Transportation Pathway
MMC Heat Preparedness Plan Heat Health Research Brief

Social determinants of health are the conditions people live in that affect many health risks and outcomes. Our social context, economic situation, and built environment can buffer climate impacts by providing us a means to cope or adapt. They can also amplify climate impacts, especially among communities that have been subjected to structural racism and other inequities. MAPC identified six social determinant pathways through which people experience climate-driven extreme heat impacts. For each pathway, MAPC conducted a brief literature review and summarized the findings into a short memo.

Key Insights

- Active transportation[1], whether to a transit station or a destination, is an important form of physical activity with widely documented health benefits.
- Extreme heat and heat waves can discourage individuals from choosing active travel modes and expose those who do walk, bike, or wait for transit to unsafe temperatures and air pollution. It can also negatively impact transportation infrastructure performance, leading to trip interruptions, collisions, and disruptions in accessing resources and employment.
- Travel behavior may be informed by an individual's thermal preferences as well as their perception of the risk posed by extreme heat and ability to shift travel behaviors to reduce heat exposure; individuals who are more aware of the risks posed by heat exposure and have mobility options are more likely to take a personal car or take an air-conditioned transit option during heat events. This suggests the importance of increased awareness about extreme heat and coping strategies, as well as ensuring populations most vulnerable to heat exposure have redundant, heat-safe transportation options.
- Field surveys of bus stops in hotter climates have found shade infrastructure (e.g., trees, shelters) to be a critical heat-mitigation strategy. Planning processes and conversations with stakeholders in the Greater Boston region suggest bus shelters may be an important heat mitigation strategy in this climate as well.
- Agencies should consider both current heat exposure and underlying social vulnerabilities to heat when determining appropriate locations for new bus shelters and other shade infrastructure.
- Changes in the climate will change meteorological conditions, influencing the formation and distribution of surface ozone, particulate matter, and their precursor pollutants and allergenic pollen. Efforts should be made to reduce air pollution emissions now to mitigate the future impact of climate change on air quality and health.

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Recommendations

- Improving awareness about the risks posed by extreme heat and heat waves to equip all transit riders, walkers, and bikers with the knowledge they need to make safe decisions.
- Ensure access to cooling in MBTA train stations and on all buses.
- Increase the number of shelters and other cooling amenities (e.g., water fountains, trees) available at bus stops.
- Agencies should consider both current heat exposure and underlying social vulnerabilities to heat when determining appropriate locations for new bus shelters and other shade infrastructure.
- Reduce air pollution emissions to mitigate the future impact of climate change on air quality and health.

Research Summary

Connections Between Transportation and Health

The connections between transportation and health have been widely documented. Active transportation allows people to build physical activity into their day. Research suggests that physically active adults have lower rates of all-cause mortality, coronary heart disease, high blood pressure, stroke, type 2 diabetes, metabolic syndrome, colon cancer, breast cancer, and depression than their physically inactive peers.[1] Extreme heat can discourage individuals from choosing active travel modes and expose those who do walk, bike, use a wheelchair or scooter, or wait for transit to unsafe temperatures and air pollution. It can also negatively impact infrastructure performance, leading to trip interruptions and collisions. This brief explores the role of extreme heat in the context of transportation. Occupational exposures and the impacts of green infrastructure are not emphasized in this brief, as they are explored separately in the Employment and Open Space & Recreation Briefs.

Impact of Heat on Travel Behavior Warm, and dry weather provides ideal conditions for outdoor leisure activities, such as recreational biking and walking, and active open-air transport modes.[2] However, the impact of temperature is parabolic. While outdoor recreation and travel activity increases with warming temperature, it drops at heat thresholds between 25° and 30°C (77°-86°F). This effect is most extensively studied in hot climates but has also been observed in

[1] U.S. Department of Transportation. (2015) Physical Activity from Transportation. Retrieved from https://www.transportation.gov/mission/health/physical-activity-transportation
[2] Böcker, L., Dijst, M., & Prillwitz, J. (2013). Impact of everyday weather on individual daily travel behaviours in perspective: a literature review. Transport reviews, 33(1), 71-91.

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North American continental cities.[3] Extreme heat results in a significant decrease in walking and biking and an increase in the use of transportation options that protect riders from direct exposure, such as air-conditioned buses and private cars.[4] Most studies agree that extreme weather has a greater impact on discretionary, leisure travel purposes than for non-discretionary trips such as commuting.[5]

Studies suggest that the impact of heat on travel behavior is contingent on the individual's thermal preferences and perception of the risk posed by extreme heat, as well as the meteorological context and mobility options. Heat thresholds are higher in hotter climates; people in a distinctly hotter climate adapt to hotter conditions in their outdoor behaviors and thermal preferences. This is significant as survey-based studies find that an individual's perception of heat explains travel and activity choices more than an objective measure of temperature. Furthermore, extreme heat may not result in changes in behavior if an individual is not concerned about or aware of the risks of high heat. Analysis of surveys found that, during extreme heat days in Jinan, China, awareness of heat risks and concern about heat was a significant factor in whether individuals who usually walked or biked shifted to private car use. The literature also finds that individual decisions are influenced by expectations of future weather, preceding weather, or succeeding weather expectations, and seasonality. Critically, travel mode choice is not something everyone has due to a variety of factors including costs, accessibility, and location. Populations with fewer mobility options may find themselves with less flexibility to adapt travel behavior to reduce heat exposure during extreme heat events.[6]

Heat Mitigation for Public Transit Riders

In the United States, public transit systems are typically designed for pedestrians and as a result the dominant mode used to access transit in urban areas is walking, with an average walk of 7.1 mins to transit and an average wait time of 9.9mins. As a result, both active and public transit users are exposed to heat while traveling to their destinations. In Boston, where the transportation system was not built to modern accessibility standards, people who need an elevator (such as parents with strollers, people with temporary injuries, or people with disabilities) can only access certain stations and may therefore have a longer journey to their stop or destination. Transit users are additionally exposed to extreme weather while waiting at stops for the next transit vehicle.

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[3] Böcker, L., Dijst, M., & Prillwitz, J. (2013). Impact of everyday weather on individual daily travel behaviours in perspective: a literature review. Transport reviews, 33(1), 71-91.
[4] Ban, J., Shi, W., Cui, L., Liu, X., Jiang, C., Han, L., Wang, R. and Li, T. (2019). Health-risk perception and its mediating effect on protective behavioral adaptation to heat waves. Environmental research, 172, 27-33.
[5] Miao, Q., Welch, E. W., & Sriraj, P. S. (2019). Extreme weather, public transport ridership and moderating effect of bus stop shelters. Journal of Transport Geography, 74, 125-133.
[6] Jacob, D. J., & Winner, D. A. (2009). Effect of climate change on air quality. Atmospheric environment, 43(1), 51-63.

Outdoor cooling infrastructure, especially bus shelters and trees, is a critical part of transportation-related heat exposure research. A field study of bus stops in Phoenix, Arizona found that by the afternoon, all human-made materials on sun-exposed surfaces were sufficiently hot to burn the skin and that all surveyed riders reported feeling hot or extremely hot. In the same study, all bus stops shade structures were found to significantly reduce measured temperature.[7] Research from Arizona and Los Angeles suggests that bus shelters significantly influence transit ridership. Overall, sheltered bus stops have a higher ridership compared to unsheltered ones in general and during extreme weather conditions. While overall ridership decreases in extreme heat conditions, sheltered stops saw an increase in bus boarding.[8]

This brief could not identify empirical research on the impact of shade structures in humid continental or temperate climates, such as those found in the greater Boston region. However, stakeholder and community engagement for regional heat health projects has found broad support for shade structures and increased tree canopy at bus stops and along popular walking routes.[9] Significantly, of the 8,500 MBTA bus stations, only 675 (less than 8%) have shelters.[10]

Increasingly, communities include heat mitigation strategies, such as cool materials, trees, green space, and shade infrastructure, in the design of the public realm (link to Open Space brief). However, the distribution of heat and shade can be spatially and socio-economically uneven. Spatial analysis has found that "redlined" neighborhoods have less tree cover, more paved surfaces, and higher summer temperatures than the city average.[11] A Boston-based study of 5 MBTA Key Bus Routes did not find shelters disproportionately located in higher-income neighborhoods but note that Key Bus Routes were eligible for 2013-14 American Recovery and Reinvestment Act funds that may have contributed to these routes having more shelters. Further analysis of all the bus stops in Boston and for the other municipalities also serviced by MBTA bus routes could yield different results.[12]

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[7] Dzyuban, Y., Hondula, D. M., Coseo, P. J., & Redman, C. L. (2021). Public transit infrastructure and heat perceptions in hot and dry climates. International journal of biometeorology, 1-12.

[8] Miao, Q., Welch, E. W., & Sriraj, P. S. (2019). Extreme weather, public transport ridership and moderating effect of bus stop shelters. Journal of Transport Geography, 74, 125-133.

[9] Pantoja, J. (2020) Keep Cool Somerville Engagement Findings Memo

[10] McFarland, A. (2018). Gimme Shelter: Are bus shelters in Boston located in higher income areas? Retrieved from https://sites.tufts.edu/gis/files/2019/05/McFarland-Andrew_UEP232_Fall2018-1.pdf

[11] Plumer, B. & Popovich, N. (2020) "How Decades of Racist Housing Policy Left Neighborhoods Sweltering." New York Times. Retrieved from https://www.nytimes.com/interactive/2020/08/24/climate/racism-redlining-cities-global-warming.html

[12] McFarland, A. (2018). Gimme Shelter: Are bus shelters in Boston located in higher income areas? Retrieved from https://sites.tufts.edu/gis/files/2019/05/McFarland-Andrew_UEP232_Fall2018-1.pdf

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Impact of Heat on Traffic Safety

Overall, the number of crashes increases during heat waves or when there are increases in temperatures. However, the magnitude of the increase in risk of an accident due to heat is smaller than other more established risk factors, such as cellphone use, or other extreme weather conditions, like heavy rain.[13] Empirical research found the greatest increase of weather-related crashes among single-vehicle accidents and the strongest association between heat and the subset of crashes that involved factors such as distractions, driver error, fatigue, or sleepiness.[14] This suggests heat causes declines in cognitive functioning and ability to focus. It is unknown whether the use of air conditioning impacts collisions or if the effects of hot temperature are indirect via, for example, reduction in sleep quality on hot days. Extreme heat also influences road conditions and tire deterioration which may be related to the risk of crashes.

Impact of Heat on Transportation Infrastructure

Extreme heat and heat waves have deleterious effects on transportation infrastructure and performance. The literature summarizes the impacts on infrastructure as including:

- Softening and buckling of concrete pavements and acceleration of deterioration for roads.
- Thermal expansion of bridge expansion joints, stressing bridge integrity.
- Steel rail–track deformities.
- Vehicle overheating and tire deterioration.
- Increase in energy consumption to cool vehicles and shipping containers; and
- Difficulty for airplanes to generate lift (the force required for an airplane to take flight).[15]

Studies find that climate-driven heat has already affected the performance of transportation infrastructure and forecast increasing impacts. Both rail systems and air traffic are projected to face increases in delays and cancelled trips[16] and the role of road and vehicle conditions in accidents was discussed earlier. Moreover, the interdependencies among transportation and other critical infrastructure sectors (such as energy) introduce the risk of significant cascading impacts

[13] Basagaña, X., Escalera-Antezana, J. P., Dadvand, P., Llatje, Ò., Barrera-Gómez, J., Cunillera, J., ... & Pérez, K. (2015). High ambient temperatures and risk of motor vehicle crashes in Catalonia, Spain (2000–2011): a time-series analysis. Environmental health perspectives, 123(12), 1309-1316.
[14] Basagaña, X., Escalera-Antezana, J. P., Dadvand, P., Llatje, Ò., Barrera-Gómez, J., Cunillera, J., ... & Pérez, K. (2015). High ambient temperatures and risk of motor vehicle crashes in Catalonia, Spain (2000–2011): a time-series analysis. Environmental health perspectives, 123(12), 1309-1316.
[15] Schwartz, H., (2011). Adapting to climate change: Another challenge for the transportation community. In Joyce Wenger, ed., Adapting transportation to the impacts of climate change: State of the practice 2011. Transportation Circular E-C152, Transportation Research Board of the National Academies, Special Task Force on Climate Change and Energy.
[16] Chinowsky, P., Helman, J., Gulati, S., Neumann, J., & Martinich, J. (2019). Impacts of climate change on operation of the US rail network. Transport policy, 75, 183-191.

across communities.[17] A common example of this type of cascading failure is an extreme heat power outage downing trains and traffic lights, forcing people to rely on active transportation modes during an episode of extreme heat.

Disruptions to the transportation network during extreme weather events will disproportionately affect populations with fewer mobility options and reduced economic ability to purchase goods and services to prepare for events. When high heat causes transportation networks to breakdown, those without redundant transportation options may find themselves unable to commute or access resources.[18]

Worker safety is a critical consideration, too. The ability to perform maintenance and do construction will be limited during heat waves due to health and safety concerns.[19]

Impact of Heat on Air Pollution

Transportation-related air pollution emission include directly emitted PM2.5 as well as precursor pollutants, such as VOCs, NOx, and SO2, which over time and space react to form surface ozone and PM2.5. Changes in the climate will change meteorological conditions, influencing the formation and distribution of surface ozone, fine particulate matter (PM2.5, or particulate matter 2.5 µm and smaller), and their pre-cursor pollutants.[20] The use of air conditioning in vehicles also increases tailpipe emissions of the ozone-precursors CO and NOx by as much as 25%, due to the increased loads on the engine leading to higher fuel consumption.[21] Hot temperatures and stagnant air are particularly conducive to the formation of ozone. Rising temperatures may have a negative effect on particulate matter formation, but climate change is likely to increase the frequency of stagnation episodes and the number of wildfires and windblown dust events, leading to an overall increase in annual mean particulate matter concentrations.

Those who spend more time outdoors commuting during ozone or wildfire periods may breathe more air pollution and be at greater risk for negative health outcomes than those who spend less time outdoors. Those who use active transportation are especially vulnerable as physical exertion

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[17] Jacob, D. J., & Winner, D. A. (2009). Effect of climate change on air quality. Atmospheric environment, 43(1), 51-63.
[18] Jacob, D. J., & Winner, D. A. (2009). Effect of climate change on air quality. Atmospheric environment, 43(1), 51-63.
[19] Schwartz, H., (2011). Adapting to climate change: Another challenge for the transportation community. In Joyce Wenger, ed., Adapting transportation to the impacts of climate change: State of the practice 2011. Transportation Circular E-C152, Transportation Research Board of the National Academies, Special Task Force on Climate Change and Energy.
[20] Kinney, P. L. (2008). Climate change, air quality, and human health. American journal of preventive medicine, 35(5), 459-467.
[21] Farrington, R., & Rugh, J. (2000). Impact of vehicle air-conditioning on fuel economy, tailpipe emissions, and electric vehicle range (No. NREL/CP-540-28960). National Renewable Energy Lab., Golden, CO (US).

results in a higher cumulative dose in the lungs. In addition, warmer temperatures will change plant habitats and species densities, creating the potential for more pollen (and mold spores), changes in pollen distribution, and an earlier start to the pollen season. Individuals who rely on active or public transit may also be exposed to higher levels pollen.[22] Heat attacks, strokes, and respiratory diseases, such as chronic obstructive lung disease, acute lower respiratory tract infections, and lung cancer, are the primary drivers of mortality associated with air pollution.[23] In addition, breathing ozone can cause short-term, reversible decreases in lung function and increase the risk of asthma-related hospital visits. Mold and pollen exposures and home dampness have been associated with exacerbation of allergy and asthma.[24] Taken as a whole, the projected increase in mortality of these pollutants due to climate change air-pollutants are significant, but small when compared to the mortality due to direct transportation-related emissions of particulate matter.[25]

Research Gaps

- Some cities have begun investing in technological tools that allow users to map heat and shade to identify the most thermally comfortable route to a planned destination. This review could not find evidence of the efficacy of this type of heat management intervention and recommends further evaluation.
- Although temperatures in the shade are cooler, the extent to which these facilities protect riders during severe heat is not understood. Additional research in the New England context is needed to determine what shelter design and materials best mitigate potential heat-health effects.
- Further analysis of bus stops coverage in all the municipalities serviced by MBTA bus routes is needed to better understand spatial patterns in coverage and identify gaps in shade-infrastructure.
- Studies on the effect of heat on outdoor activity and travel behavior focus on mode shift rather than direct effects on the individual's health.

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[22] Kinney, P. L. (2008). Climate change, air quality, and human health. American journal of preventive medicine, 35(5), 459-467.
[23] Fann, N. L., Nolte, C. G., Sarofim, M. C., Martinich, J., & Nassikas, N. J. (2021). Associations Between Simulated Future Changes in Climate, Air Quality, and Human Health. JAMA Network Open, 4(1), e2032064-e2032064.
[24] Kinney, P. L. (2008). Climate change, air quality, and human health. American journal of preventive medicine, 35(5), 459-467.
[25] Fann, N. L., Nolte, C. G., Sarofim, M. C., Martinich, J., & Nassikas, N. J. (2021). Associations Between Simulated Future Changes in Climate, Air Quality, and Human Health. JAMA Network Open, 4(1), e2032064-e2032064.

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