NATIONAL CAPITAL REGION EXTREME HEAT TOOLKIT FOR TRANSPORTATION PLANNING

Item A - Transit Impacts Assessment

June 2026




National Capital Region
Transportation Planning Board

NATIONAL CAPITAL REGION EXTREME HEAT TOOLKIT FOR TRANSPORTATION PLANNING: TRANSIT IMPACTS ASSESSMENT

Published on June 30, 2026.

ABOUT COG

The National Capital Region Transportation Planning Board (TPB) is the federally designated metropolitan planning organization (MPO) for metropolitan Washington. It is responsible for developing and carrying out a continuing, cooperative, and comprehensive transportation planning process in the metropolitan area. Members of the TPB include representatives of the transportation agencies of the states of Maryland and Virginia and the District of Columbia, local governments, the Washington Metropolitan Area Transit Authority, the Maryland and Virginia General Assemblies, and nonvoting members from the Metropolitan Washington Airports Authority and federal agencies. The TPB is staffed by the Department of Transportation Planning at the Metropolitan Washington Council of Governments (COG).

CREDITS

This report was prepared for the Metropolitan Washington Council of Governments (COG) Transportation Planning Board (TPB) by ICF. This project was led by Katherine Rainone and Pierre Gaunaurd from TPB, and this report was prepared by individuals from ICF including Brenda Dix, Emelia Suljic, Amanda Vargo, Jasmyn Noel, and Dasha Latvis in close collaboration with TPB.

PHOTO CREDITS

BeyondDC/Flickr (MARC and Crystal City), Pierre Gaunaurd/COG (bus stop), Ted Eytan/Flickr (Georgetown)

ACKNOWLEDGEMENTS

The preparation of this report was financially aided through grants from the District of Columbia Department of Transportation; Maryland Department of Transportation; Virginia Department of Transportation; the Virginia Department of Rail and Public Transportation; U.S. Department of Transportation, Federal Highway Administration; and the U.S. Department of Transportation, Federal Transit Administration.

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Introduction

The Transit Impacts Assessment is one component of the National Capital Region Extreme Heat Toolkit for Transportation Planning. The toolkit examines how extreme heat affects the transportation system and provides resources to help member agencies begin identifying, evaluating, and adapting to heat-related risks.

This assessment builds on TPB's 2024 risk-based vulnerability assessment, which evaluated extreme heat vulnerability for several transit asset types, including bus stops, rail stations, and rail lines. The results indicated that public transit and active transportation are highly sensitive to extreme heat, which drives both physical and operational impacts to these systems. High temperatures can create heat kinks where rail tracks buckle, increasing the risk of derailment, and leading to slow orders and service delays. Additionally, transit riders walking to, or waiting at stations can be sensitive to health risks, such as heat stroke.[1]

Goals & Objectives

The Transit Impacts Assessment supports regional resilience efforts by:

I. Improving understanding of past and future extreme heat risk, including downstream impacts, to help inform future planning and resilience efforts.

II. Quantifying impacts to ridership and fare revenue.

III. Quantifying the impacts of slow orders on operating costs for transit agencies and travel time burden for transit riders.

Building on this work, TPB's subsequent Transportation Resilience Improvement Plan (TRIP) identified the need for additional analysis to better understand how extreme heat affects public transit riders, particularly those who rely heavily on transit or live in urban heat islands. The **Transit Impacts Assessment** responds to that need by presenting a preliminary examination of observed and projected extreme heat impacts on transit operations and ridership. It includes two complementary assessments that characterize these impacts across the National Capital Region:

- A **qualitative overview of downstream impacts** on health and access, service and operations, and economic outcomes.
- A **quantitative assessment of select extreme heat impacts** using WMATA and VRE data to approximate lost fare revenue from changes in rail ridership, as well as cascading operational costs and travel time burdens from slow orders.

Rail transit plays a critical role in regional mobility. According to TPB's 2025 State of the Commute survey, 21 percent of commuters rely on the train as their primary or secondary commute mode.[2] The region's rail system comprises three primary transit services:[3]

1. The **Washington Metropolitan Area Transit Authority's (WMATA) Metrorail** serves approximately four million people across the District of Columbia (DC), Virginia, and Maryland and is the second busiest and third longest urban rail system in the country.
2. The **Virginia Railway Express (VRE)**, operated by the Northern Virginia Transportation Commission and the Potomac Rappahannock Transportation Commission, provides weekday commuter rail service along the I-66 and I-95 corridors and links suburban Virginia communities to downtown DC.

[1] Liu, L, et al. 2025. Measuring Exposure to Extreme Heat in Public Transit Systems. https://doi.org/10.1016/j.jtrangeo.2025.104383
[2] TPB. 2026. 2025 State of the Commute Technical Report. https://www.mwcog.org/documents/2026/01/21/state-of-the-commute-survey-report--carsharing-featured-publications-state-of-the-commute-telework-travel-surveys/
[3] TPB. 2026. State of Public Transportation 2024 Report. https://www.mwcog.org/documents/2026/02/09/state-of-public-transportation-report-bus-rail-tpb-transit/

3. The **Maryland Area Regional Commuter (MARC)** rail system, operated by Maryland's Transit Administration, provides commuter rail service in Maryland and into DC and parts of West Virginia.

The results of the Transit Impacts Assessment are intended to inform future resilience planning and investment decisions. The assessment concludes with future enhancements that could further explore the impacts of extreme heat across transportation modes, including bus and active transportation, as additional data become available.

Extreme Heat Impacts for Transit Operations and Users

Rising temperatures in the National Capital Region pose significant challenges to the safety and reliability of the transportation network. The following sections provide an overview of three categories of extreme heat-related impacts to the region's transit system and its users (Figure 1):

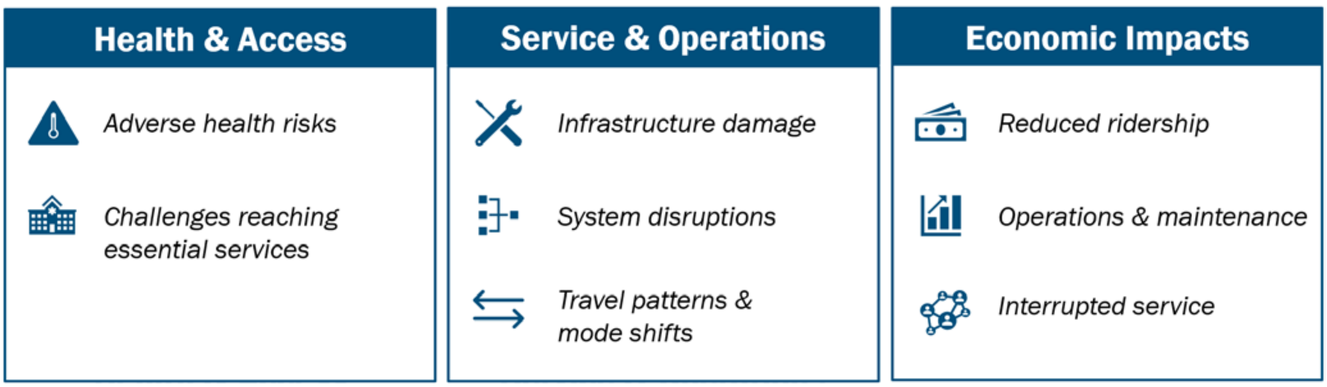

Figure 1. Overview of the major categories of heat-related impacts to the region's transit system and users.

HEALTH AND ACCESS

Extreme heat can result in adverse health effects for transit operators and riders, due either to direct exposure to the high temperatures or as a result of heat-related disruptions that complicate access to essential services.

Adverse Health Risks

Exposure to extreme heat places transit riders and workers at risk of heat-related illnesses such as heat stroke and heat exhaustion.[4] Vulnerable populations (see text box) are at even higher risk of experiencing severe heat-related health outcomes.[5,6] High temperatures also worsen air quality.[7] Exposure to poor air quality can exacerbate existing health

Heat Vulnerable Populations

- *Individuals with comorbid health conditions*
- *Older adults and young children*
- *Outdoor workers and commuters*
- *Socially vulnerable or isolated populations*
- *Individuals without air conditioning or access to cooling spaces*
- *Individuals without a personal vehicle who may be more dependent on transit and active transportation modes*

[4] National Institute for Occupational Safety and Health (NIOSH). 2024. Heat-related Illnesses. https://www.cdc.gov/niosh/heat-stress/about/illnesses.html
[5] Milman, O. 2026. 'Woefully Unprepared': Extreme Heat Will Double US Hospitalizations by 2040, Study Finds. www.theguardian.com/environment/2026/jun/09/extreme-heat-double-hospitalizations-2040-study
[6] EPA. 2021. Climate Change and Social Vulnerability in The United States: A Focus on Six Impacts. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf
[7] U.S. Environmental Protection Agency (EPA). 2021. Climate Change and Social Vulnerability in The United States: A Focus on Six Impacts. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf

conditions such as asthma, cardiovascular disease, and other respiratory illnesses.

Commuters spend significant time outdoors while traveling to stops and stations, waiting on platforms, or transferring between services. These activities can result in prolonged exposure to high temperatures which makes transit users (especially those who lack the ability to mode shift during dangerous conditions) particularly vulnerable. Frontline workers, including bus drivers, maintenance crews, and station staff, also face sustained exposure during heatwaves.

In 2025, WMATA analyzed heat severity and tree canopy around their Metrorail stations.[8] For each station, WMATA mapped its *Pedshed*, or area around a station where pedestrians are likely to be walking or biking on the sidewalk to and from the station and thus are most likely to be exposed to extreme heat. This StoryMap provides insight into areas where commuters may face health risks due to high heat severity and lack of shade, such as around the Mount Vernon Sq 7th St -Convention Center station in downtown D.C (Figure 2).

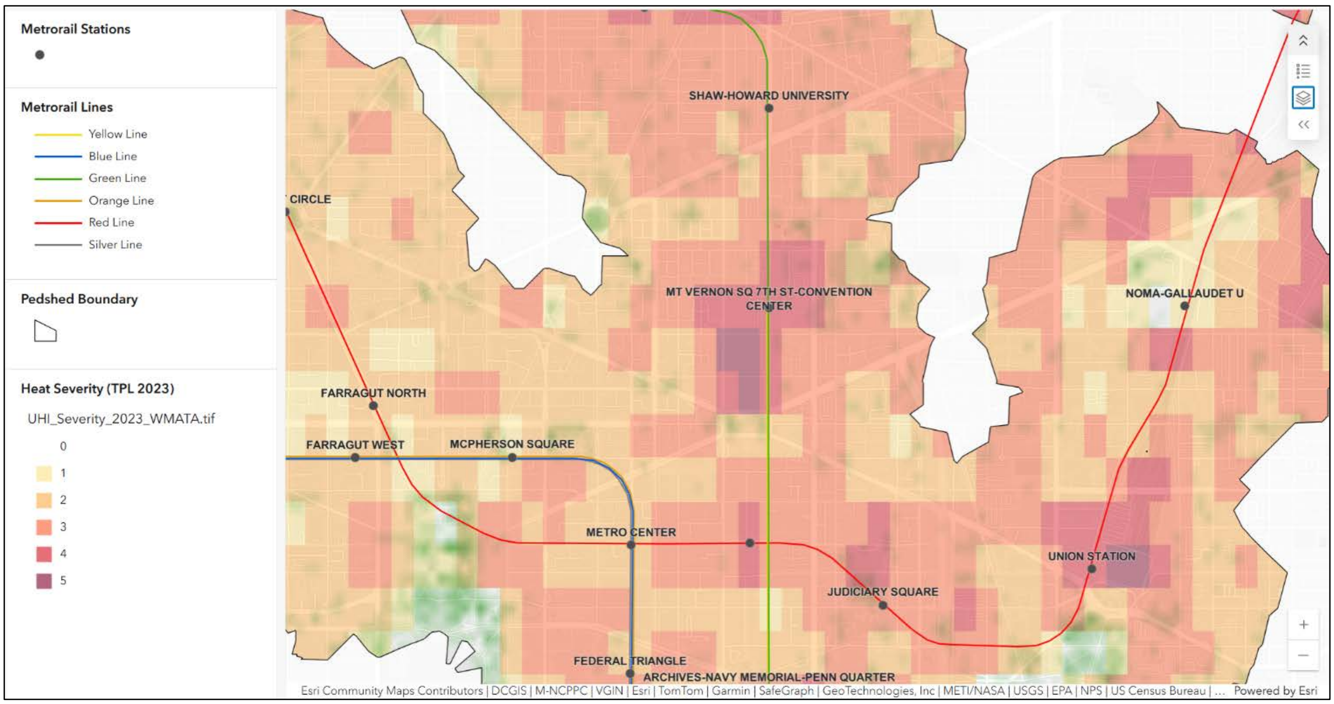

Figure 2. Screenshot of heat exposure near Metro lines and stations in downtown D.C from WMATA's Heat Exposure for Metro Riders StoryMap. Source: WMATA, 2025.

During extreme heat events, transit agencies may decrease or slow service to reduce strain and damage on assets, potentially leading to overcrowding from decreased service frequency, as well as longer waits in the heat. Packed buses or trains, especially those experiencing HVAC issues, can heighten health risks for riders.

Challenges Accessing Essential Services

Extreme heat events may also cause service disruptions or cancellations that prevent people from reaching critical goods and services such as cooling centers, emergency services, workplaces, healthcare or childcare facilities, and other vital resources. People without alternative forms of transportation, and those at risk of heat-related illnesses, are particularly affected. These cascading access barriers can deepen existing struggles for transit-dependent communities.

[8] WMATA. 2025. Heat Exposure for Metro Riders. https://storymaps.arcgis.com/stories/e16e3fe110d2432ebcb0f2c0697931d8

SERVICE AND OPERATIONS

Extreme heat increases the risk of transit infrastructure failure, prompting agencies to slow operations to protect equipment, which can cause system-wide disruptions and affect travel patterns. For specific examples of how some of these risks have impacted the region, refer to the analysis described in the **Quantified Impacts for Transit Owners and Users** section of this assessment.

Infrastructure Damage

Heat accelerates wear on transit infrastructure, prompting more frequent inspections, repairs, and replacements. For example, high temperatures can cause rail tracks to expand and deform, creating "sun kinks" or "heat kinks" that require immediate slow orders or single tracking to prevent derailments.[9] Agencies including VRE, WMATA, and MARC regularly issue or respond to slow orders on abnormally high temperature days or during rapid temperature fluctuations to proactively reduce risk where kinks may have formed but have not yet been identified. When sun kinks occur, affected track segments must be taken out of normal service until repairs are completed. Recent examples of heat-related transit disruptions include the following:

- In **July 2012**, 10 consecutive days of temperatures over 95°F caused a heat kink that led three railcars to derail in Prince George's County.[10]
- On **June 20, 2024**, rail temperatures exceeded 135°F (metal rails get hotter than air temperatures), prompting WMATA to limit all trains to a maximum speed of 35 mph.[11] VRE also implemented heat orders due to this event.
- On **July 14, 2024**, rail temperatures exceeded 135°F again, prompting systemwide speed restrictions on above-ground track segments for WMATA, MARC, and VRE service.[12] WMATA also implemented single tracking on the Blue and Yellow Lines after a heat kink formed near Crystal City (Figure 3).[13]
- WMATA implemented another heat order a year later due to high rail temperatures on **June 24, 2025.**[14] According to internal records, MARC and VRE also implemented heat orders due to this event.

Figure 3. Heat kink on WMATA's Blue and Yellow rail service line on July 14, 2024. Source: DCNewsNow, 2024.

Extreme heat also places significant stress on onboard and station air-conditioning systems, increasing the likelihood of equipment failure. As described in the **Health and Access** section above, this creates dangerous conditions for riders. When cooling systems falter, interior temperatures can rise rapidly, and commuters waiting on platforms or in enclosed stations can be exposed to even higher heat-stress.

[9] VRE. n.d. Blog - Train Delays. https://www.vre.org/blog-train-delays/

[10] Trautman, T. 2012. Metro says heat kink likely caused derailment. https://www.washingtonpost.com/blogs/dr-gridlock/post/metro-heat-kink-in-rail-likely-caused-derailment/2012/07/07/gJQAKJTEUW_blog.html

[11] Woolsey, A. 2024. NOW: Metro slows down trains due to high temperatures. https://www.ffxnow.com/2024/06/20/now-metro-slows-down-trains-due-to-high-temperatures/

[12] Tuss, T. 2024. Metrorail lowers train speeds as rail temps top 135°. https://www.nbcwashington.com/news/local/transportation/metrorail-lowers-train-speeds-as-rail-temps-top-135/3666284/

[13] Allen, G., & Farrell, B. 2024. Metro puts above-ground speed restriction into place due to heat. https://www.dcnewsnow.com/news/local-news/washington-dc/blue-yellow-lines-single-tracking-due-to-kink-from-extreme-heat/

[14] Failla, Z. 2024. Heat Wave Slows Metro Trains as Rail Temps Hit 135 Degrees In DC, Maryland, Virginia. https://dailyvoice.com/md/brooklyn-park/heat-wave-slows-metro-trains-as-rail-temps-hit-135-degrees-in-dc-maryland-virginia/

Together, these infrastructure and equipment impacts increase operational and maintenance expenditures during extreme heat days and create broad systemic disruptions that can have resounding impacts throughout the region, especially for industries and people that depend upon functional transit.

System Disruptions

As discussed above, transit agencies slow service and reduce operations at certain ambient and rail temperature thresholds to minimize infrastructure damage. Because regional rail networks operate on tightly scheduled corridors with multiple operators, a heat-related delay due to slow orders on one line can cause cascading impacts across the system. Conflicts at stations, bottlenecks at junction points, and mismatched headways disrupt operations for multiple services and compounds delays for riders.

Rail Heat Order Delays in Virginia

The Virginia Passenger Rail Authority compared monthly heat-related delay minutes for Virginia rail with average daily high temperatures from February to October in 2022 and 2023. Results show a peak delay of 6,276 minutes in July 2023, representing a 53 percent increase from July 2022 and corresponding with an 8.1°F rise in temperature.

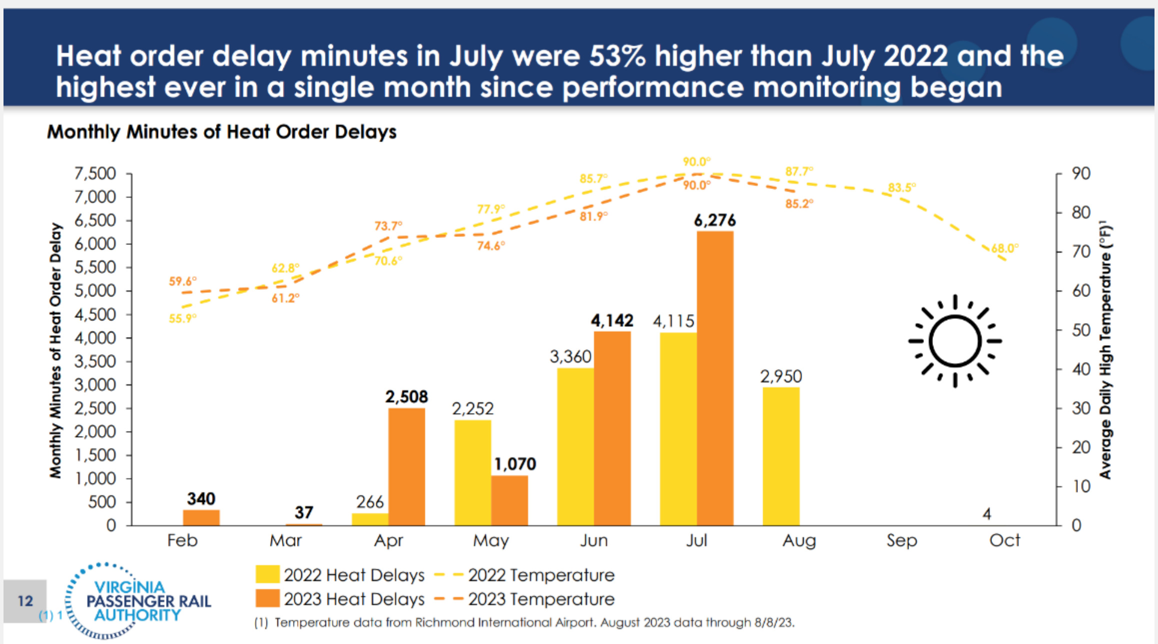

Figure 4. Chart showing the relationship between monthly Virginia rail heat order delay duration and average daily temperature in 2022 and 2023. Source: Virginia Passenger Rail Authority, 2023.

Travel Patterns and Mode Shifts

Studies suggest that travel patterns and rider behavior shift during extreme heat conditions.[15] Ridership may decline on certain routes (particularly those that serve outdoor destinations or that rely on outdoor transit stations) while demand may increase for trips to cooling centers or indoor facilities.

Some travelers may also avoid active transportation modes during high heat. Walking and biking often serve as connections to and from transit stops, so high temperatures can make it harder for riders to

[15] Ngo, N., & Bashar, S. 2024. The impacts of extreme weather events on U.S. Public transit ridership. https://www.sciencedirect.com/science/article/abs/pii/S1361920924004619

access stations. Figure 5 illustrates this relationship by plotting Capital Bikeshare trips per day alongside average daily temperature in 2010 and 2011.[16] Ridership is generally low in the colder months and higher in the warmer months. However, there is a noticeable dip in ridership in July and August when temperatures are at their hottest (above 80°F). Due to these high temperatures, cyclists chose not to use Capital Bikeshare. This means they either chose not to travel, or they switched to alternative modes of transportation that might be more comfortable on a very hot day (i.e., cars, bus). As riders opt for air-conditioned travel alternatives such as personal vehicles or ride-hailing services, this may lead to increased roadway congestion.

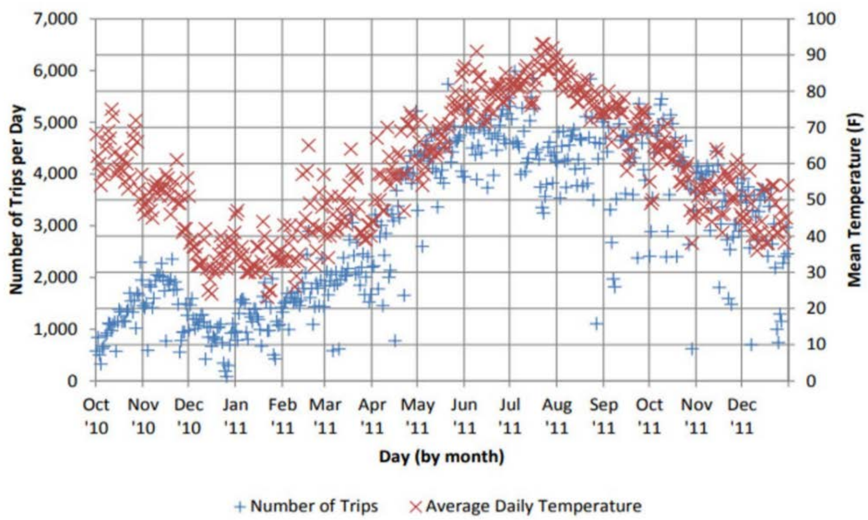

Figure 5. Total number of Capital Bikeshare trips per day compared to average temperature per day. Source: Gebhart and Noland, 2014.

ECONOMIC IMPACTS

The range of disruptions to transit operations and rider behavior described above all translate into economic losses for transit stakeholders, including travelers, transit agencies, regional businesses, and freight operators.

Cost of Reduced Ridership

When heat drives commuters to forgo trips or shift to alternative modes of service, transit ridership declines.[17] This translates into reduced fare revenue for transit owners. *Lost fare revenue due to reduced ridership is estimated in the* **Cost of Reduced Ridership** *section below.*

Cost of Operations and Maintenance

The operations and maintenance demands associated with extreme heat translate into additional costs for transit agencies (e.g., fuel, depreciation, and labor costs).[18] For example, and as described above, high temperatures may require agencies to increase cooling in enclosed areas (i.e., stations, train cars, buses).

[16] Gebhart, K., & Noland, R. 2014. The impact of weather conditions on bikeshare trips in Washington, DC. https://link.springer.com/article/10.1007/s11116-014-9540-7

[17] Ngo, N., & Bashar, S. 2024. The impacts of extreme weather events on U.S. Public transit ridership. https://www.sciencedirect.com/science/article/abs/pii/S1361920924004619

[18] Office of the Secretary, U.S. Department of Transportation. 2025. Benefit-Cost Analysis Guidance for Discretionary Grant Programs. https://www.transportation.gov/sites/dot.gov/files/2025-05/Benefit%20Cost%20Analysis%20Guidance%202025%20Update%20II%20%28Final%29.pdf

Increased use of cooling infrastructure necessitates more frequent maintenance and emergency repairs, especially during heat-related infrastructure failures, as well an increased energy costs for running the equipment more. As another example, heat-related delays may increase the amount of fuel and labor required to keep transit running and transit owners ultimately bear this cost. *Delay-related owner costs are estimated in the* **Cost of Heat Delays** *section below.*

Cost of Interrupted Service

Heat-related slow orders affect both passenger and freight operations along shared corridors. Freight carriers may face delays and reduced throughput that leads to downstream supply chain complications and revenue loss. Local businesses that rely on foot traffic from transit riders may also experience lower customer volumes during slow orders or service disruptions. Disruptions also mean longer commutes and decreased productivity, the cost of which transit users ultimately bear. *Delay-related user costs are estimated in the* **Cost of Heat Delays** *section below.*

Analyzing the Cost of Inaction

TPB has conducted five benefit-cost analysis (BCA) case studies of transportation assets within the TPB service territory to demonstrate the cost of inaction, compare low-cost and high-cost solution options, and provide support for the benefits of proactive resilience investment. The transit case studies include:

- **Rail Stop:** Greenbelt station in Greenbelt, MD. This station is served by both MARC and WMATA and serves roughly 2,100 passengers per day during the summer.
- **Rail Line:** Silver Line between Loudoun Gateway and Washington Dulles International Airport. This section is served by WMATA and sees roughly 5,000 passengers per day through the Dulles Station.
- **Bus Stop:** Army Navy Drive & South Joyce Street westbound/southbound bus stop in Arlington, VA. This stop serves roughly 70 riders per day.

The case studies consider costs from both extreme heat and flood exposure. For extreme heat, the case studies quantify heat-related health costs for users through emergency department visits and hospitalizations. For more details, see TPB's Regional Transportation Resilience Economic Analysis.

Quantified Impacts for Transit Owners and Users

Extreme heat affects transit owners (operators) and users (riders) alike. It disrupts service which drives economic losses for transit operators, and it subjects riders to delays that may result in their prolonged (increasingly dangerous) exposure to the extreme heat conditions. For this assessment, TPB quantified a subset of specific costs to transit owners and users associated with these impacts to begin to understand the cascading impacts of extreme heat on both transit owners and riders. The specific costs included in this assessment were estimated using data made available by WMATA and VRE.[19] This assessment has two primary components:

- **Cost of Reduced Ridership:** Using WMATA and VRE historic and projected ridership data, TPB approximated the financial loss that transit owners may bear due to changes in this metric (i.e., changes in ridership driven by heat-related mode shift or users deciding to forego a discretionary trip).
- **Cost of Heat Delays:** In combination with industry-standard operating and value-for-time costs, TPB used VRE's historical database of slow orders to approximate the cost that the traveling public might bear due to these delays. This analysis does not quantify the broader impacts of heat for users, like heat-related threats to users' health.

These high-level analyses are a first step towards quantifying heat-related losses using available data.

Cost of Reduced Ridership

This analysis uses historic and projected ridership data to determine how heat may impact transit ridership across the National Capital Region, and how these changes might translate into economic impacts for transit agencies.

METHODOLOGY

TPB developed a three-step quantitative methodology for this analysis. The approach integrates projected temperature data with observed ridership and operational data for WMATA Metrorail and VRE to quantify how extreme heat affects transit use and how those impacts may change in the future.

The methodology **(1)** approximates baseline ridership, **(2)** assesses how ridership has historically been impacted during extreme heat events, and **(3)** projects the extent of these heat-related impacts under future climate conditions.

Step 1: Set a Baseline

For both transit agencies, TPB identified three representative extreme heat events or "case studies" to evaluate how ridership may respond under high-temperature conditions. To isolate the impact of heat on any observed changes in ridership, each of these case studies reflects a period over which temperatures were distinctly high. In other words, these case studies do not reflect instances of extremely hot days during an already very hot period. They instead reflect abnormally high heat conditions during an otherwise normal period, to increase the likelihood that any changes in ridership might be attributed to the high heat conditions. TPB also verified that each selected case study resulted in known operational disruptions (i.e., slow orders) using publicly available sources, such as news articles and internal transit agency data, as available. TPB assessed several case studies and chose to include those that were representative of the standard ridership patterns and excluded those that were outliers driven by external factors.

[19] TPB anticipates adding MARC to the transit impacts assessment as data becomes available later this year (2026).

For each case study, TPB defined "baseline ridership" by determining the average daily ridership for two weeks before and two weeks after the high heat event, on the equivalent days of the week.

Case Studies

Tuesday, September 5 – Friday, September 8, 2023

- VRE affected by slow orders
- 86.2°F average ambient temperature at Ronald Reagan National Airport
- Three consecutive days with highs above 95°F

Agencies Analyzed: VRE

Thursday, June 20 – Sunday, June 23, 2024

- WMATA and VRE affected by slow orders
- 86.1°F average ambient temperature at Ronald Reagan National Airport
- Three consecutive days with highs above 95°F; heat emergency activated
- Record-breaking temperatures, highest since August 2016
- Climatologically abnormal for time of year

Agencies Analyzed: VRE, metro

Saturday, July 13 – Wednesday, July 17, 2024

- WMATA, MARC, and VRE affected by slow orders
- 88.5°F average ambient temperature at Ronald Reagan National Airport
- Daily highs of 95°F to 103°F, high nighttime lows
- Excessive heat warning
- Record-breaking high temperatures

Agencies Analyzed: metro

Monday, June 23 – Thursday, June 26, 2025

- WMATA, MARC, and VRE affected by slow orders
- 86.8°F average ambient temperature at Ronald Reagan National Airport
- Four consecutive daily highs above 95°F; heat index exceeding 105°F
- Climatologically abnormal for time of year

Agencies Analyzed: VRE, metro

Step 2: Quantify Observed Impacts

To quantify the observed impact of extreme heat on transit ridership, TPB compared the average daily ridership during each case study to its respective baseline ridership, as determined in Step 1. This produced an average percent change in ridership that could reasonably be attributed to the extreme heat conditions. TPB translated any change in ridership into economic impacts for transit operators by calculating the difference in average daily fare revenue earned during baseline versus high heat conditions. For this calculation, TPB used available fare data to create a proxy average trip fare for both transit agencies.

Step 3: Project Future Impacts

This step offered an approximation of how impacts to future ridership and fare revenue might escalate as temperatures rise. TPB generated climate projections for the region to estimate the frequency of high heat days (i.e., days exceeding 90°F) in 2030 and 2050, based on a high emissions scenario (SSP5-8.5). TPB then used the observed relationship between extreme heat and ridership (determined in Step 2) to estimate the magnitude of these impacts under future climate conditions, based on the transit agencies' projections for ridership in 2030 and 2050. As an illustrative example of the projections that TPB generated, Figure 6 displays the projected high heat days in 2050 against WMATA Metrorail stations.

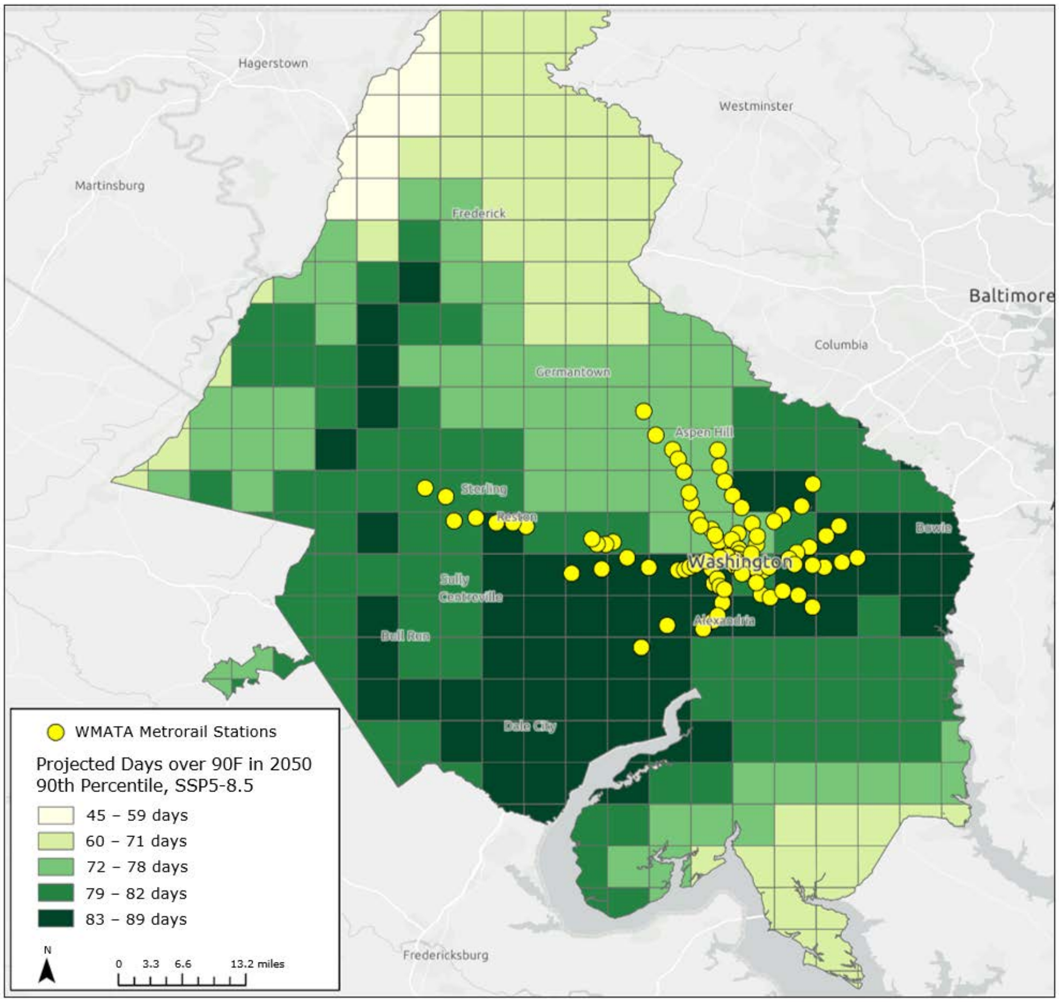

Figure 6. Map of projected days exceeding 90°F in 2050 under a high emissions scenario and WMATA Metrorail stations.

RESULTS

The results of this Ridership Analysis offer an approximation of a direct cost that transit agencies ("Owners") may incur due to the impact of extreme heat on rail ridership, now and in the future.

WMATA

On average, TPB calculated an approximate 3.4 percent decrease[20] in Metrorail ridership during the three high heat event case studies. Assuming an average fare of $3.18[21], this corresponds to an estimated $36,903 in lost fare revenue per day during extreme heat events. These impacts are likely driven by heat-related slow orders that reduce train frequency, as well as decreased rider willingness to walk to or wait for

[20] The percent change in ridership varied widely by heat event, as shown Table 1. This variability likely reflects a combination of factors beyond temperature alone, including system changes over time, differences in service conditions, weekend versus weekday travel patterns, and broader demand shifts such as the federal return-to-office order in the Washington, DC region in early 2025. Similar variability is documented in the literature: studies of New York City subway ridership during extreme heat find declines that differ widely by time of day, location, and rider group, with larger reductions during off-peak periods and weekends (e.g., Zhao et al., 2026; Guo et al., 2026).
[21] TPB assumed an average fare of $3.18 by averaging the peak, off peak, and weekend rates for 2025.

transit in extreme heat. Table 1 summarizes the observed ridership changes and estimated revenue losses, as described.

Table 1. Observed Ridership and Estimated Revenue Impacts for WMATA Metrorail During Extreme Heat Events.

Heat Event	Average Baseline Daily Ridership	Average High Heat Daily Ridership	Percent Change in Ridership under High Heat Conditions	Estimated Daily Fare Revenue Lost due to Heat Event
Thursday, June 20 – Sunday, June 23, 2024	334,781	308,859	-7.7%	$82,518
Saturday, July 13 – Wednesday, July 17, 2024	336,554	329,728	-2.0%	$21,730
Monday, June 23 – Thursday, June 26, 2025	506,280	504,251	-0.4%	$6,460

While these results suggest that extreme heat reduces Metrorail ridership during individual events, overall demand for WMATA Metrorail service is projected to increase. As overall ridership increases, more transit users will be exposed to extreme heat conditions, particularly those who rely on transit for non-discretionary trips. In tandem, climate projections indicate that extreme heat conditions will become increasingly frequent and severe. **Table 2** summarizes the projected changes in ridership, extreme heat exposure, and associated revenue impacts.

Table 2. Projected Changes in Ridership, Extreme Heat Exposure, and Estimated Revenue Impacts for WMATA Metrorail.

Metric	Observed	2030 Projection	2050 Projection
Annual Ridership Change (relative to 2025)	--	+2%	+23%
High Heat (>90°F) Days per Year	~32	66	88
Estimated Annual Fare Revenue Loss	$1.2M	$2.8M	$4.6M

VRE

TPB observed an approximate 3.6 percent decrease in VRE ridership across the September 2023 and June 2024 high heat events and a 3.56 percent increase in ridership during the June 2025 high heat event. Overall, this reflects an average ridership decrease of 1.21 percent across these case studies, corresponding to an approximate $1,514 in fare revenue loss per day. The increase in ridership during the 2025 heat event may reflect external factors, like potential road closures or traffic that could encourage temporary mode shift to transit or the return to office mandate for federal government employees.[22] Table 3 summarizes the observed ridership changes and estimated revenue losses during extreme heat events, assuming an average fare of $7.10.

[22] VRE. 2024. Annual Comprehensive Financial Report for Years Ended June 30, 2025 and 2024. https://www.vre.org/assets/1/6/Virginia_Railway_Express_06_30_2025_Annual_Comprehensive_Financial_Report_-_as_issued.pdf

Table 3. Observed Ridership and Estimated Revenue Impacts for VRE During Extreme Heat Events.

Heat Event	Baseline Daily Ridership	High Heat Daily Ridership	Percent Change in Ridership under High Heat Conditions	Estimated Daily Fare Revenue Lost due to Heat Event
Tuesday, September 5th – Friday, September 8th, 2023	6,616	6,391	-3.4%	$1,601
Thursday, June 20 – Sunday, June 23, 2024	5,303	5,102	-3.79%	$1,427
Monday, June 23 – Thursday, June 26, 2025	10,773	11,156	(+) 3.56%	(+) $2,723

VRE ridership is expected to greatly increase over time due to planned expansions, contributing to greater exposure to extreme heat conditions. At the same time, extreme heat is projected to become more frequent across VRE's service area, increasing the likelihood of operational disruptions and associated rider impacts. Table 4 summarizes the projected changes in ridership, extreme heat exposure, as well as associated revenue impacts for the September 2023 and June 2024 high heat events.

Table 4. Projected Changes in Ridership, Extreme Heat Exposure, and Estimated Revenue Impacts for VRE.

Metric	Observed	2030 Projection	2050 Projection
Annual Ridership Change (relative to 2025)	—	+69%	+210%
High Heat (>90°F) Days per Year	~36	65	88
Estimated Annual Fare Revenue Loss	—	$250k	$617k

KEY TAKEAWAYS

While ridership impacts vary by system and individual heat event, TPB observed that extreme heat is generally associated with decreased ridership across rail services (Figure 7). However, this change is significantly colored by external factors. The change in ridership is clearer and more significant for WMATA Metrorail likely because a larger proportion of Metrorail users take the train discretionarily. When taking the train is a choice, it is more likely that extreme temperatures may be a factor in riders' decision making. VRE is a commuter rail and thus most trips on VRE lines are not discretionary.[23,24] In other words, users need to get to work, especially after the 2025 federal return to office order, and uncomfortable outdoor conditions are likely insufficient to drive behavioral changes. For this reason, the minimal observed changes in ridership for VRE are likely mode shifts, not discretionary travelers forgoing their planned trip due to inclement weather.

[23] TPB. 2026. State Of Public Transportation 2024 Report. https://www.mwcog.org/documents/2026/02/09/state-of-public-transportation-report-bus-rail-tpb-transit/
[24] VRE. 2025. 2025 Customer Opinion Survey Results. https://www.vre.org/assets/1/6/2025_CSS.pdf

Overall, the results indicate that extreme heat has a moderate but observable impact on transit ridership and fare revenue as a result, and these impacts are expected to increase over time as extreme heat days become more frequent.

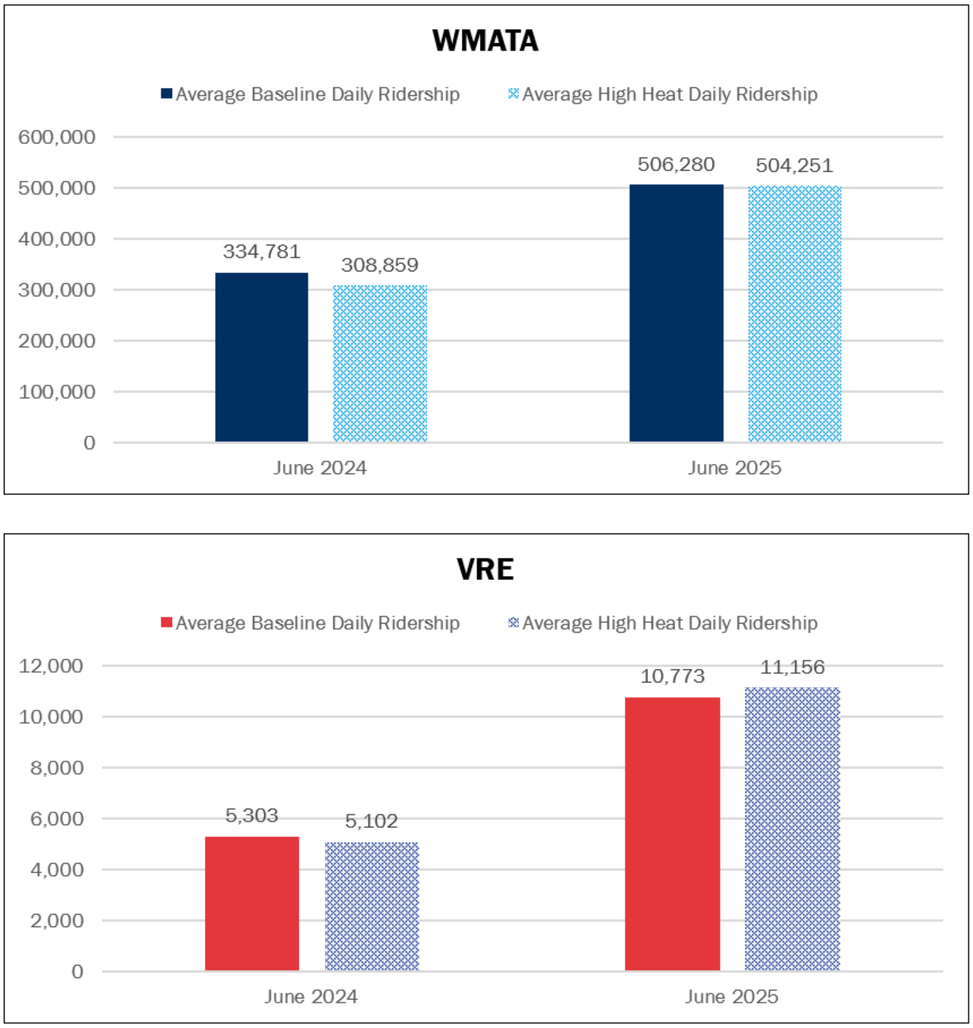

Figure 7. Comparison of baseline and high heat ridership during the June 2024 and June 2025 case study periods.

Cost of Heat Delays

Heat-related slow orders lead to compounding delays which increase operating costs for transit agencies and add travel time burden for riders. The following assessment begins to quantify these costs under current and future climate conditions.

METHODOLOGY

VRE provided TPB with a robust database that documents all rail disruptions from 2015 to 2025. This data enabled TPB to approximate select operational and value-for-time costs incurred by transit riders during heat-related delays on VRE rail lines over this period.

For this analysis, TPB followed an approach that **(1)** identifies the riders impacted by VRE's historical, heat-related delays, **(2)** defines low, average, and high impact delay scenarios based on the observed ridership and delay durations, **(3)** monetizes the impacts of those delay scenarios, and **(4)** projects the magnitude of those impacts under future climate conditions.

Step 1: Identify Impacted Riders

TPB extracted events that specifically cited heat as a reason for the delay in the database. TPB then conducted an analysis to quantify how many riders were on the train at any given point during each specific heat-related delay—for each station, on each train, in each trip direction, and during each delay event—using station level on and offboarding data.

Step 2: Define Low, Average, and High Impact Delay Scenarios

Using the information gleaned in Step 1, TPB determined the low, average, and high number of riders impacted when a single VRE train was delayed by a heat-related slow order. TPB also determined the low, average, and high number of minutes that a single delay lasted. Delay duration was determined separately because shorter delays do not necessarily impact fewer riders. In other words, more people are impacted if a full train is delayed for one minute than if an empty train is delayed for any length of time. This allowed TPB to define a low, average, and high impact delay scenario (e.g., the low scenario assumes the lowest observed ridership and the lowest observed delay duration, etc.).

Step 3: Monetize Impacts

TPB monetized each delay by applying standard values derived from the Federal Highway Administration's (FHWA) Benefit Cost Analysis Guidance 2025 Update II, adjusted to 2026 dollars. TPB approximated "Owner Cost" (i.e., the cost to the transit operator) using the standard value for operating costs incurred hourly for hauling commuter trains ($750.80 per hour of delay). Similarly, TPB approximated "User Cost" (i.e., the cost to the impacted transit riders) by applying the standard value of person-time per hour of personal travel and commuting ($21.20 per hour of person-time).

Step 4: Project Future Impacts

According to the database, VRE lines experience an average of 20 days with heat-related slow orders per year. This is relatively similar to the historic baseline of approximately 36 high heat days per year at VRE stations, especially given the human error introduced by the slow order data collection process which involves train operators manually recording the details of the delays. To project the impacts of slow orders under future climate conditions, TPB assumed that VRE would experience one slow order per high heat day. Using climate projections of days exceeding 90°F (i.e., high heat days), TPB multiplied the calculated costs per delay by the anticipated number of heat-related delays that will occur in the year 2030 and 2050 to produce an annual cost for each of these time horizons.

RESULTS

This approach produced the Owner and User Costs incurred per delay for one train. The sum of these components represents the total "*Cost per Train*" during a given delay. In practice, each slow order usually impacts multiple trains—according to VRE's historic data, anywhere from one to 11 trains are impacted by one slow order, with an average of approximately three trains impacted per delay. Based on this assumption, TPB multiplied the total "*Cost per Train*" by three to estimate the total "*Cost per Delay*." Finally, TPB calculated the annual cost of slow orders in the years 2030 and 2050 by multiplying the cost per delay by the frequency of high heat days in those years. Table 5 summarizes these results for the low, average, and high impact delay scenarios.

Table 5. Owner and User Costs per Train, Per Delay, and Per Year Under Future Climate Conditions.

Delay Scenario	Delay Duration	Riders Impacted	Owner Cost	User Cost	Cost per Train	Cost per Delay	Annual Cost, Observed	Annual Cost, 2030	Annual Cost, 2050
	(min)	(n)	$/train/delay			$/delay	$/year		
Low	1	4	$ 13	$ 90	$ 103	$ 308	$ 6k	$ 20k	$ 26k
Avg	10	431	$ 127	$ 9,143	$ 9,270	$ 27,810	$ 567k	$ 1.8M	$ 2.4M
High	47	1,229	$ 588	$ 26,050	$ 26,638	$ 79,914	$ 1.6M	$ 5.2M	$ 6.9M

KEY TAKEAWAYS

As extreme heat events become more frequent and overall ridership continues to grow, the heat-related costs incurred by transit agencies and users alike will escalate. While discretionary transit users may have the flexibility to reduce their transit use during extreme heat conditions, this is not a choice that non-discretionary travelers can make. Those who rely upon the train to commute to work or access essential services remain exposed to extreme heat conditions and this analysis offers a preliminary look at the costs they might bear as a result.

Future Enhancements

The components of this assessment provide a narrow view into the broad landscape of heat-related losses. For example, with more data and further coordination with the regional transit agencies, TPB could complete a comprehensive cost assessment that quantifies each of the major impacts described in the first, qualitative section of this assessment. The combined results of the quantitative portion of this assessment highlight the importance of improving the transit system's resilience to extreme heat, for the benefit of transit operators and users alike. Future studies could include:

- Analyzing the impact of heat-related service disruption on access to emergency services, jobs, cooling centers, etc.
- Incorporating extreme heat data into TPB's Travel Demand Model (TDM) to better understand mode shifts during extreme heat events (e.g., shifts from active/public transit to personal vehicles or rideshares).
- Conducting a survey (or adding targeted questions to existing commuter surveys) to better understand the behavior and decisions that transit users make during extreme heat events.
- Quantifying the broader range of extreme heat impacts on the health and wellbeing of transit users, particularly those that use transit non-discretionarily (e.g., incorporating geographic and social drivers of transit use and heat vulnerability, like socioeconomic indicators or proximity to stations, to understand how some riders may be disproportionately vulnerable to heat).
- Expanding the quantitative ridership and cost assessment to include buses and bikeshare.
- Exploring extreme heat impacts at specific rail and bus stations in the region that have high heat exposure, which could also include evaluating the costs and benefits of implementing different cooling solution options at these specific locations.
- Characterizing the localized, heat-relevant risks and costs to transit users along their entire commute (e.g., walking to a specific transit stop, mid-commute mode switching).

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