chicago Climate Action Plan to conduct detailed analyses and implementation plans to improve resilience of CTA assets to climate impacts (21). There are three tasks in CTA’s pilot workplan: Survey system vulnerabilities; create project implementation plans for applying adaptation principles to three projects; integrate adaptation into CTA standard business practices (36).

- **Island Transit** (Galveston, TX) in partnership with **Hillsborough Area Regional Transit** (Tampa, FL), **Metro** (Houston, TX) and the Texas Transportation Institute are working on a project that will evaluate costs associated with maintenance of a state of good repair in the face of climate impacts for the three Gulf Coast transit agencies (21). Pilot outcomes will include climate change adaptation strategies that will assist the...
agencies in protecting capital assets, mitigating weather impacts, minimizing service
impacts, and ensuring passenger safety and comfort (37).

- **LACMTA** will move forward with their ongoing climate change adaptation work by
integrating it into LACMTA’s Environmental Management System and Environmental
Information Management System, developing metrics to measure effectiveness of
adaptation strategies, and conducting extensive outreach (33).

- **Metropolitan Atlanta Rapid Transit Authority** (MARTA) will focus on how
MARTA’s asset management system can be used to monitor climate changes and help to
identify strategies to respond to impacts. Objectives include identifying lessons that can
be applied to other transit systems and building relationships between MARTA and
climate adaptation experts to improve planning and investment decisions (38).

- **San Francisco Bay Area Rapid Transit District** (BART) will analyze its vulnerabilities
to sea-level rise, heavy downpours, and flooding in 50 and 100 year scenarios, using
hazard and risk analysis and development of adaptation and implementation strategies
(39).

- **Sound Transit** is undertaking a project that will use workshops to engage staff and
directors from across the agency and leverage University of Washington climate research
and state DOT climate work (21). Project results will be incorporated into the agency’s
sustainability plan, environmental management system, and other agency programs (21).
Expected outcomes include an advancement of the state of the practice of risk assessment
and adaptation planning; enhancement of agency capacity for climate impacts assessment
and adaptation planning; and development of working regional partnerships (40).

- **Southeastern Pennsylvania Transportation Authority** (SEPTA) will conduct a
detailed analysis of past service disruptions, future climate scenarios, risks, and
adaptation options for the Manayunk/Norristown commuter rail line (41). Expected
outcomes are cost assessments for impacts such as passenger delays and capital
infrastructure repair; practical guidance to ground the adaptation strategy in reality and
provide a scalable model; and partnerships that will be valuable for broader regional
adaptation initiatives (42).

In addition to the FTA pilots, several transit agencies took part in Federal Highway
Administration (FHWA) pilot projects revolving around the FHWA conceptual model for
assessing vulnerability and risk of climate change effects on transportation infrastructure:

- A draft climate impacts assessment report was recently completed for **New Jersey
Transit** (NJ TRANSIT). The report, titled “Resilience of NJ TRANSIT Assets to Climate
Impacts,” includes information such as identification and mapping of specific climate
impacts on NJ TRANSIT’s assets and a description of resilience strategies for the
impacts identified (including high-level costs and benefits for each of the resilience
strategies) (43). In addition, impacts to the agency’s rail infrastructure were assessed as
part of North Jersey Transportation Planning Authority’s conceptual model pilot funded
by FHWA (44). The pilot used a ranking system to assess the criticality of assets, using
aspects such as connectivity, magnitude of service, and redundancy, and analyzed the
potential impacts of climate changes such as SLR, storm surge, precipitation,
temperature, and flooding (45).
- **Oahu Transit Services** participated in the Oahu Metropolitan Planning Organization pilot to assess the vulnerability and risk for five areas, including a transit facility near Hawaii International Airport that houses 1,800 employees, 531 buses, and 166 vehicles for a public transit service for persons with disabilities who are unable to use the City's bus service. Climate factors included in their assessment include SLR, storm surge, wind, high-intensity rainfall, and air temperature. The pilot team also identified “an immediate and significant need” to develop downscaled projections for wind, rainfall, storm and hurricane wind speeds, and stream flood projections under the combined conditions of higher sea levels and increased rain intensity (46).

- **SFMTA** participated in the San Francisco/Metropolitan Transportation Commission pilot, which considered a range of criteria for assessing vulnerability and risk, many of which focus on identifying assets likely to be affected by SLR. The transit network, including bus routes, rail lines and stations, and ferry terminals, was considered a major transportation asset for the report investigation. The report lists several lessons learned from the pilot, many of which relate to data collection and use, but which also touch on issues surrounding definitions of terms related to the climate change discussion and how to treat different assets (47).

There were two agencies which took part in other pilot projects.

- **Cape Cod Regional Transit Authority** participated in a pilot study and report funded by FHWA, the National Park Service, and the U.S. Fish and Wildlife Service, that served as an opportunity to pilot and evaluated scenario planning as a method for addressing transportation-based adaptation to climate change (48).

- **Wave Transit** in Mobile, AL is included as a key stakeholder in the second phase of the FHWA’s Gulf Coast Study, described previously (27).

Three transit agencies had explicitly considered future climate changes in projects.

- **LACMTA** is considering future climate changes in projects as part of Los Angeles’ Measure R program, which allocated funding towards traffic relief and transportation upgrades throughout the county (32).

- **Sonoma Marin Area Rail Transit District** (SMART) is conducting a bridge scour analysis of two bridges over rivers that are under tidal influence, taking into account projected SLR (4).

- **TriMet** in Portland, Oregon, received an award from the FTA for their innovative inclusion of climate change information in the Environmental Impact Statement (EIS) for the Portland-Milwaukee light rail project (49). The EIS includes analysis of whether the bridge height will be a concern for boaters in the future, due to flooding or the long-term effects of climate change (50).

Besides those which have already been listed, asset or performance vulnerability analyses regarding climate change have been conducted either by or for several transit agencies, including LACMTA (33), New Jersey Transit (43), and New York MTA (34).
A SURVEY OF U.S. TRANSIT AGENCIES

In spring 2012, an online survey was conducted among US public transportation agencies in order to gain an understanding what activities agencies were undertaking in terms of planning for climate change. In partnership with the American Public Transportation Association (APTA), the survey was distributed to approximately 300 agencies. Survey participation was targeted at general managers, transit agency planning staff, and sustainability/environmental contacts, though it was not strictly limited to those respondents. Questions elicited information such as whether the agencies were involved in climate change adaptation activities, which activities they have or are currently engaged in to assess potential impacts of weather and climate change on their facilities and operations and the relative importance of different resources to effectively assess these impacts. In total, respondents from 64 different agencies representing 28 states completed the survey, yielding a 21% response rate. Of the 150 agencies originally investigated in this paper, 53 responded (35% response rate).

The findings for the survey are described here in three parts: the current conditions and outlook regarding climate change and/or future weather impacts, current and future activities around climate change adaptation, and barriers and needs.

Current Conditions and Outlook

Respondents reported that their facilities and operations had been impacted in the last decade by major storm events (92%), flooding (49%) and heat waves (49%). Impacts from inundation, wildfire, and/or erosion were experienced less frequently. As a result of these impacts, agencies indicated that facilities were more often temporarily closed and/or service was impacted. Only a couple agencies noted that facilities were irreparably damaged due a specific event. Responses indicate that agencies are most concerned about an increase in the magnitude or frequency of severe weather events and flooding, which is likely correlated with the majority of adaptation activities happening in coastal locations – the threat of future sea level rise and increased magnitude and/or frequency of hurricanes may loom large. Not surprisingly, the responses indicate less overall concern with current impacts that are more region-specific, such as erosion/landslides, inundation, and wildfire.

Current and Future Climate Change Activities

More than 60% of respondents felt that it was somewhat important for their organizations to prepare for future impacts of climate change, although it is not a strong factor being considered in the current decision making or planning process. Surprisingly, 28% of the respondents indicated that their organization feels that climate change is currently impacting their community, though an equally large portion indicated uncertainty in estimating when their organization will experience impacts. Looking into the future, sixty percent of respondents indicated that their organization feels it will be impacted by climate change within 50 years. Given the average time horizon for plans and projects is about 17 and 10 years, respectively, it is likely that many of these organizations believe the plans and projects they are currently working on could be affected by climate change. However, only 21 respondents indicated that their agency was currently involved in adaptation climate change planning activities.
Responses indicate that at least 38% of agencies are collecting cost data and/or other information and data about weather events or climate projections to assess the impact on their infrastructure and operations. In addition, the majority of the agencies (57%) have identified assets and infrastructure that are vulnerable to extreme weather events, while only 13% have done the same for projected climate changes. However, nearly 34% of the agencies are not collecting or using any data related to extreme weather or climate change.

For active agencies, emergency preparedness (79%), operations (73%), and planning (80%) areas of their organization are the most involved in discussions or decisions regarding climate change activities and planning. In recognition that this is a truly multi-departmental endeavor, management/leadership, design, environmental, asset management, and maintenance areas of the organizations were also listed by more than half of the respondents. Many of the respondents indicated that emergency preparedness for weather-related events was the focal point for this issue. Responses also indicate that agencies are focusing on activities in the form of developing operating procedures, emergency response planning efforts, incorporating adaptation into planning efforts, or participating in pilot projects, including conducting vulnerability assessments, developing a climate adaptation strategy and integrating with existing or developing asset management systems and environmental management systems. Another focus was research about potential climate change impacts. Less common activities included scenario analysis, both to identify facilities that may be impacted under different climate change impact assumptions and to inform the location or design of planned transportation facilities. Nearly a third of respondents indicated they were not engaged in activities to identify climate potential impacts to their transportation system.

**Barriers and Needs**

Responses indicate three major barriers that limit organizations from incorporating climate change adaptation: lack of funding (staffing & resources and project related funds), adaptation is low organizational priority, and need for better data and tools (localized and consumable data). In many ways these barriers are intertwined. Under current fiscal constraints, agencies are struggling to address issues and activities outside the core mission. As seen in the above discussion, much of the current activities are being funded through federal pilot projects. In order to successfully incorporate climate adaptation, agencies will need to bring climate change under the umbrella of their mission and include it as part of the normal funding allocation process. A large part of the challenge for agencies and their leadership seems to be the act of balancing core priorities, current needs and funding with the uncertainties that are associated with climate change and the long range impacts.

Some agencies emphasized that the local or state politics around the issue of climate change was a major barrier. This seems to be an issue for certain areas of the country and could play a part in the response rate of the survey. Though respondents did not indicate that lack of climate change knowledge within the political community was a common barrier, the lack of funding available to these agencies to conduct climate adaptation activities is linked to attitudes toward climate adaptation at the political level. To this point, at least three agencies were unable to complete the survey due to apprehension from political leadership. It is a circular issue -- politicians may not understand the effects of climate change on their local infrastructure and operations, which could
lead to a lack of political support, but without that support, funding will not increase, and without funding, agencies cannot study the effects that climate change will have on their systems.

For agencies starting adaptation activities, the lack of information on climate science and cost information on climate impacts appears to be a crucial barrier. Agencies are in need of a wide range of information to help them understand and address needs. The availability of geographically specific climate projections and impacts data and methodologies for assessing vulnerability of assets were noted as an important need necessary for effective climate change adaptation planning. This is information and data is also important to raise the awareness and to develop a dialogue within the agencies on the issue. In the survey conducted for this paper some agencies indicated that they have been able to collect data to identify existing transportation system vulnerabilities to flooding and major storm events, but this is a minority. Responses seem to indicate a funding issue for agencies to update or create asset management systems that inventory system vulnerabilities and critical infrastructure.

In looking to support agencies in adaptation activities, respondents also highlighted the need for guidance related to both developing climate change action plan, policies, or best practices (61%), as well as general guidance and technical assistance (50%), and tools (55%). Though webinars/trainings and were not widely indicated as a need, more than half of respondents (60%) indicated that webinars and trainings were a useful format to receive climate change science information. One respondent indicated that GIS-based maps with climate impacts would be useful, as they could be laid over infrastructure maps. Another respondent emphasized the importance of interactive exchange as the way to “move the needle.” One example of an action that has been taken to address this barrier (though not for transit-specific needs) is the Department of Transportation’s Transportation and Climate Change Clearinghouse Webpage (http://www.climate.dot.gov/impacts-adaptations/index.html), which contains several documents and links to other websites that provide information on issues from the impacts of climate change on design standards to planning for climate change at the local level.

**CONCLUSION**

Transit infrastructure and operations across the U.S. are at risk from the current and projected impacts of climate change. Transit agencies have been focused primarily on mitigation strategies to reduce greenhouse gases, but a small subset has begun to address climate change adaptation to avoid or mitigate the projected consequences of a changing climate. Though there is a growing foundation of transportation adaptation research, there is a specific need for research around transit-focused adaptation. In particular, region-specific impacts and the vulnerabilities of transit systems should be examined in more detail, as should transit agency responses to climate change and any barriers that agencies have experienced to implementing climate adaptation measures. When planning for climate change adaptation at the transit level, agencies must first investigate the relevant climate change impacts on a regional scale. This will require a strengthening of the relationship between climate scientists and public transportation planners. Once the likely impacts are known, it is possible to assess vulnerabilities based on these impacts, and adapt best practices, planning, and designs in order to be resilient to the anticipated climate changes.
Findings indicate that transit agencies are starting to address the imminent or present challenges posed by climate changes on their infrastructure and operations. Most of the adaptation activities are occurring by a smaller subset of agencies that either are located near the coast or have had recent weather events causing agency action, and in general, many of the activities are funded by outside sources including pilot project grants. The results of the survey indicate that a number of agencies have been impacted in recent years by many of the weather events expected to increase in frequency and severity due to climate change, and there is a need for more information and support for these agencies to begin to consider climate change adaptation in their planning efforts. Furthering awareness of likely climate change impacts at the local level in the near and more distant future elevates the importance of adaptation planning education among the agency staff, public and decision makers. Increased awareness of the risks posed by climate change may contribute to allocation of funding to conduct necessary data collection, especially cost data, and comprehensive planning efforts. Outreach and education within and across state and local agencies and development of staff expertise on projected climate change impacts and adaptation strategies are also necessary to guarantee successful implementation of planning actions.

To better address climate change adaptation for transit in future plans, key resources, such as locally relevant data on current and projected climate change impacts must be developed along with inventories of critical transit infrastructure and overall transportation system vulnerabilities. Additionally, planning strategies, including improved agency coordination to ensure that goals and actions are consistent across plans, and awareness and outreach programs should be adopted to better integrate climate change adaptation recommendations into transit plans.

Transit agencies could benefit from incorporating vulnerabilities from multiple disciplines both within their organization (including engineering, planning, and security) and with other city or regional agencies (e.g., those concerned with emergency management, economic development, parks and recreation, city planning, and environmental protection). By bringing together an interdisciplinary group of people who are working to address a wide range of impacts from climate change, solutions can be more sustainable and integrated into local planning efforts.

Because transit agencies are inherently more road users than owners, it would seem transit agencies would also gain much value working with other state and local government agencies to develop common impact scenarios to better facilitate information sharing and coordinated planning efforts. In addition to preparing for anticipated future impacts of climate change, agencies need also to collect data on weather impacts already observed as well as monitor changes that occur over time. Development of local and regional clearinghouses for climate change data projections and planning documents are recommended to ensure that multiple agencies and disciplines have access to common data and to avoid the costs associated with parallel data collection and analysis efforts.

Though the major barrier for the agencies to address this issue is funding, the FTA and some agencies are starting to use funds to aid in the development programs, conduct projects, and provide needed support services to agencies. In the presence of all of these barriers to transit climate adaptation, FTA began an initiative in 2011 to adapt public transportation assets and services to the impacts of climate change in order to meet shared goals of mobility, state of good repair, safety, and sustainability (53). This initiative and the pilot projects described in previous sections should begin to address some of the barriers discussed above by providing funding for...
transit agencies (or partnerships with transit agencies) to assess the vulnerability of transit assets and services to climate change hazards. The FTA has also helped to bridge the gap between transit and climate change adaptation by contributing significantly to both phases of the USDOT’s Gulf Coast study.

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