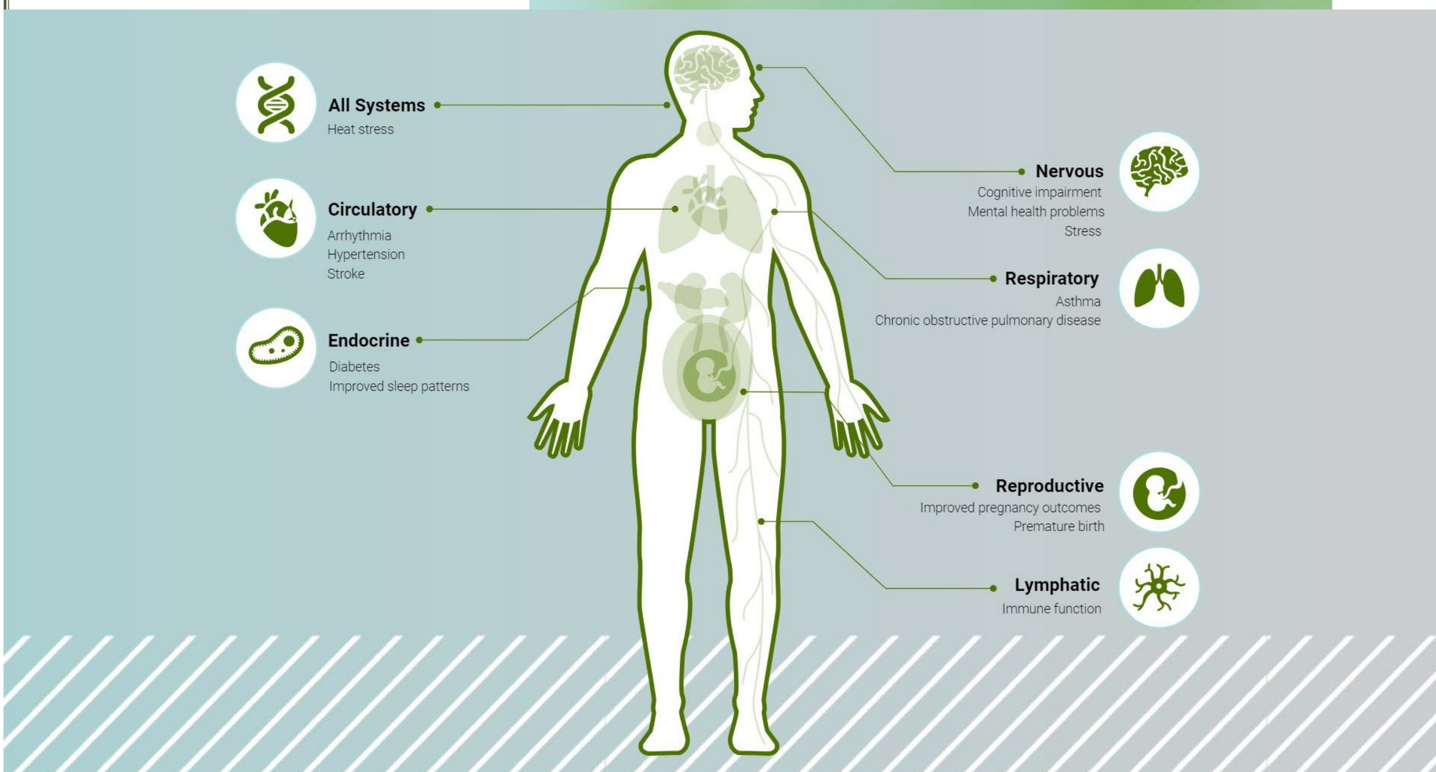
DEVELOPING A HEALTH EQUITY FRAMEWORK AND PRACTITIONER TOOLKIT TO ENHANCE THE PUBLIC HEALTH BENEFITS OF TRANSPORTATION INFRASTRUCTURE



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16. Abstract

The Health Equity Framework was developed to help decision-makers, practitioners, and members of the public better understand the linkages between the transportation infrastructure and health, as well as the approaches to enhance health equity in the transportation system. The framework can be used to minimize the negative impacts of transportation on health and help create transportation systems that support and enhance public health. The Center for Advancing Research in Transportation Emissions, Energy, and Health's (CARTEEH's) Health Equity Framework is unique because it views the transportation infrastructure through a health equity lens and provides an integrated approach for tackling the complex relationship between transportation and health. The framework combines various health equity objectives aimed at ensuring the development and maintenance of transportation systems that promote sustainability, accessibility, and the overall well-being of the public regardless of an individual's physical ability, socioeconomic status, or racial status. By integrating these objectives with a practitioner toolkit, the Health Equity Framework aims to enhance transportation systems and provide new and innovative solutions to measure and implement health equity.

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Executive Summary

As the intimate relationship between the transportation system and health outcomes is increasingly recognized, a growing interest exists in ensuring that transportation infrastructure is designed to meet the needs of the travelling public and enhance public health. The Center for Advancing Research in Transportation Emissions, Energy, and Health (CARTEEH) takes a holistic approach when examining this relationship between transportation and public health by looking at all impacts of the transportation infrastructure on public health. As the United States faces a transformational period in its transportation system, researchers at CARTEEH determined that transportation infrastructure should be sustainable, multimodal, accessible, resilient, and technological (SMART) to ensure that public health needs are met amidst a rapidly changing transportation landscape.

As part of CARTEEH's SMART initiative, the Health Equity Framework was developed to help decision-makers, practitioners, and members of the public better understand the linkages between transportation infrastructure and health, as well as provide several approaches that enhance health equity in the transportation system. The framework can be used to minimize the negative impacts of transportation on health and help create a SMART transportation system. The Health Equity Framework is unique because it views the transportation infrastructure through a health equity lens and provides an integrated approach to tackling the complex relationship between transportation and health.

When developing the Health Equity Framework, researchers evaluated several existing frameworks to determine any gaps in practitioner's needs and subsequently ensure that CARTEEH's Health Equity Framework could be immediately utilized by implementors to enhance health equity. The framework features eight objectives that focus on key contributors to health equity. The objectives were developed with practitioners and implementors in mind given their close associations with the direct impacts and implications of transportation infrastructure on health. To ensure that practitioners could readily implement the framework, researchers developed the CARTEEH Health Equity Toolkit for practitioners (www.carteeh.org/health-equity). The toolkit includes a variety of proven strategies that help achieve each health equity objective, as well as indictors that measure the impact of each objective, and a variety of existing tools that can help practitioners further implement health equity in transportation infrastructure decision-making. Finally, all strategies, indicators, and tools provided within the Health Equity Toolkit consider the impacts of every phase of the transportation infrastructure life cycle including policy and planning, project development, material selection, construction, operations, maintenance, and end of life.

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Introduction

Transportation is a critical component of modern society, enabling access to goods, services, and opportunities that improve quality of life and promote positive health outcomes. The relationship between transportation and health is complex and multifaceted, with transportation influencing health both directly and indirectly. Exposure to air pollution and physical injuries resulting from road accidents are some of the direct impacts of transportation; indirect effects are associated with impacts on physical activity opportunities, land use, and access to healthcare and social services (Litman, 2013). Unfortunately, these indirect impacts are often overlooked during transportation planning and, if not accounted for, can lead to vast disparities in health outcomes, particularly for lower-income individuals and those with inadequate transportation in urban areas (Solomon et al., 2020).

The growing understanding of the connection between health and transportation has led to the development of conceptual models that attempt to clarify this connection. Examples include the work conducted by Glazner et al. (2021) and Khreis et al. (2021) in which extensive literature was synthesized to identify 14 pathways that holistically view the transportation system through a health lens. This research helped form the foundation of the Center for Advancing Research in Transportation Emissions, Energy, and Health's (CARTEEH's) health equity focused philosophy. As part of the sustainable, multimodal, accessible, resilient, and technological (SMART) initiative, the Health Equity Framework builds on the 14 pathways research to provide transportation implementors with straightforward health equity objectives and a toolkit to help practitioners further implement health equity in transportation infrastructure decision-making. Figure 1 provides an overview of the SMART initiative and Health Equity Framework.

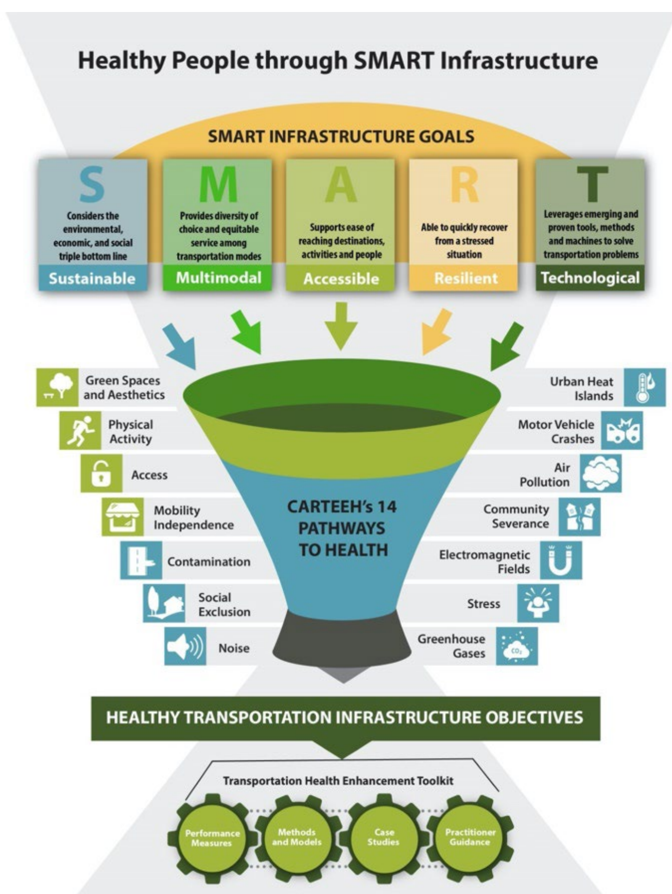

Figure 1. SMART initiative and Health Equity Framework.

Literature Review

Figure 2 shows the critical pathways established in Glazener et al. (2021) and Khreis et al. (2021), which can be divided into two groups: (1) pathways that are beneficial to health and (2) pathways that are detrimental to health. The following subsections describe the pathway-related literature that was used to help create the Health Equity Framework.

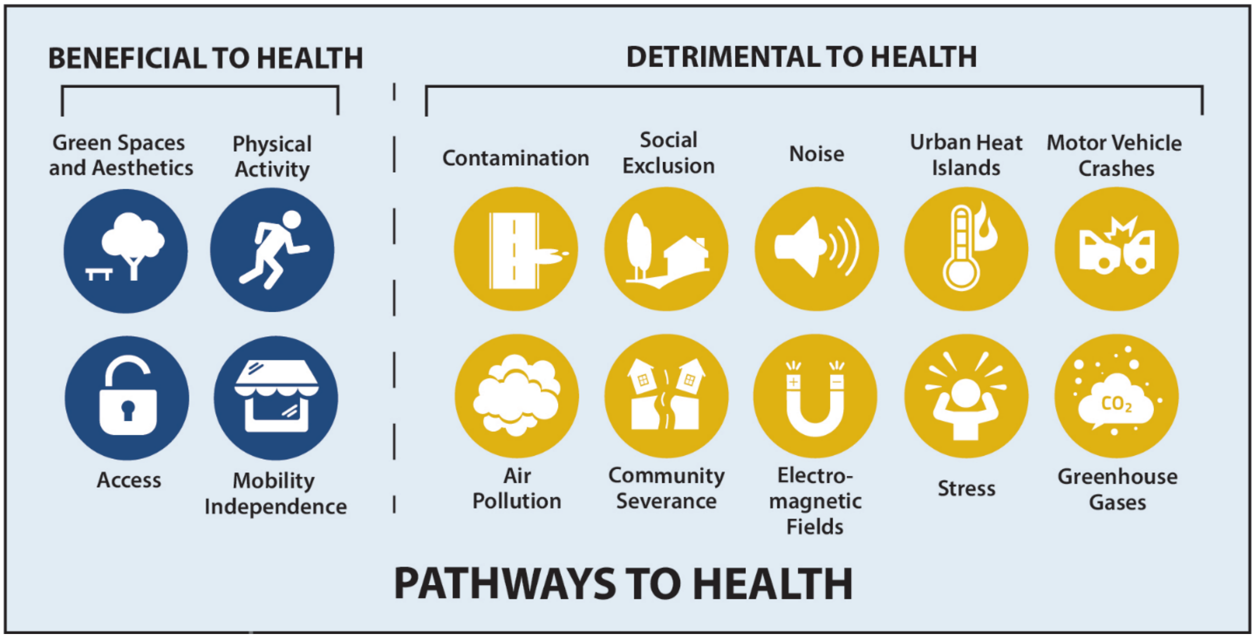

Figure 2. Pathways Between Health and Transportation (Glazener et al, 2021, Khreis et al., 2021).

Pathways Beneficial to Health

Transportation infrastructure can provide notable health benefits by providing opportunities for physical activity, enhancing green space and aesthetics of urban environments, and increasing access to health-related destinations. The following subsections provide high-level introductions of these pathways by incorporating relevant and diverse literature. The mobility independence pathway was excluded from the literature review because this pathway was not included in the development of the Health Equity Framework.

Physical Activity

Transportation infrastructure plays a significant role in determining access to physical activity opportunities and influencing health outcomes across many groups. A well-designed built environment can motivate people to walk or bike to their destinations, including public transportation stops. Engaging in physical activity has been proven to have a positive impact on health by reducing the risk of chronic diseases such as diabetes, obesity, and cardiovascular disease (Centers for Disease Control and Prevention [CDC], 2022; Hamer & Chida, 2008; Hu et al., 2007). Physically active individuals tend to have lower rates of all-cause mortality, high blood pressure, stroke, diabetes, and certain types of cancer (U.S. Department of Health and Human Services [HHS], 1996). Walking or bicycling as a mode of transportation or to locations where public transit is available, including bus stops, can contribute toward achieving the daily physical activity guidelines (Freeland et al., 2013). Even multiple, short-term physical activity sessions throughout the day, each lasting at least 10 minutes, offer comparable health benefits (HHS, 2008). Common built environment themes that have been linked to higher physical activity rates include the presence of sidewalks and crosswalks, bike lanes, reduced speed limit, and other traffic calming measures (Boarnet et al., 2011; Sallis et al., 2012).

Research has indicated that neighborhoods with well-designed transportation infrastructure and access to public transportation are associated with better health outcomes and greater physical activity (Mueller et al., 2015). As a result, multimodal travel is projected to promote physical activity. For instance, several studies have found that neighborhoods with good transportation infrastructure, including sidewalks, bike lanes, and public transportation, had higher physical activity rates and lower rates of obesity and diabetes than neighborhoods with poor transportation infrastructure (Pavlick et al., 2020; Sener et al., 2016).

Moreover, studies have found that most public transportation routes frequently offer sidewalks for pedestrians to freely cross at interchange locations, bus stops, and train stations. In the United States, research by Agrawal and Schimek (2007) reported that transit access trips made up 16 percent of all waking trips and constituted a substantial part of walking. To further demonstrate this claim and demonstrate the degree of physical activity obtained by commuters, Besser and Dannenberg (2005) carried out a study to assess the daily level of physical activity gained by Americans only by walking to and from transportation. The researchers discovered that the walks to and from the transportation terminals were a substantial source of physical exercise for Americans who used public transportation, with a median rate of over 19 minutes and over 29 percent of individuals achieving more than the recommended 30 minutes of daily physical activity by walking to and from transit. The degree of physical activity commuters participate in is influenced by the availability of various transportation modes or alternatives. For example, research by MacDonald et al. (2010) showed that commuters engaged in higher levels of physical activity when they utilized the light-rail system—a popular form of transportation in the United States—compared to commuters who used other forms of transportation.

However, transportation infrastructure can also present a major obstacle to physical activity. The lack of certain infrastructure components in some communities can limit people's ability to engage in physical activity because they may not feel safe walking or cycling on roads with no bike lanes or sidewalks. Limited public transportation options can encourage sedentary lifestyles, which can negatively impact health outcomes (Van Schalkwyk & Mindell, 2018). For instance, research has shown that the distribution of certain built environment features, like sidewalks and crosswalks, are not equally distributed between high-income neighborhoods and low-income and minority communities (Boarnet et al., 2011; Mackett & Brown, 2011; Van Schalkwyk & Mindell, 2018). Consequently, higher rates of chronic diseases, such as obesity and diabetes, may exist in these neighborhoods if these individuals lack opportunities for physical activity (Pucher et al., 2010).

Green Space and Aesthetics

The interconnection between transportation and green space influences the health and well-being of urban residents (Wolch et al., 2014). By planning transportation networks that provide access to green spaces and support sustainable forms of transportation, communities can become healthier, safer, and more livable. Accessibility is key to this relationship; green spaces that are located far from residential areas require dependable and accessible transportation for residents to enjoy their benefits. According to a study by Cheng et al. (2021), diverse modes of transportation, such as cycling and public transportation, are fundamental to utilizing urban green spaces and reaping the benefits they offer for human health and well-being.

Green areas provide opportunities for physical activity including walking, cycling, and playing, all of which can improve health outcomes. In addition, research by Maas et al. (2006) linked green spaces to several additional health benefits, such as decreased stress, improved mood, and increased overall life satisfaction. Yet, as lower-income groups frequently have less access to these spaces, access to green space is acknowledged as a problem for environmental justice (Wolch et al., 2014).

Green transportation corridors also provide advantages beyond biodiversity; they also improve local economies, employment, tourism, recreation, public health, water management, and the sustainability of energy and transportation systems (European Commission, 2019a; Natural Walking Cities, 2019). In the transportation sector, combining green spaces with existing transportation systems may increase scenic value and connectivity, boosting leisure and tourism revenue. Further, lowering storm control expenses and environmental pollutants may be accomplished by combining permeable pavements with green spaces. Green spaces or green embankments alongside transportation infrastructure can serve as sound barriers, moderate water runoff, filter air pollution by reducing particulate levels, and minimize stormwater flows (European Commission, 2019a). The long-term preservation of nature and biodiversity, the reduction of the transportation sector's carbon footprint, the preservation of the biological integrity of the landscape, and the avoidance of wildlife-related traffic accidents all benefit the physical environment.

Access to Healthy Destinations

According to Glazener at al. (2021) and Khreis et al. (2021), *access* is defined as the ability to reach jobs, education, goods, and services. This definition is related to the idea of basic mobility, which refers to an individual's ability to access services and pursuits that are deemed necessary, such as healthcare and employment prospects, as well as a certain amount of social interaction and recreational pursuits (Litman, 2020). Some methods to increase accessibility and basic mobility include built environment interventions related to transit-oriented development and complete streets policies. *Complete streets* refers to various policies or practices that ensure roadways can accommodate walking, biking, public transportation, and vehicle flow while also connecting roadway users to nearby residential and recreational activities (Litman, 2013). This approach shares the overarching goals of transit-oriented development, which aims to create compact, walkable, and mixed-use built environments to help individuals reach their destinations (Federal Transit Administration, 2022).

A well-developed public transportation system can provide a reliable and practical mode of transportation for those who cannot afford to own or operate a personal vehicle, increasing their access to resources, employment opportunities, and social and cultural events while also facilitating opportunities for physical activity (Musselwhite et al., 2015). Public transportation plays a crucial role in accessing healthcare, including connecting people to primary care, preventative treatments, and post-hospitalization appointments (Syed et al., 2013; Wolfe et al., 2020). Patients have a higher chance of staying healthy and avoiding expensive hospital stays or ambulatory services when they can access doctor appointments, treatment locations, and pharmacies. However, limited mobility might compel patients or healthcare organizations to pay for more expensive modes of transportation, such as taxis, or lead patients to miss appointments, which can worsen medical issues and consume medical resources (Litman, 2020). By expanding access to medical care, nutritious food, essential services, work opportunities, and social connections, increased public transportation accessibility can help enhance physical and mental health, as well as health equity (Heaps et al., 2021). Additionally, public transportation is a crucial factor in accessing healthcare for populations considered to be *transportation disadvantaged* such as older adults, individuals with disabilities, and lower-income individuals (Williams & Tremblay, 2019).

Researchers have attempted to evaluate and create tools that quantify the accessibility of public transportation based on how long it takes to travel by public transportation and how easy it is for individuals to reach a bus station and their destinations. For example, the Public Transport Accessibility Level, created by the London Borough of Hammersmith and Fulham, is used to evaluate the public transport network in greater London (London Datastore News, 2013). This tool considers the distance that must be traveled by foot to reach a public transportation access point, the dependability of the nodes that provide the service, the variety of services offered in the service area, and the typical waiting time (Joyce & Dunn, 2009).

Pathways Detrimental to Health

While opportunities exist for transportation infrastructure to lead to positive health outcomes, some of the most frequently studied linkages between transportation and health are the pathways that contribute to negative health outcomes. These outcomes include transportation-related air and noise pollution, motor vehicle crashes, greenhouse gas (GHG) emissions, social exclusion, roadway contamination, urban heat islands, and community severance. The following subsections provide high-level introductions of these pathways by incorporating relevant and diverse literature. The electromagnetic fields pathway was excluded from the literature review because this pathway was not included in the development of the Health Equity Framework.

Traffic-Related Air Pollution

Air pollution is a major environmental concern due to its adverse effects on human health and is one of the main causes of health problems for most people, especially those living in urban areas (Anenberg et al., 2019). Although many sources contribute to air pollution—including from the agricultural, energy production, and industrial sectors—the transportation sector is one of the largest pollutant contributors (Environmental Protection Agency [EPA], 2023a). The main pollutants emitted from transportation sources include particulate matter, volatile organic compounds, nitrogen oxides, carbon monoxide, and sulfur dioxide.

Mobile sources of air pollution can be divided into two categories: (1) on-road vehicles (e.g., passenger vehicles, trucks) and (2) non-road vehicles (e.g., airplanes, boats) (EPA, 2023b). In addition to pollutants released during vehicle operation and fuel generation, cars, trucks, and buses generate pollution at all stages of their lives. The distribution and refinement of fuels, as well as the manufacture and disposal of vehicles, contribute to additional emissions.

Air pollution from transportation has been linked to a variety of health problems, depending on the type of pollutant inhaled and other individual factors. The particulate matter and nitrogen oxides emitted from vehicles can cause respiratory problems, including bronchitis, asthma, and other chronic obstructive pulmonary diseases (COPD) (Kampa & Castanas, 2008). Particulate matter is also capable of penetrating deep into the lungs where it causes inflammation that leads to cardiovascular diseases such as heart attacks and strokes. Air pollution from transportation has also been associated with an increased risk of lung cancer (Cohen, 2000; Wahab et al., 2019). Furthermore, air pollution from transportation has been linked to premature death, with estimates suggesting that exposure to air pollution causes about 8.8 million premature deaths worldwide every year (Peaslee et al., 2020).

Children, older adults, and individuals with pre-existing health conditions, such as heart disease and lung cancer, are especially vulnerable to the adverse effects of air pollution from transportation (EPA, 2023c). Children who are exposed to air pollution during their formative years are at a higher risk of developing respiratory problems, including asthma and bronchitis, which can have long-term health and economic impacts (Bai et al., 2018). Many studies have evaluated the effects of transportation emissions on the overall burden of disease, either in the context of all emission sectors (Lelieveld et al., 2015; Silva et al., 2016) or with a focus specifically on transportation emissions (Anenberg et al., 2017; Chambliss et al., 2014). These studies consistently predicted that tailpipe emissions from transportation sources—such as on-road vehicles, shipping, and other non-road mobile sources—caused significant harm to public health, particularly in areas of the world where large percentages of the population live near elevated levels of transportation activities. In 2017, it was predicted that fine particulate matter ($PM_{2.5}$) contributed to 2.9 million premature deaths due to ischemic heart disease, stroke, COPD, lung cancer, lower respiratory infections, and type 2 diabetes (Stanaway et al., 2018; Anenberg et al., 2019). These studies also calculated that ground-level ozone was responsible for 472,000 COPD-related premature deaths (Anenberg et al., 2019).

Motor Vehicle Crashes

Traffic injuries from motor vehicle crashes is a significant worldwide public health issue and is currently the leading cause of death for children and young adults aged 5–29 (World Health Organization [WHO], 2022). Road traffic injuries can incur serious injuries and life-long disabilities, subsequently leading to losses in productivity or even death. Vulnerable road users (VRUs) such as pedestrians, bicyclists, and motorcyclists are disproportionately impacted by vehicle-related collisions and are more likely to be severely injured (Organization for Economic Cooperation and Development, 1998). In addition to these three groups, other road users may be more at-risk, particularly older adults, individuals with disabilities, and children due to their physical or mental development that may impact how they interact with surrounding vehicles and roadway infrastructure. Motor vehicle crashes involving vulnerable road users (informally known as *traffic violence*) is often due to a multitude of factors;

vulnerable road users are in a less protected position in the built environment compared to drivers, making them more susceptible to injury.

Although estimates for the absolute number of crash-related fatalities for both vehicle occupants and non-occupants in the United States have decreased between 1975 and 2020 (National Highway Traffic Safety Administration [NHTSA], 2023), recent motor vehicle data from the NHTSA revealed a 16-year high in traffic fatalities, with upward trends in on-road crashes, speed-related crashes, and crashes among various age groups, as well as pedestrian, bicyclist, and motorcyclist fatalities (NHTSA, 2022). These increasing trends may be due to the steady increase in vehicle miles traveled (VMT) and overall traffic volumes over the past several decades (Federal Highway Administration [FHWA], 2022). Unfortunately, nonfatal crashes involving vulnerable road users—particularly crashes between vulnerable road users not involving a vehicle—are likely to be heavily underreported and undocumented (Constant & Lagarde, 2010). This lack of data can make it difficult to identify where interventions are needed in the built environment to improve road user safety.

Some risk factors and predictors of traffic collisions include speeding, distracted driving, poor road infrastructure, dim lighting conditions, unsafe pedestrian behaviors (including unsafe crossing or lack of helmet use), and other driver or pedestrian characteristics (Billah et al., 2021; WHO, 2022; Yannis et al., 2020). Moreover, the transportation infrastructure in some urban areas may not be designed to consider alternative modes of active transportation such as biking and walking. In the United States, vehicle ownership rates have outpaced population growth. At the same time, many urban areas have continued to expand outwards, leading to higher percentages of the population living further from urban centers but still commuting to work in the city (FHWA, 2021). To accommodate the growth in traffic levels stemming from these factors, many cities have widened roadways and focused on facilitating motor vehicle throughput, which can result in less separation between vehicles and VRUs and more traffic violence incidences.

Noise

Transportation-related noise pollution is a significant environmental issue that can have many adverse effects on human health, including hearing loss, sleep disturbance, cardiovascular disease, stress, and annoyance (Jariwala et al., 2017; Omubo-Pepple et al., 2010). In many urban cities, the burden of noise pollution can be quite high due to the accumulation of vehicles, especially during peak-time traffic hours. Exposure to transportation noise can severely impact quality of life, particularly for residents located in densely populated urban areas (Nitschke et al., 2014).

Research has shown that transportation noise exposure can cause hearing loss, especially among individuals living near major roadways (Paaschier-Vermeer & Passchier, 2000; Wang et al., 2021). Additionally, prolonged exposure to transportation noise can lead to sleep disturbance, which can result in a decrease in cognitive function, an increase in stress, and a decrease in overall well-being (Halperin, 2014). Transportation noise has also been linked to diabetes and cardiovascular disease through mechanisms such as elevated stress hormones, increased blood pressure, and altered heart rate variability (Münzel et al., 2021; Thacher et al., 2021). Studies have also linked urban noise exposure to cases of premature death (Sohrabi & Khreis, 2020). Several studies have also suggested that transportation noise pollution has a negative impact on mental health and well-being. For instance, studies have reported that exposure to transportation noise is associated with an increased risk of developing depression and increased anxiety levels (Münzel et al., 2021; Stansfeld et al., 2017).

Greenhouse Gas Emissions

Burning fossil fuels, such as gasoline and diesel, to power vehicles contributes to a large share of the total greenhouse gas emissions both in the United States and worldwide. In urban areas, the transportation sector was responsible for about 27 percent of the total U.S. GHG emissions in 2020 (EPA, 2022a). In 2007, the transportation sector in the United States contributed 29 percent of the nation's total GHG emissions, where passenger vehicles and light-duty trucks accounted for 60 percent, medium- and heavy-duty trucks accounted for about 20 percent, and aviation accounted for around 12 percent of the transportation emissions (U.S. Department of Transportation [USDOT], 2009). Despite the slight decline in GHG emissions in 2020 (mostly attributable to the COVID-19 pandemic), the transportation sector accounted for approximately 37 percent of CO_2 emissions worldwide in 2021 (International Energy Agency, 2023). This contribution was larger than any other economic sector, including the agricultural, commercial, and residential, industry, and electricity sectors. The largest on-road contributors to GHG emissions include passenger cars and light-, medium-, and heavy-duty trucks, while non-road contributors include airplanes, ships, and trains. Between 1990 and 2020, overall GHG emissions from the transportation sector have increased due to an increase in VMT because of urban sprawl, population growth, and other factors (EPA, 2022b).

Because GHG emissions are a leading cause of climate change, the transportation sector can play a pivotal role in combatting the climate crisis (USDOT, 2023). Researchers are actively studying methods to reduce transportation emissions, including the use of alternative fuels, electric vehicles, and other advanced technologies to improve fuel efficiency, as well as quantifying the amount of GHG emissions during road projects to identify areas for improvement (Albuquerque et al., 2020). Transportation agencies are also working toward implementing urban planning designs that can reduce travel demand by encouraging more active forms of transportation or the use of public transportation systems.

Likewise, in Europe, the transportation sector accounts for a quarter of greenhouse gas emissions and is the primary contributor to air pollution in cities. Emissions from the transportation industry remain higher than they were in 1990, making it one of the few economic sectors in the European Union (EU) where this is the case (European Commission, 2019b). More than 70 percent of all EU GHG emissions from transportation in 2019 were from this sector, with road transportation as the major emitter by far.

Social Exclusion

The term *social exclusion* refers to barriers that prohibit people from fully participating in society, including in public services, work, education, and other endeavors (United Nations, 2016). This exclusion can be exacerbated by transportation in several ways. For instance, limited accessibility or affordability of transportation for certain groups can limit their ability to access essential services, employment opportunities, and social activities, leading to increased social exclusion and isolation (Litman, 2003). These groups can include individuals who are physically disadvantaged (e.g., older adults), low-income households that are unable to own a personal vehicle, or individuals with other disabilities. A spatial mismatch between the location of employment opportunities and affordable housing can also make it difficult for low-income households and individuals to access job opportunities, further increasing social exclusion (Zhou et al., 2013).

Additionally, the lack of public transportation in certain areas can limit the mobility of individuals and households, particularly for those individuals without access to a private vehicle (Church et al., 2010). Moreover, disinvestment in public transportation systems can result in declining service quality, reduced accessibility, and increased fares, limiting the mobility of individuals and households (Ma et al., 2018).

Unfortunately, social isolation has been linked to a range of health concerns, including increased feelings of loneliness, putting individuals at risk for depression, anxiety, heart disease, emergency hospitalizations, dementia, and premature death (CDC, 2021). Certain populations (e.g., older adults, minorities, immigrants) have also been shown to be at increased risk of experiencing the health effects associated with social isolation due to several factors, such as living alone or experiencing discrimination.

Contamination

Transportation-related contamination can come from a variety of sources, including gasoline, oils, grease, polycyclic aromatic hydrocarbons (PAHs), particulate matter, heavy metals, and other pollutants on the roadways (EPA, 1995; Markiewicz et al., 2017; Marr et al., 2004). Therefore, the transportation sector has been identified as one of the major non-point source contributors to urban stormwater runoff pollution (Müller et al., 2020). When it rains, contamination from vehicles and road construction can flow directly into streams, lakes, and other bodies of water, potentially contributing to detrimental ecological and health impacts. Fortunately, various methods exist to mitigate runoff contamination; these solutions can include preventing and cleaning up spills or other accidents on the roadways, incorporating green infrastructure, and using more permeable road surface materials (FHWA, 2017; McFarland et al., 2019).

Additionally, rail transport is a major contributor to organic and inorganic pollution due to the use of lubricating oils and condenser fluids; the conveyance of oil-based products, metal ores, fertilizers, and chemicals; and the application of herbicides (Malawska & Wikomirski, 2000; Liu et al. 2009). PAHs and heavy metals are the two main categories of pollution associated with railroad transportation. PAHs can cause cancer and mutations in living things in addition to their high toxicity, notable stability, and cumulative impact on the environment (International Agency for Research on Cancer, 1983). PAHs in railway settings primary originate from the materials required to operate the rolling stock, such as machine grease, fuel oils, and transformer oils. Creosote, which is frequently used to impregnate exterior wood constructions like railroad ties, is another significant source of PAHs (Moret et al., 2007). However, the most often discovered and well-researched contaminants in railway areas that harm the environment are heavy metals (Chillrud et al. 2005; Liu et al. 2009).

Urban Heat Islands

Urban heat islands (UHIs) are a negative health effect of transportation infrastructure and refer to areas in cities that are warmer than the surrounding rural areas. The formation of UHIs can result from several factors, such as high concentrations of heat-absorbing surfaces (e.g., buildings, roads) and a lack of vegetation (Shahmohamadi et al., 2010). UHIs also contribute to higher urban daytime temperatures, increasing the risks of heat-related illnesses and deaths, particularly among vulnerable populations like the elderly and people with pre-existing medical conditions (Buscail et al., 2012).

In addition, UHIs can lead to elevated urban levels of air pollutants and greenhouse gases, which can have a range of negative health effects such as respiratory problems, heart disease, and stroke (EPA, 2022c). UHIs have also been reported to cause increased levels of urban noise pollution, which can have various adverse effects on health, such as sleep disturbance, stress, and hearing loss (Kousis & Pisello, 2020).

Community Severance

Community severance refers to the physical and social separation of different land uses, neighborhoods, and communities, often resulting in individuals having less access to goods and services (Mindell & Karlsen, 2012). The expansion of the road network, particularly highways, has physically separated communities by acting as barriers that make it difficult for people to walk or cycle between various places. Moreover, the widespread use of cars has enabled people to live further away from their workplaces and social activities, resulting in a dispersed pattern of land use that has increased the distance between different land uses such as residential areas, commercial centers, and schools (Frumkin, 2002). This dispersed land use pattern can result in detrimental impacts to air quality, motor vehicle crashes, traffic violence, physical activity, and even water quality.

According to James et al. (2005), community severance is the presence of an actual or perceived barrier to commuters moving through an area caused by the transportation infrastructure. The perception of higher traffic levels at faster speeds can represent barriers to pedestrian movement; this perceived barrier has been correlated with reduced well-being (Anciaes et al., 2019; Mindell et al., 2017). In certain severe situations, residential communities become *locked-in* because they are encircled on all sides by barriers to both transportation and non-transportation. While most previous studies have focused on the significance of transportation infrastructures as a physically challenging barrier, the same infrastructure may also be seen as a psychological barrier that is simple to overcome due to their unfavorable visual impact (Mindell & Anciaes, 2020). The consequences of community severance can contribute to or exacerbate inequality. For instance, severance typically has a greater impact on the impoverished. More affluent individuals often have better access to cars and may opt to live in locations with more severance, which can shield them from many of its negative effects. Along with greater exposure, impoverished individuals frequently have a higher sensitivity to air pollution, which disproportionately impacts those who already have a cardiorespiratory illness (Mindell & Anciaes, 2020).

In the past, transportation systems have often been designed primarily for cars with inadequate facilities for pedestrians and cyclists, making it challenging and sometimes unsafe for people to walk or cycle. This single-mode design focus increases community severance. Additionally, the growth of cities and suburban areas has been characterized by low-density, sprawling development that can lead to greater distances between different land uses, making it even more challenging for people to walk or cycle and exacerbating community severance (Resnik, 2010). Therefore, the concept of *smart growth*, which emphasizes mixed land uses, compact designs, walkable and bikeable infrastructure, and a variety of transportation options, is becoming increasingly preferred by transportation planners to combat the issue of community severance (EPA, 2022d).

Need for Practitioner Guidance

Challenges in Developing Transportation Infrastructure

As discussed in previous sections, the ever-increasing trend of urbanization has led to a growth in the worldwide motor vehicle fleet, urban sprawl, and increased travel demands over the last several decades (Poumanyvong et al., 2012). Today, more than half of the world's population lives in urban areas, and this share is much larger in many high-income countries (Ritchie & Roser, 2018). By 2050, it is estimated that this figure will jump to nearly two-thirds of the world's population living in urban areas. This trend has resulted in the development of car-oriented transportation policies and infrastructure that prioritized drivers' needs and maximizing vehicle flow. This one-directional approach has prioritized the convenience of car travel over other considerations, such as the impact on the environment and the health of individuals and communities. However, the aging transportation infrastructure in many towns and cities has struggled to meet today's transportation needs.

In more recent years, a paradigm shift in thinking about transportation systems has led to efforts by transportation planners to switch their focus to alternative modes of transportation like walking, cycling, and using public transportation (Yannis & Chaziris, 2022). Many cities around the world have begun heavily investing in bike lanes, pedestrian walkways, crosswalks, and shared-use or multi-use paths to create safe and convenient transportation alternatives. This pattern has come to fruition following the recognition by researchers, transportation professionals, and urban planners that many mobility problems will not necessarily be solved by simply adding more vehicle lanes.

While this switch can increase physical activity levels and lead to other beneficial results, it is important to note that it does not necessarily guarantee improved health outcomes for all communities, particularly for low-income or underserved communities who have historically been left out of the transportation planning process. Other factors like air pollution, noise, or connectivity to resources are often still not part of the core considerations when designing transportation infrastructure.

A Multidisciplinary Approach

The surrounding built environment is recognized by *Healthy People 2030* (HHS, 2020) as one of the five main social determinants of health that affects a range of quality-of-life outcomes. Therefore, a more holistic approach to transportation planning is necessary to ensure that everyone's health and mobility needs—regardless of their socioeconomic status—are fully integrated into the decision-making process. Additionally, the 14 pathways linking transportation and health make it clear that a multidisciplinary approach to planning is necessary to address these complex interactions and ensure that transportation planning maximizes the benefits and minimizes the adverse effects on health. This approach requires the expertise of health professionals who understand the health impacts of transportation and the mitigation strategies for those effects. This approach must also consider the needs of vulnerable road users—such as pedestrians, cyclists, and those with disabilities—who are often most impacted by transportation decisions but may not have a voice in the planning process.

To address these issues, the Health Equity Framework was developed to present a more effective approach to infrastructure development and transportation planning by combining different strategies, tools, and key performance indicators. This framework attempts to bridge the gap between research-oriented and practiceoriented approaches by developing a web-based user interface that presents practitioner-focused guidance to a range of interested stakeholders and the public.

Integration of Health Equity

The Health Equity Framework is unique because it views the transportation infrastructure through a health equity lens and provides a comprehensive approach to solving the complex problems surrounding the interactions between transportation and health. Rather than simply looking at one specific aspect of transportation and the impact on health, it considers larger societal implications and seeks to build transportation systems that are beneficial to all, regardless of physical ability, socioeconomic status, or racial status. The framework seeks to adhere to the USDOT's 2022 Equity Action Plan goals of expanding access and opportunities to underserved, overburdened, and disadvantaged communities (USDOT, 2022). Some of the Plan's highlighted equity actions include the empowerment of these communities in the transportation decision-making process, ensuring investments are beneficial to the community members, and improving access to affordable transportation options. The Health Equity Framework's attempt to integrate health into the transportation planning process can be an essential step in achieving these equity goals.

Existing Frameworks

Transportation infrastructure is a complex process that requires weighing various needs and interests like sustainability, accessibility, and safety. With a growing knowledge of the role that transportation plays in shaping health outcomes and promoting health equity, guidance that describes how to incorporate health considerations into transportation planning is needed. One way of providing this guidance to practitioners is through the development of frameworks that allow stakeholders to receive specific information that best fits their organization's needs. In addition to CARTEEH's Health Equity Framework, a range of frameworks have been previously developed to help practitioners, researchers, and the public understand how to approach planning for transportation infrastructure. Some key frameworks include the following:

- ThinkStreetSmart.
- USDOT Transportation and Health Tool.
- FHWA Health in Corridor Planning Framework.
- A Guidebook for Sustainability Performance Measurement for Transportation Agencies.

The researchers would like to note, however, that this is not an exhaustive list of existing frameworks. The following subsections will introduce each of these frameworks, providing relevant background information and a general description of how these frameworks can be used before highlighting the potential gaps that these frameworks may not address.

ThinkStreetSmart

Background and Purpose

The ThinkStreetSmart web-based tool provides many resources for evidence and implementation including synthesized research, case studies, and implementation guides. Strategies for improvements fall into three main categories: (1) transportation, (2) land use, and (3) engagement. ThinkStreetSmart is the website for StreetSmart, a nonprofit research organization that offers resources for policymakers and practitioners on integrating public health, equity, and climate considerations in transportation planning.

Framework Description

To use the tool, the user navigates to the Strategies tab on the ThinkStreetSmart website. This page presents an overview of the Strategies section, including introductory text and an example of a strategy page (as shown in Figure 3), and a key for understanding the contents and components of a strategy. This overview also outlines the three overarching themes: (1) transportation strategies, (2) land use strategies, and (3) engagement strategies (Figure 4). The Transportation Strategies section contains three subheadings: (1) Transportation Infrastructure, (2) Transportation Demand Management, and (3) Public Transit. The user can click a bullet beneath the subheadings to link to a new page. The subsequent page details the specific strategy, such as Active Travel to School, providing a summary, proven and likely outcomes, a note about equity and inclusion, complementary strategies, and implementation guidance.

The proven outcomes on each strategy page include results supported by scientific research. In the case of Active Travel to School, reduced risk of injury and increased walking, biking, and physical activity are proven outcomes from introducing programs for walking or biking to school (Figure 5). Supporting research is cited in the descriptive section of the Proven Outcomes page. The strategy page also includes likely outcomes, but the research on these likely outcomes is not yet conclusive and further research is needed to make more definitive claims on the connections between each strategy and the results. In the case of Active Travel to School, improved health outcomes and sense of community, reduced VMT, and reduced air pollution and greenhouse gas emissions are all likely outcomes of Active Travel to School Programs. This section also contains links to supporting research.

Each strategy page also includes a note on equity and inclusion. On the Active Travel to School strategy page, this section acknowledges that low-income and communities of color have specific barriers and considerations for transportation. This section also discusses the decision the Safe Routes Partnership has made to remove the topic of enforcement from their framework and includes a link to a fact sheet created by the Transportation Equity Caucus on the role of law enforcement in traffic safety.

Complementary strategies are also included within each strategy. These related strategies support and are interrelated with others. Traffic Calming and Bicycle Infrastructure are two of the complementary strategies that support Active Travel to School. Improving bicycle infrastructure is a crucial step toward creating safe active transportation to schools. Similarly, traffic calming can improve safety on streets near schools to reduce the risk of injuries and encourage walking and cycling to schools.

Finally, each strategy also includes an Implementation Guidance section that includes guides, reports, briefs, and fact sheets from sources such as the U.S. Department of Transportation and the Safe Routes Partnership. Included in this section are case studies and workbooks for further guidance. While each strategy includes supportive research and implementation guidance, strategies do not include performance measures.

Figure 3. What's in a Strategy? page on ThinkStreetSmart website.

Transportation Strategies

Transportation Infrastructure

- Bicycle Infrastructure
- Pedestrian Infrastructure
- Traffic Calming

Transportation Demand Management

- Active Travel to School
- Employer-Based Trip Reduction Programs
- Voluntary Travel Behavior Change Programs
- Parking Availability and Pricing
- Road User Pricing

Public Transit

- Transit Access
- Transit Service

Land Use Strategies

- Local Accessibility (Local Access to Destinations)
- Regional Accessibility (Regional Access to Destinations)
- Land Use Mix
- Residential Density
- Street Network Connectivity

Engagement Strategies

- Community Engagement

Figure 4. Strategy themes on ThinkStreetSmart website.

Proven Outcomes

Active travel to school is a recommended strategy for increasing walking and bicycling, increasing physical activity, and reducing traffic-related risks of injury (**Community Guide, 2018**). Safe Routes to School and Walking School buses are scientifically supported strategies for increasing walking and bicycling and increasing physical activity (**County Health Rankings & Roadmaps, 2017**; **County Health Rankings & Roadmaps, 2019**).

Figure 5. Proven Outcomes page on ThinkStreetSmart website.

USDOT Transportation and Health Tool

Background and Purpose

The Transportation and Health Tool (THT) was developed by the USDOT in coordination with the CDC to provide easy access to data that practitioners can use to examine the health impacts of transportation systems. These data are used as indicators or metrics for measuring the impacts of transportation on health based on data comparisons between states or between metropolitan regions. One indicator examines the share of all trips by walking or cycling over 10 minutes long, which can be used to measure physical activity levels from transportation. The THT indicators contain raw scores and adjusted scores between 0 and 100 that designate the percentile of a region of interest compared to other regions in the country. For example, a region like San Francisco falls in the 99th percentile of transit trips per capita, which means that San Francisco residents take a remarkably high number of transit trips per person compared to residents of other U.S. cities. The tool also provides further information and resources so that agency staff can better understand the relationship between health and transportation within its Literature and Resources section. This section includes links to peer-reviewed research studies as well as links to resources such as the National Complete Streets Coalition Policy Atlas.

Framework Description

The THT is a web-based tool that includes indicator data, profile pages for indicators, strategies, literature and resources, and background and methodology information. Each of these sections are included in a navigation sidebar from the tool's homepage. Users can learn more about each section by following any of the sidebar links (shown in Figure 6). This navigation page is available from any page on the THT website.

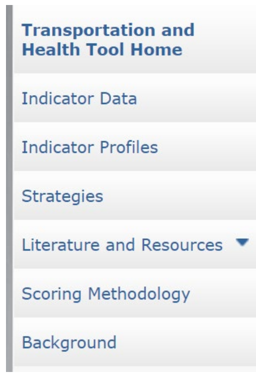

Figure 6. Navigation sidebar in the USDOT Transportation and Health Tool.

The THT can be used by examining indicator data at the state or metropolitan area level through the Indicator Data link. The indicator data page contains an introductory paragraph explaining what indicators are and how they can be used. Figure 7 shows the interactive map used for exploring transportation data on the Indicator Data page. The user selects a state, an urbanized area, or a metropolitan area on the map to view all indicators for the selected area of interest.

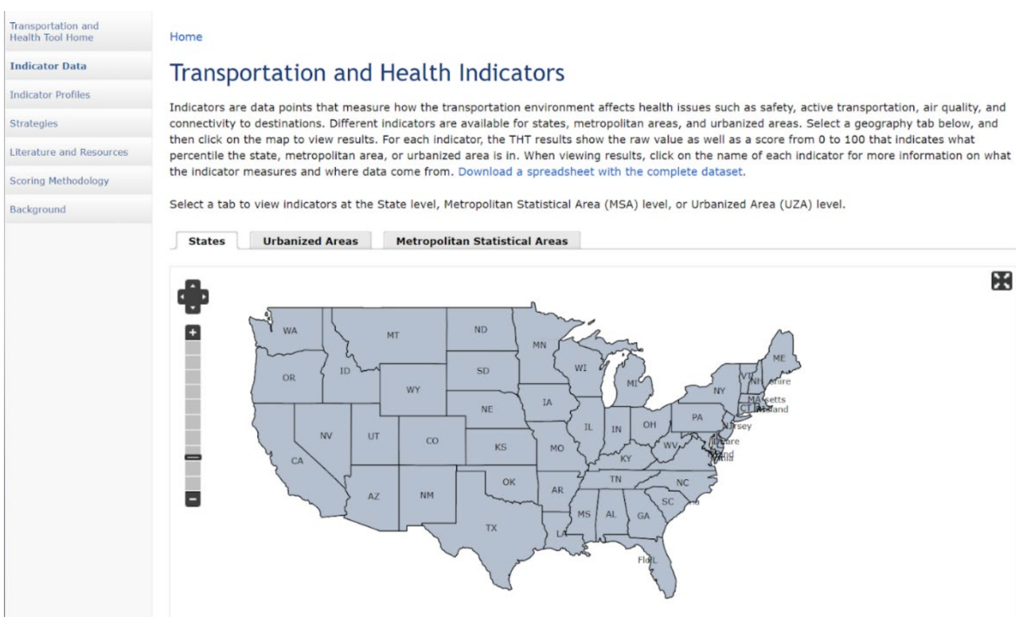

Figure 7. Transportation and Health Indicators page in the USDOT Transportation and Health Tool.

The tool can also be used through the Indicator Profiles tab from the navigation bar. This profiles page contains links to the following 14 indicators:

- Alcohol-Impaired Fatalities.
- Commute Mode Shares.
- Complete Streets Policies.
- Housing and Transportation Affordability.

- Land Use Mix.
- Person Miles Traveled by Mode.
- Physical Activity from Transportation.
- Proximity to Major Roadways.
- Public Transportation Trips Per Capita.
- Road Traffic Fatalities by Mode.
- Road Traffic Fatalities Exposure Rate.
- Seat Belt Use.
- Use of Federal Funds for Bicycle and Pedestrian Efforts.
- Vehicle Miles Traveled Per Capita.

The user can follow the link to a specific indicator profile to obtain more information. Clicking an indicator, such as Physical Activity from Transportation, directs the user to a dedicated indicator profile page that includes a description of the indicator, related strategies, the transportation and health connection, a section about the data, suggestions for how the data can be used, and references used.

The THT also contains a section describing literature and resources for further study. The THT claims that transportation impacts public health through five major areas or themes: (1) active transportation, (2) safety, (3) cleaner air, (4) connectivity, and (5) equity. By clicking the Learn More button for a theme, the user is directed to a new webpage containing an explanatory section on its relationship to public health and the ways that transportation agencies can address this relationship, the related indicators in the THT that impact this theme, and further resources and research studies conducted on the subject.

FHWA Health in Transportation Corridor Planning Framework

Background and Purpose

The Federal Highway Administration created the Health in Transportation Corridor Planning Framework to support transportation agency efforts to incorporate health into corridor planning processes. It is intended to be used within an existing corridor planning process rather than as a stand-alone or parallel process. The framework can be used throughout an entire planning process or at a particular stage within a process. It identifies helpful data sources, tools, or other resources that can be used in the planning process.

Framework Description

The Health in Transportation Corridor Planning Framework is a step-by-step manual designed to provide guidance throughout a corridor planning process to integrate health considerations into a transportation planning process. The framework begins with a background section that outlines the purpose of the guide and a Getting Started section that answers basic questions such as “why” and “what does public health mean?” This Getting Started section also includes labeled icons for navigation through the guide. The guide then progresses to a checklist that identifies how the framework might be used within the planning process. The checklist asks if the user’s planning study matches the steps outlined in the guide. The guide can be rearranged to suit the needs of an individual agency’s process. The checklist also asks what stage in the process the transportation agency is currently in. The guide can be used at any point within the planning process. It also asks if the planning agency has existing relationships or partnerships with health professionals or organizations. These existing relationships can streamline the process. And, finally, the checklist asks if an interest in public health exists within the planning agency. Interdepartmental or interagency relationships can strengthen the corridor planning process.

The framework then guides the user through each of the following six steps:

1. Define Transportation Problems and Public Health Issues.
2. Identify Transportation and Health Needs.
3. Develop Goals and Objectives.
4. Establish Evaluation Criteria.

5. Develop and Evaluate Alternatives.
6. Identify Alternatives that Support Health.

Each step begins with a descriptive section that explains the purpose of the step, a section of questions to consider, a list of potential stakeholders or partners, and questions to inform decision-making. Each step also includes a data section that describes general data that may be useful as well as several specific data suggestions. Resources and examples from practice are also included within each step.

A Guidebook for Sustainability Performance Measurement for Transportation Agencies

Background and Purpose

A Guidebook for Sustainability Performance Measurement for Transportation Agencies is part of a larger project sponsored by the National Cooperative Highway Research Program (NCHRP) (Zietsman et al., 2011). The authors created the guidebook to help transportation agencies understand sustainability and apply that understanding to their core functions. It is designed to facilitate the incorporation of sustainability into transportation planning through performance measurement. Performance measures can be used for evaluation, accountability, communication, description, or informing decisions. The guidebook can be used by any transportation agency or department and can be adapted to suit their needs in ongoing operations or for new initiatives.

The guidebook includes a discussion of the background of sustainability and theory of its application, performance measurements for sustainability, as well as detailed references and resources. It addresses the following six major focus areas within transportation:

1. Planning.
2. Programming.
3. Project development.
4. Construction.
5. Maintenance.
6. Operations.

Framework Description

The guidebook is organized by chapters. The first chapter begins with an explanation of the guide and its organization and next offers descriptions of each of the chapters. The second chapter discusses sustainability and its relationship to transportation agencies and includes a discussion of implementation approaches for performance measures. The subsequent chapters provide a general overview and explanation of framework use and step-by-step explanations regarding the use of each framework component. The next chapters offer resources, a checklist, and examples of agencies applying performance measures. The concluding chapter offers a summary of the material contained within the guidebook and additional resources in an appendix.

The framework can be used to evaluate progress, assess current conditions, develop forecasts, make decisions, or communicate with stakeholders. The first step in using the guidebook is to understand sustainability. To this end, the guide outlines the four key principles of sustainability as follows:

1. Preserving and restoring ecological systems.
2. Fostering community health and vitality.
3. Promoting economic development and prosperity.
4. Ensuring equity.

The second step in the process is to develop transportation sustainability goals. The guidebook identifies 11 key goals for transportation agencies, reproduced in Table 1. The table shows each of the 11 key goals and provides an explanatory definition for each goal. The first key goal—safety—is an important public health goal. A safe transportation system and a reduction in traffic fatalities and injuries is one way to improve public health. The last key goal—reducing transportation-related emissions—also impacts public health.

Table 1. Recommended Transportation Sustainability Goals (Zietsman et al., 2011)

Sustainability Goal	Definition
1. Safety	Provide a safe transportation system for users and the general public.
2. Basic accessibility	Provide a transportation system that offers accessibility that allows people to fulfill at least their basic needs.
3. Equity/equal mobility	Provide options that allow affordable and equitable transportation opportunities for all sections of society.
4. System efficiency	Ensure that the transportation system's functionality and efficiency are maintained and enhanced.
5. Security	Ensure that the transportation system is secure from, ready for, and resilient to threats from all hazards.
6. Prosperity	Ensure that the transportation system's development and operation support economic development and prosperity.
7. Economic viability	Ensure the economic feasibility of transportation investments over time.
8. Ecosystems	Protect and enhance environmental and ecological systems while developing and operating transportation systems.
9. Waste generation	Reduce waste generated by transportation-related activities.
10. Resource consumption	Reduce the use of nonrenewable resources and promote the use of renewable replacements.
11. Emissions and Air Quality	Reduce transportation-related emissions of air pollutants and greenhouse gases.

The third step, after establishing goals, is to develop objectives. Objectives are specific actions to be taken to meet an agency's established goals. These objectives are organized by focus area. The six listed areas of focus are reproduced in Table 2. Each of the six focus areas in the table are explained in further detail in the Object/Performance Measure column.

The fourth step is to develop performance measures. These performance measures assess an agency's progress on a given objective. These performance measures can be classified as outcome, output, and process measures. Outcome performance measures evaluate the results or impacts of a program or policy. Output performance measures examine a product that is a result of a process action. Process performance measures assess elements of an agency's practice that support a goal or objective. For example, each of the three performance measures can be applied to a goal such as reducing waste generated by transportation-related activity. The outcome, in this case, can be measured by a change in the amount of waste produced. The output can also be measured by any change in the percentage of activities with a waste diversion goal, and the process can be evaluated by determining whether an asset management system exists.

The fifth step is to implement performance measures, which can be applied in many ways. Measures can be used for description to understand how an agency currently operates or for evaluation to identify problems and current performance. Measures can also be applied for accountability to establish responsibility or for decision support to prioritize or select a particular option above others in decision-making processes. Finally, performance measures can be used for communication—internally or externally. The relationships between these application types are reproduced in Figure 8. The applications are interrelated, and some steps inform others. Communication, for example, can be implied by any of the other applications, but can also be an application by itself.

The fundamental framework components and the relationship between these components are shown in Figure 9. Overarching framework components include activities such as stakeholder engagement that should be considered throughout the entire process. Auxiliary components are optional related aspects that can supplement the framework application process. Developing a definition of sustainability and organizational sustainability initiatives and performance measures are considered auxiliary in this process.

Table 2. Transportation Focus Areas for Objectives and Performance Measures (Zietsman et al., 2011)

Focus Area	Objective/Performance Measure
1. Planning	Planning activities include the development of long-range plans, strategies, and frameworks intended to improve one or more functional areas of the transportation system (or the entire system). Documentation resulting from planning activities may highlight a general or categorical set of problems, outline a general program of projects or activities calculated to effect change over time, and provide an estimate of the resources required; it rarely will delve into specific project parameters. Examples may include regional transportation plans, master plans, strategic highway safety plans, and long-range thematic studies or plans. Transportation planning has strong links to land use planning and comprehensive planning, which could be taken into consideration where possible.
2. Programming	Programming is the process of determining which set of projects will be funded and the timing of that investment. These decisions are based on the policies, strategies, and other plans identified in the planning focus area. Funding availability must be considered for this process; it may include a project prioritization tool and often requires broad input from throughout an agency and its partners. Example outcomes may include transportation improvement programs and unified planning work programs.
3. Project development	Project development involves defining the specific attributes of the projects selected during the programming area, including alternatives analysis, engineering, design, specifications, environmental and regulatory analysis, and required mitigation. Example outcomes may include alternatives analysis, environmental impact assessments, and project designs.
4. Construction	Construction involves building new transportation facilities; the addition or removal of ramps or flyovers; the addition or removal of lanes; and the addition or demolition of bridges, tunnels, or other integrated infrastructure.
5. Maintenance	Maintenance activities are broad and include routine and preventive maintenance. Significant maintenance and improvement activities such as paving/repaving and major infrastructure improvements such as re-decking are also included.
6. System operations	Operations include all active or passive non-construction activities or systems dedicated to sustaining or improving the functionality of the transportation network. System operations include network monitoring, signalization and signage, traffic/driver information systems, tolling and managed lanes, speed control and enforcement, parking management, turning, merging permissions and restrictions, incident management, public transportation routing and management, and the management of integrated transportation and non-transportation infrastructure.

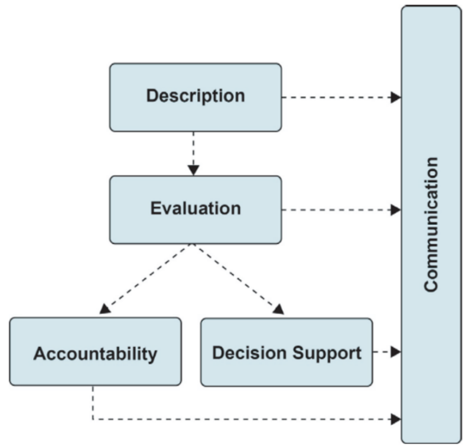

Figure 8. Relationship between application types (Zietsman et al., 2011).

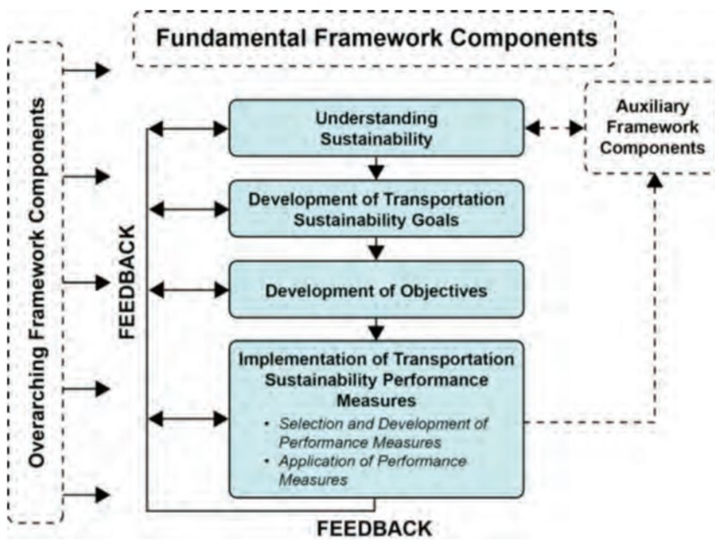

Figure 9. Sustainability performance measurement framework (Zietsman et al., 2011).

The sixth and final step is to refine the framework and apply feedback. The process is iterative and depends upon ongoing feedback to ensure its proper function. A checklist included in Chapter 7 can be used for reviewing the framework. This checklist is a self-assessment tool that contains *yes* or *no* questions to identify areas that need further review. The checklist helps to answer key questions including the following:

1. Are the sustainability principles addressed?
2. Do you have the data needed to implement the measures?
3. Will the measures provide the information needed?
4. Does your framework work?

The appendices contain more detailed information regarding the use of the framework. Appendix B contains a compendium of performance measures available for use. These performance measures are tied to specific goals and grouped within the six focus areas: (1) planning, (2) programming, (3) project development, (4) construction, (5) maintenance, and (6) operations. For example, the last goal—reduce transportation-related emissions of air pollutants and greenhouse gases—contains objectives and several performance measures. An example from the Planning focus area is shown in Figure 10.

Goal 11: Emissions and Air Quality—Reduce Transportation-Related Emissions of Air Pollutants and Greenhouse Gases						
#	Objectives	Measure A	Measure B	Measure C	Measure D	Measure E
Focus Area 1: Planning						
11.1	**Reduce activity that generates pollutant emissions (travel, trip length, mode split, emissions)**	Change in trips, vehicle trips, vehicle miles traveled (VMT), percent non-driver, tons of emissions per day	Change in percentage of commercial vehicles by EPA tier compliance			
11.2	**Reduce polluting exhaust emissions (criteria pollutants and GHGs)**	Change in emissions by criteria pollutant, total, and by mode/ton mile	Lane miles of new access improvements to intermodal and port facilities	Number of new separated rail crossings replacing grade crossings		
11.3	**Increase land use compactness, density, and balance of interacting uses (compactness, density, balance)**	Change in jobs/housing balance	Change in zoned residential density levels around essential service hubs			

Figure 10. Example objectives and performance measures for Goal 11: Emissions and Air Quality—Reduce Transportation-Related Emissions of Air Pollutants and Greenhouse Gases (Zietsman et al., 2011).

Under the overarching goal of Emissions and Air Quality, possible objectives are organized in rows 11.1, 11.2, and 11.3. The columns labeled A through E contain performance measures that can be implemented to address the corresponding objectives within the larger goal. To measure the success of the objective to "increase land use compactness, density, and balance of interacting uses" (11.3), an agency could measure the change in the jobs to housing ratio (Measure A) or the changes in zoning for residential density levels around essential services (Measure B). Appendix D provides further examples of performance measure use in the form of case studies from specific agencies. Each example contains the following information:

- Focus area.
- Objective.
- Measure.
- Agency name.
- Document/website section.
- Agency example measure.
- Methodology.
- Data source(s).
- Analysis scale.
- Background.

The Texas Department of Transportation (TxDOT) is used to illustrate how performance measures can be used for objectives within the emissions and air quality goal in the programming focus area. The objective that TxDOT addressed was to "program projects that reduce pollutant emissions." The measure that TxDOT used to evaluate this objective was the "change in percentage of commercial vehicles by EPA tier compliance due to program." This example objective and measure are taken from the Texas Emission Reduction Plan (TERP). The agency's example measure was to "reduce air emissions from vehicles and construction equipment by encouraging the use of alternative fuel vehicles." The background explanation provided outlines how TxDOT acknowledged the issue of air pollution and created the TERP program, which provides financial incentives so that companies can purchase vehicles with lower emissions below the EPA's Tier II standards. The methodology section acknowledges the role of driving vehicles and the operation of construction equipment in air pollution and pollution's impact on health conditions. The scale of analysis was statewide.

Lessons Learned

While each of the frameworks provides constructive resources and other information related to transportation planning, none of them are exactly alike. Some emphasize a stepwise planning process that integrates performance measurement throughout all stages of the process, while others focus on being an informational resource for a vast array of transportation-related topics. Each of the frameworks also has different intended audiences; both the FHWA Health in Transportation Corridor Planning Framework and A Guidebook for Sustainability Performance Measurement for Transportation Agencies are geared toward transportation agencies and planners, while the USDOT THT and ThinkStreetSmart framework can also be used by other stakeholders, practitioners, and the public.

The developers of the Health Equity Framework identified consistent themes between each of the previous frameworks (e.g., equity, performance measurement, sustainability, implementation guidance, etc.) and incorporated these themes into one practitioner-focused toolkit. The following section describes the process of developing the Health Equity Framework and practitioner toolkit and describes how practitioners can use it to implement effective health-focused transportation solutions.

Health Equity Framework and Toolkit

This section dives deeper into the conceptualization and developmental process of the Health Equity Framework. A web-based tool that features the Health Equity Framework and practitioner toolkit can be found at https://www.carteeh.org/health-equity/. As previously mentioned, the framework is built on the foundation established in CARTEEH's 14 pathways (Glazener et al., 2021, Khreis et al., 2021). The 14 pathways between transportation and health were compressed into eight comprehensive objectives. This section explores the subtle nuances that differentiate CARTEEH's Health Equity Framework from other frameworks and sheds light on how it has been developed over time. This section also introduces the framework's corresponding practitioner toolkit that has been created by CARTEEH to support the framework's eight objectives. It is important to emphasize that while the practitioner toolkit is meant to assist in achieving and measuring the Health Equity Framework's objectives, it is not part of the framework itself. Instead, the toolkit serves as a deployable collection of strategies, indicators, and tools to measure the framework's objectives and health equity.

Development of the Health Equity Framework

The framework's main goal is to achieve equitable transportation infrastructure that helps maximize health outcomes of every individual. To accomplish this, the 14 pathways connecting transportation and health were restructured into eight actionable objectives (Table 3). These objectives were designed to achieve specific outcomes and are accompanied by several implementable strategies (discussed in the following section). Consideration of these eight objectives while planning, developing, and maintaining transportation infrastructure has the potential to reduce the risk of various diseases and bodily harm.

While the 14 pathways provide clear roadmaps linking the transportation infrastructure with health outcomes, they are not action-oriented. Instead, they serve more as theoretical implications rather than actionable steps. On the other hand, the Health Equity Framework's objectives allow for the application of specific strategies, guidance for implementation, and performance measurement. They also highlight a wide range of important stakeholders that are essential for implementation.

Development of the Health Equity Framework's Practitioner Toolkit

The Health Equity Framework's practitioner toolkit is an essential resource for measuring the effectiveness of the framework's objectives. The toolkit was developed to provide a comprehensive set of qualitative and quantitative data that can be used to track progress and convert data into valuable information. Although the information in the toolkit was not exclusively developed by CARTEEH researchers, the information has been compiled and integrated to measure the progress toward achieving the goals of the eight objectives. The toolkit is divided into selectable strategies, indicators, and existing tools—all of which are explained in the following sections.

Table 3. Health Equity Framework's Objectives, Pathways, and Descriptions

Objective	Included Pathway	Description
1. Reduce vehicle emissions and energy consumption	Air pollution, greenhouse gases	This objective involves implementing several strategies such as minimizing vehicle idling, opting for fuel-efficient cars, introducing a carbon tax, etc., while keeping sustainability, health equity, transportation demand management (TDM), and infrastructure modification as the anchor. The process involves various phases, such as policymaking, planning and programming, project development, operations, and maintenance. Stakeholders who are involved in this objective are local governments, transit agencies, metropolitan planning organizations (MPOs), vulnerable road users (e.g., pedestrians, cyclists), private developers, etc.
2. Increase connectivity and social inclusion	Social exclusion, community severance	The aim of this objective is to achieve a high degree of connectivity and social inclusion among community members and the target population. Policymakers, transit agencies, local governments, automakers, fleet managers, and many employers are identified as key players in accomplishing this objective. Strategies such as implementing integrated ticketing systems, facilitating multimodal access to transportation, and introducing vehicle automation have been identified.
3. Increase equitable access to destinations that improve public health	Access	This objective involves implementing various strategies, such as bike sharing, fixed-route shuttles, lower transit fares, promoting cycling, and developing compact cities, to ensure equitable accessibility to all destinations irrespective of one's economic, racial, or cultural background. Stakeholders involved in this initiative include healthcare providers, transit agencies, vulnerable road users, MPOs, non-governmental organizations, and policymakers. To achieve this objective, it is essential to adopt an equitable approach and implement TDM and infrastructure modification strategies.
4. Increase active transportation options	Physical activity	This objective blends strategies like fuel taxes, vehicle ownership taxes, first-last mile infrastructure and other strategies to necessitate the use of public transportation and encourage active living. The theme of this objective is to create a more sustainable and healthier environment by reducing the reliance on personal vehicles, which often contribute to sedentary lifestyle, and by encouraging individuals to engage in physical activity as part of their daily routine. By combining these efforts, the objective aims to promote a more integrated approach to transportation and urban planning that benefits both individuals and the broader community.
5. Increase equitable access to destinations that improve public health	Urban heat islands, green space and aesthetics	This objective is focused on enhancing green spaces and reducing the absorption of heat in urban areas. The aim here is to create beautiful and sustainable environments that will improve the quality of life for residents. To achieve this objective, various strategies, such as urban greening initiatives, road redesigns and repurposing, and policies that prioritize the creation and maintenance of parks and green spaces in the community have been identified. The success of this objective relies on the involvement of various stakeholders, including policymakers, MPOs, local governments, and private

		developers. By promoting green spaces and reducing the presence of heat-absorbing structures, the negative effects of urbanization can be mitigated. Creating more green spaces and promoting sustainability will not only beautify urban areas but also promote a healthier and more livable environment for residents.
6. Reduce runoff and contamination from transportation	Contamination	By implementing laser-focused strategies such as curb elimination, vehicle maintenance, street cleaning, and vegetation runoff controls, this objective takes actionable steps toward reducing runoffs and environmental contamination. This objective was developed with a deep understanding of the contamination pathway as described by Glazener et al. (2021) and Khreis et al. (2021). This objective also emphasizes the vital role that various stakeholder like policymakers, law enforcement officials, school boards, and drainage engineers play to ensure implementation.
7. Improve safety for all users	Motor vehicle crashes	Ensuring safety in transportation is essential to promoting public health. This seventh objective, which builds upon the motor vehicle crashes pathway, provides a more comprehensive approach to mitigating transportation risks through a range of action-oriented strategies. This objective meticulously outlines the strategies, details methods for implementation, and provides a comprehensive list of stakeholders. Not only does it aim to reduce road accidents, but it also prioritizes the overall safety of the community. This objective is more policy- and transportation planning-oriented because it advocates for the integration of strategies such as intelligent transportation systems (ITS), distracted driving initiatives, speed reduction initiatives, and many others. By effectively implementing these measures, transportation planners can make a substantial impact on reducing the number of accidents and injuries. Furthermore, the integration of ITS technologies can enable real-time monitoring of transportation systems, thus allowing for prompt response and mitigation of safety risks.
8. Minimize traffic noise	Noise	This objective prioritizes the reduction of noise pollution emanating from transportation. A range of strategies have been developed to achieve this reduction, including the utilization of low-noise vehicles, tires, and road surfaces among others. Policy-oriented strategies such as vehicle restrictions, noise emission standards, and speed reduction initiatives are also highlighted. These measures can help to significantly reduce the impact of noise pollution on human health and well-being. Implementing this objective, however, requires the involvement of key stakeholders, such as policymakers, car owners, and federal agencies.

Practitioner Toolkit: Strategies

Under the framework's practitioner toolkit, dozens of strategies exist that can be applied by transportation agencies, metropolitan planning organizations, and other stakeholders to help meet the goals of each of the eight objectives. These implementable strategies may fit into one or more of the eight objectives (Table 3) based on how they are applied in real-world settings. Depending on how the practitioner prefers to sort and view the strategies, strategies can also be organized according to one or more themes. Table 4 lists and describes the six themes used to sort the strategies.

Table 4. Toolkit Strategy Themes and Descriptions

Theme	Description
Infrastructure modification	Includes transportation, sewage, water, and green infrastructure modifications.
Sustainability	Includes environmentally conscious solutions, such as electrification of vehicles, emission inspection programs, clean and efficient freight, vehicle maintenance, other equipment modifications, and best practices with runoff and noise pollution.
Transportation demand management	Includes modifying human behavior to reduce traffic congestion, such as alternative work schedules, car sharing/bike sharing, telecommuting, tax systems, congestion charges, parking fees, park and rides, etc. Targets traveler behavior and mode choice to lower traffic demands.
Transportation system management	Includes solutions to better manage the existing transportation infrastructure to improve traffic flow and safety through better management and operations, including speed limit reduction, ITS, circulation changes, signage, safety improvements, and traffic/parking regulations.
Smart growth	Includes smart growth patterns, compact cities, mixed land use, zoning, and building siting.
Equity	Includes strategies that specifically relate to accessibility for all populations and eliminating disparities.

The strategies can also be categorized according to project life cycle phases, which include the following:

- Policy and planning.
- Project development.
- Material selection.
- Construction.
- Operations.
- Maintenance.
- End of life.

Table 5 provides examples of how select strategies map to different objectives, themes, and life cycle phases.

In addition to themes and life cycle phases, strategies can be further filtered according to who is involved in their implementation. Various organizations and actors are included in the sortable list, including but not limited to automakers, construction companies, federal agencies, policymakers, and local health departments.

Once a user selects a strategy of interest, they are directed to that strategy's page, which includes a description of the strategy; its related objective(s) and life cycle phase(s); the strategy's mechanism for helping achieve the objective(s); and the individuals, groups, or agencies that should play a role in its implementation. This page also includes further guidance for implementation, real-world examples of the implemented strategy, and a list of resources for additional information related to the strategy.

Table 5. Example Strategies and Associated Objectives, Themes, and Life Cycle Phases

Strategy	Objective	Theme	Life Cycle Phase
Develop and increase electrification infrastructure	1. Vehicle emissions	Infrastructure modification Sustainability	Policy and planning Project development Material selection
First-last mile infrastructure	2. Connectivity and inclusion 3. Healthy destinations 4. Active transportation 7. Less traffic violence	Infrastructure modification Smart growth Equity	Policy and planning Project development

Practitioner Toolkit: Key Performance Indicators

Whereas the strategies can be browsed by users interested in implementable approaches to achieve one of the eight objectives, users can also browse through the Key Performance Indicators (KPIs) section in the toolkit. These KPIs can be used by practitioners and other stakeholders who are concerned with using established metrics to assess the impact or effectiveness of strategies that have been deployed. Users can sort the KPIs according to objective as well as quantitative or qualitative measurements. Table 6 provides several example KPIs that can be used to measure the impact of interventions to achieve the various objectives.

Table 6. Example Key Performance Indicators

Objective	Key Performance Indicator	Type
Reduce vehicle emissions and energy consumption	Change in vehicle miles traveled before/after intervention	Quantitative
Increase equitable access to destinations that improve public health	Increase in access to healthcare	Qualitative
Increase equitable access to destinations that improve public health	Number of people using green space	Quantitative
Improve safety for all users	Improved road conditions	Qualitative

Practitioner Toolkit: Tools

In addition to strategies and performance indicators, users can also browse the Health Equity Framework's practitioner toolkit to find a list of existing tools that have been developed by other researchers, institutions, or agencies that are available to measure the health impacts of each objective. Although this is not an all-inclusive list of every tool that has been produced, this toolkit does provide an extensive list that can be used by a variety of practitioners to further implement health equity in transportation infrastructure decision-making. These tools can also be used in conjunction with the KPIs; for example, if the user is interested in the Change in Measured Ambient Air Quality KPI, one tool at their disposal includes the Air Quality Index, which provides a scale to report the level of air pollutants in the air at a given location.

References

Albuquerque, F. D., Maraqa, M. A., Chowdhury, R., Mauga, T., & Alzard, M. (2020). Greenhouse gas emissions associated with road transport projects: Current status, benchmarking, and assessment tools. *Transportation Research Procedia, 48*, 2018–2030. https://doi.org/10.1016/j.trpro.2020.08.261

Anciaes, P. R., Stockton, J., Ortegon, A., & Scholes, S. (2019). Perceptions of road traffic conditions along with their reporting impacts on walking are associated with wellbeing. *Travel Behaviour and Society, 15*, 88–101. https://doi.org/10.1016/j.tbs.2019.01.006

Anenberg, S., Miller, J., Henze, D., & Minjares, R. (2019). *A Global Snapshot of the Air Pollution-Related Health Impacts of Transportation Sector Emissions in 2010 and 2015*. International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2022/01/Global_health_impacts_transport_emissions_2010-2015_20190226_1.pdf

Anenberg, S. C., Miller, J., Minjares, R., Du, L., Henze, D. K., Lacey, F., ... & Heyes, C. (2017). Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets. *Nature, 545*(7655), 467–471. https://doi.org/10.1038/nature22086

Agrawal, A. W., & Schimek, P. (2007). Extent and correlates of walking in the USA. *Transportation Research Part D: Transport and Environment, 12*(8), 548–563. https://doi.org/10.1016/j.trd.2007.07.005

Bai, L., Su, X., Zhao, D., Zhang, Y., Cheng, Q., Zhang, H., Wang, S., Xie, M. and Su, H. (2018). Exposure to traffic-related air pollution and acute bronchitis in children: season and age as modifiers. J Epidemiol Community Health, 72(5), pp.426-433. https://doi.org/10.1136/jech-2017-209948

Besser, L. M., & Dannenberg, A. L. (2005). Walking to public transit: Steps to help meet physical activity recommendations. *American Journal of Preventive Medicine, 29*(4), 273–280. https://doi.org/10.1016/j.amepre.2005.06.010

Billah, K., Sharif, H. O., & Dessouky, S. (2021). Analysis of pedestrian-motor vehicle crashes in San Antonio, Texas. *Sustainability, 13*(12). https://doi.org/10.3390/su13126610

Boarnet, M. G., Forsyth, A., & Oakes, J. M. (2011). The street level built environment and physical activity and walking: Results of a predictive validity study for the Irvine Minnesota Inventory. *Environment and Behavior, 43*(6), 735–775. https://doi.org/10.1177/0013916510379760

Buscail, C., Upegui, E. & Viel, J. F. (2012). Mapping heatwave health risk at the community level for public health action. *International Journal of Health Geographics, 11*, 38. https://doi.org/10.1186/1476-072X-11-38

Centers for Disease Control and Prevention (CDC). (2022). *Benefits of Physical Activity*. https://www.cdc.gov/physicalactivity/basics/pa-health/index.htm

Centers for Disease Control and Prevention (CDC). (2021). *Loneliness and Social Isolation Linked to Serious Health Conditions*. https://www.cdc.gov/aging/publications/features/lonely-older-adults.html

Chambliss, S., Miller, J., Façanha, C., Minjares, R., & Blumberg, K. (2013). *The Impact of Vehicle and Fuel Standards on Premature Mortality and Emissions.* The International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2021/06/ICCT_HealthClimateRoadmap_2013_revised.pdf

Cheng, S., Liao, Z., & Zhu, Y. (2021, May 28). Dynamic changes in community deprivation of access to urban green spaces by multiple transport modes. *Frontiers in Public Health, 9*. https://doi.org/10.3389/fpubh.2021.615432

Chillrud, S. N., Grass, D., Ross, J. M., Coulibaly, D., Slavkovich, V., Epstein, D., ... & Brandt-Rauf, P. (2005). Steel dust in the New York City subway system as a source of manganese, chromium, and iron exposures for transit workers. *Journal of Urban Health*, *82*, 33–42. https://doi.org/10.1093/jurban/jti006

Church, A., Frost, M., & Sullivan, K. (2000). Transport and social exclusion in London. *Transport Policy, 7*(3), 195–205. https://doi.org/10.1016/S0967-070X(00)00024-X

Cohen, A. J. (2000). Outdoor air pollution and lung cancer. *Environmental Health Perspectives, 108*. https://doi.org/10.1289/ehp.00108s4743

Constant, A., & Lagarde, E. (2010). Protecting vulnerable road users from injury. *PLoS Medicine, 7*(3). https://doi.org/10.1371/journal.pmed.1000228

Environmental Protection Agency (EPA). (2023a). *Smog, Soot, and Other Air Pollution from Transportation*. https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-other-air-pollution-transportation

Environmental Protection Agency (EPA). (2023b). *How Mobile Source Pollution Affects Your Health*. https://www.epa.gov/mobile-source-pollution/how-mobile-source-pollution-affects-your-health

Environmental Protection Agency (EPA). (2023c). *Research on Health Effects from Air Pollution*. https://www.epa.gov/air-research/research-health-effects-air-pollution

Environmental Protection Agency (EPA). (2022a). *Fast Facts on Transportation Greenhouse Gas Emissions*. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

Environmental Protection Agency (EPA). (2022b). *Sources of Greenhouse Gas Emissions*. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Environmental Protection Agency (EPA). (2022c). *Heat Island Impacts*. https://www.epa.gov/heatislands/heat-island-impacts

Environmental Protection Agency (EPA). (2022d). *About Smart Growth*. https://www.epa.gov/smartgrowth/about-smart-growth

Environmental Protection Agency (EPA). (1995). *Controlling Nonpoint Source Runoff Pollution from Roads, Highways, and Bridges*. https://archive.epa.gov/owow/NPS/roads.html

European Commission. (2019a). *Green Infrastructure and the Transport Sector.* https://ec.europa.eu/environment/nature/ecosystems/pdf/Green%20Infrastructure/GI_transport.pdf

European Commission. (2019b). *Transport Emissions*. https://climate.ec.europa.eu/eu-action/transport-emissions_en

Federal Highway Administration (FHWA). (2022). *Travel Monitoring: Traffic Volume Trends*. https://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm

Federal Highway Administration (FHWA). (2021). *The Transportation Future: Trends, Transportation, and Travel*. https://www.fhwa.dot.gov/policy/otps/TPS_2020_Trends_Report.pdf

Federal Highway Administration (FHWA). (2017). *Strategies to Address Stormwater Runoff Issues Through Permeable Surfaces*. https://www.fhwa.dot.gov/pavement/sustainability/articles/strategies_address.cfm

Federal Transit Administration (FTA). (2022). *Transit-Oriented Development*. https://www.transit.dot.gov/TOD

Freeland, A. L., Banerjee, S. N., Dannenberg, A. L., & Wendel, A. M. (2013). Walking associated with public transit: Moving toward increased physical activity in the United States. *American Journal of Public Health, 103*(3), 536–542. https://doi.org/10.2105/AJPH.2012.300912

Frumkin, H. (2002). Urban sprawl and public health. *Public Health Reports, 117*(3), 201–217. https://doi.org/10.1093/phr/117.3.201

Glazener, A., Sanchez, K., Ramani, T., Zietsman, J., Nieuwenhuijsen, M. J., Mindell, J. S., ... & Khreis, H. (2021). Fourteen pathways between urban transportation and health: A conceptual model and literature review. *Journal of Transport & Health*, *21*. https://www.sciencedirect.com/science/article/pii/S2214140521001006

Halperin, D. (2014). Environmental noise and sleep disturbances: A threat to health? *Sleep Science, 7*(4), 209–212. https://doi.org/10.1016/j.slsci.2014.11.003

Hamer, M., & Chida, Y. (2008). Active commuting and cardiovascular risk: A meta-analytic review. *Preventive Medicine, 46*(1), 9–13. https://doi.org/10.1016/j.ypmed.2007.03.006

Heaps, W., Abramsohn, E., Skillen, E. (2021). Public transportation in the us: A driver of health and equity. *Health Affairs Health Policy Brief*. https://doi.org/10.1377/hpb20210630.810356

Hu, G., Jousilahti, P., Antikainen, R., & Tuomilehto, J. (2007). Occupational, commuting, and leisure-time physical activity in relation to cardiovascular mortality among Finnish subjects with hypertension. *American Journal of Hypertension, 20*(12), 1242–1250. https://doi.org/10.1016/j.amjhyper.2007.07.015

International Agency for Research on Cancer (IARC). (1983). Polynuclear aromatic compounds, part 1: Chemical, environmental, and experimental data. *IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man, IARC Scientific Publications, 32*, 33–451. https://cir.nii.ac.jp/crid/1572543024419681792

International Energy Agency (IEA). (2023). *Transport: Improving the Sustainability of Passenger and Freight Transport*. https://www.iea.org/topics/transport

James, E., Millington, A., & Tomlinson, P. (2005) *Understanding Community Severance Part 1: Views of Practitioners and Communities*. United Kingdom Department for Transport. http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/adobepdf/163944/Understanding_Community_Sev1.pdf

Jariwala, H. J., Syed, H. S., Pandya, M. J., & Gajera, Y. M. (2017). Noise pollution & human health: A review. *Indoor Built Environments, 1*(1), 1–4. https://www.researchgate.net/profile/Hiral-Jariwala/publication/319329633_Noise_Pollution_Human_Health_A_Review/links/59a54434a6fdcc773a3b1c49/Noise-Pollution-Human-Health-A-Review.pdf

Joyce, M., & Dunn, R. (2009). A proposed methodology for measuring public transport accessibility to employment sites in the Auckland CBD. *32nd Australasian Transport Research Forum*. https://www.researchgate.net/publication/254609293_A_proposed_methodology_for_measuring_public_transport_accessibility_to_employment_sites_in_the_Auckland_CBD

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution, 151*(2), 362–367. https://doi.org/10.1016/j.envpol.2007.06.012

Khreis, H., Sohrabi, S., & Glazener, A. (2021). *Fourteen Pathways between Urban Transportation and Health: A Conceptual Model, Literature Review, and Burden of Disease Assessment*. Center for Advancing Research in

Transportation Emissions, Energy, and Health University Transportation Center. https://www.carteeh.org/wp-content/uploads/2021/07/03-21-TTI-Fourteen-Pathways-between-Urban-Transportation-and-Health-Khries.pdf

Kousis, I., & Pisello, A. L. (2020). For the mitigation of urban heat island and urban noise island: Two simultaneous sides of urban discomfort. *Environmental Research Letters, 15*(10). https://doi.org/10.1088/1748-9326/abaa0d

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature, 525*(7569), 367–371. https://doi.org/10.1038/nature15371

Litman, T. (2020). *Evaluating Public Transportation Health Benefits*. Victoria Transport Policy Institute. https://www.vtpi.org/tran_health.pdf

Litman, T. (2013). Transportation and public health. *Annual Review of Public Health, 34*, 217–233. https://doi.org/10.1146/annurev-publhealth-031912-114502

Litman, T. (2003). *Social Inclusion as a Transport Planning Issue in Canada*. Victoria Transport Policy Institute. https://vtpi.org/soc_ex.pdf

Liu, H., Chen, L. P., Ai, Y. W., Yang, X., Yu, Y. H., Zuo, Y. B., & Fu, G. Y. (2009). Heavy metal contamination in soil alongside mountain railway in Sichuan, China. *Environmental Monitoring and Assessment, 152*, 25–33. https://doi.org/10.1007/s10661-008-0293-7

London Datastore News (2013). *Public Transport Accessibility Levels*. https://data.london.gov.uk/dataset/public-transport-accessibility-levels

Ma, L., Kent, J., & Mulley, C. (2016). *Transport Disadvantage, Social Exclusion and Subjective Wellbeing: The Role of Built Environment–Evidence from Sydney, Australia.* Institute of Transport and Logistics Studies. https://ses.library.usyd.edu.au/bitstream/handle/2123/19516/ITLS-WP-16-18.pdf?sequence=1&isAllowed=y

Maas, J., Verheij, R.A., Groenewegen, P.P., de Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology & Community Health, 60*, 587–592. http://dx.doi.org/10.1136/jech.2005.043125

MacDonald, J. M., Stokes, R. J., Cohen, D. A., Kofner, A., & Ridgeway, G. K. (2010). The effect of light rail transit on body mass index and physical activity. *American Journal of Preventive Medicine, 39*(2), 105–112. https://doi.org/10.1016/j.amepre.2010.03.016

Mackett, R. L., & Brown, B. (2011, December 1). Transport, physical activity and health: Present knowledge and the way ahead. *UCL Discovery*. https://discovery.ucl.ac.uk/id/eprint/1333502/

Malawska, M., & Wiłkomirski, B. (2000). Soil and plant contamination with heavy metals in the area of the old railway junction Tarnowskie Góry and near two main railway routes. *Roczniki Panstwowego Zakladu Higieny, 51*(3), 259–267. https://europepmc.org/article/med/11138482

Markiewicz, A., Björklund, K., Eriksson, E., Kalmykova, Y., Strömvall, A., & Siopi, A. (2017). Emissions of organic pollutants from traffic and roads: Priority pollutants selection and substance flow analysis. *Science of the Total Environment, 580*, 1162–1174. https://doi.org/10.1016/j.scitotenv.2016.12.074

Marr, L. C., Grogan, L. A., Wöhrnschimmel, H., Molina, L. T., Molina, M. J., Smith, T. J., & Garshick, E. (2004). Vehicle traffic as a source of particulate polycyclic aromatic hydrocarbon exposure in the Mexico City metropolitan area. *Environmental Science & Technology, 38*(9), 2584–2592. https://doi.org/10.1021/es034962s

McFarland, A. R., Larsen, L., Yeshitela, K., Engida, A. N., & Love, N. G. (2019). Guide for using green infrastructure in urban environments for stormwater management. *Environmental Science: Water Research & Technology, 5*, 643–659. https://doi.org/10.1039/C8EW00498F

Mindell, J. S., Anciaes, P. R., Dhanani, A., Stockton, J., Jones, P., Haklay, M., Groce, N., Scholes, S., & Vaughan, L. (2017). Using triangulation to assess a suite of tools to measure community severance. *Journal of Transport Geography, 60*, 119–129. https://doi.org/10.1016/j.jtrangeo.2017.02.013

Mindell, J. S., & Anciaes, P. R. (2020). Chapter seven: Transport and community severance. *Advances in Transportation and Health,* 175–196. https://doi.org/10.1016/B978-0-12-819136-1.00007-3

Mindell, J. S., & Karlsen, S. (2012). Community severance and health: What do we actually know? *Journal of Urban Health, 89*(2), 232–246. https://doi.org/10.1007/s11524-011-9637-7

Moret, S., Purcaro, G., & Conte, L. S. (2007). Polycyclic aromatic hydrocarbon (PAH) content of soil and olives collected in areas contaminated with creosote released from old railway ties. *Science of the Total Environment*, *386*(1–3), 1–8. https://doi.org/10.1016/j.scitotenv.2007.07.008

Mueller, N., Rojas-Rueda, D., Cole-Hunter, T., de Nazelle, A., Dons, E., Gerike, R., Götschi, T., Int Panis, L., Kahlmeier, S., & Nieuwenhuijsen, M. (2015). Health impact assessment of active transportation: A systematic review. *Preventive Medicine, 76*, 103–114. https://doi.org/10.1016/j.ypmed.2015.04.010

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of the Total Environment, 709*. https://doi.org/10.1016/j.scitotenv.2019.136125

Münzel, T., Sørensen, M., & Daiber, A. (2021). Transportation noise pollution and cardiovascular disease. *Nature Reviews Cardiology, 18*(9), 619–636. https://doi.org/10.1038/s41569-021-00532-5

Musselwhite, C., Holland, C., & Walker, I. (2015). The role of transport and mobility in the health of older people. *Journal of Transport & Health, 2*(1), 1–4. https://doi.org/10.1016/j.jth.2015.02.001

National Highway Traffic Safety Administration (NHTSA). (2022). *Early Estimates of Motor Vehicle Traffic Fatalities and Fatality Rate by Sub-Categories in 2021*. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813298

National Highway Traffic Safety Administration (NHTSA). (2023). *People Killed and Injured, by Person Type and Vehicle Type, 1975–2020* [Data Set].

Natural Walking Cities. (2019). *Green Corridors–Essential Urban Walking and Natural Infrastructure*. https://naturalwalkingcities.com/green-corridors-essential-urban-walking-and-natural-infrastructure/

Nitschke, M., Tucker, G., Simon, D. L., Hansen, A. L., & Pisaniello, D. L. (2014). The link between noise perception and quality of life in South Australia. *Noise and Health*, *16*(70), 137–142. https://www.noiseandhealth.org/text.asp?2014/16/70/137/134913

Omubo-Pepple, V. B., Briggs-Kamara, M. A., & Tamunobereton-ari, I. (2010). Noise pollution in Port Harcourt Metropolis: Sources, effects, and control. *Pacific Journal of Science and Technology, 11*(2), 592–600. https://www.researchgate.net/profile/Valentine-Omubo-Pepple/publication/228422335_Noise_Pollution_in_Port_Harcourt_Metropolis_Sources_Effects_and_Control/links/541073390cf2df04e75d5cd4/Noise-Pollution-in-Port-Harcourt-Metropolis-Sources-Effects-and-Control.pdf

Organization for Economic Cooperation and Development (OECD). (1998). *Safety of Vulnerable Road Users*. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/DOT/RTR/RS7(98)1/FINAL&docLanguage=En

Passchier-Vermeer, W., & Passchier, W. F. (2000). Noise exposure and public health. *Environmental Health Perspectives, 108*(suppl 1), 123–131. https://doi.org/10.1289/ehp.00108s1123

Pavlick, D., Faghri, A., DeLucia, S., & Gayen, S. (2020). Human health and the transportation infrastructure. *Journal of Human Resource and Sustainability Studies, 8*(3), 219–248. https://doi.org/10.4236/jhrss.2020.83013

Peaslee, M., Nelson, J., Reed, E., & Sexton, L. (2020). Effect of air quality alerts on intended behavior change. *Advances in Intelligent Systems and Computing, 1215*, 386–393. https://doi.org/10.1007/978-3-030-51549-2_51

Poumanyvong, P., Kaneko, S., & Dhakal, S. (2012). Impacts of urbanization on national transport and road energy use: Evidence from low, middle, and high income countries. *Energy Policy, 46*, 268–277. https://doi.org/10.1016/j.enpol.2012.03.059

Pucher, J., Buehler, R., Bassett, D. R., & Dannenberg, A. L. (2010). Walking and cycling to health: A comparative analysis of city, state, and international data. *American Journal of Public Health, 100*, 1986–1992. https://doi.org/10.2105/AJPH.2009.189324

Resnik, D. B. (2010). Urban sprawl, smart growth, and deliberative democracy. *American Journal of Public Health, 100*(10), 1852–1856. https://doi.org/10.2105/AJPH.2009.182501

Ritchie, H., & Roser, M. (2018). *Urbanization*. Our World in Data. https://ourworldindata.org/urbanization

Sallis, J. F., Floyd, M. F., Rodríguez, D. A., & Saelens, B. E. (2012). The role of built environments in physical activity, obesity, and CVD. *Circulation, 125*(5), 729–737. https://doi.org/10.1161/CIRCULATIONAHA.110.969022

Sener, I. N., Lee, R. J., & Elgart, Z. (2016). Potential health implications and health cost reductions of transit-induced physical activity. *Journal of Transport & Health, 3*(2), 133–140. https://doi.org/10.1016/j.jth.2016.02.002

Shahmohamadi, P., Che-Ani, A. I., Ramly, A. B., Maulud, K. N., & Mohd-Nor, M. F. (2010). Reducing urban heat island effects: A systematic review to achieve energy consumption balance. *International Journal of Physical Sciences, 5*(6), 626–636. https://academicjournals.org/journal/IJPS/article-full-text-pdf/DBB8AC426195

Silva, R. A., Adelman, Z., Fry, M. M., & West, J. J. (2016). The impact of individual anthropogenic emissions sectors on the global burden of human mortality due to ambient air pollution. *Environmental Health Perspectives, 124*(11), 1776–1784. https://doi.org/10.1289/EHP177

Sohrabi, S., & Khreis, H. (2020). Burden of disease from transportation noise and motor vehicle crashes: Analysis of data from Houston, Texas. *Environment International, 136*. https://doi.org/10.1016/j.envint.2020.105520

Solomon, E. M., Wing, H., Steiner, J. F., & Gottlieb, L. M. (2020). Impact of transportation interventions on health care outcomes: A systematic review. *Medical Care, 58*, 384–391. https://doi.org/10.1097/MLR.0000000000001292

Stansfeld, S., Babisch, W., Gallacher, J., Smuk, M., & Clark, C. (2017). *Noise Sensitivity, Health and Mortality: A Review and New Analyses*. International Commission on Biological Effects of Noise. http://www.icben.org/2017/ICBEN%202017%20Papers/Keynote01_Stansfeld_4161.pdf

Stanaway, J. D., Afshin, A., Gakidou, E., Lim, S. S., Abate, D., Abate, K. H., ... & Bleyer, A. (2018). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. *The Lancet, 392*(10159), 1923–1994. https://doi.org/10.1016/S0140-6736(18)32225-6

Syed, S. T., Gerber, B. S., & Sharp, L. K. (2013). Traveling towards disease: Transportation barriers to health care access. *Journal of Community Health, 38*(5), 976–993. https://doi.org/10.1007/s10900-013-9681-1

Thacher, J. D., Poulsen, A. H., Hvidtfeldt, U. A., Raaschou-Nielsen, O., Brandt, J., Geels, C., Khan, J., Münzel, T., & Sørensen, M. (2021). Long-term exposure to transportation noise and risk for type 2 diabetes in a nationwide cohort study from Denmark. *Environmental Health Perspectives, 129*(12). https://doi.org/10.1289/EHP9146

United Nations. (2016). *Chapter I: Identifying Social Inclusion and Exclusion*. https://www.un.org/esa/socdev/rwss/2016/chapter1.pdf

U.S. Department of Health and Human Services (HHS). (2008). *2008 Physical Activity Guidelines for Americans*. https://health.gov/sites/default/files/2019-09/paguide.pdf

U.S. Department of Health and Human Services (HHS). (2020). *Healthy People 2030.* https://health.gov/healthypeople

U.S. Department of Health and Human Services (HHS). (1996). *Physical Activity and Health: A Report of the Surgeon General*. Centers for Disease Control and Prevention. http://www.cdc.gov/nccdphp/sgr/pdf/sgraag.pdf

U.S. Department of Transportation (USDOT). (2023). *Climate Action*. https://www.transportation.gov/priorities/climate-and-sustainability/climate-action

U.S. Department of Transportation (USDOT). (2022). *Equity Action Plan*. https://www.transportation.gov/sites/dot.gov/files/2022-04/Equity_Action_Plan.pdf

U.S. Department of Transportation (USDOT). (2009). *Hearing on Transportation's Role in Climate Change and Greenhouse Gases, July 14, 2009*. https://www.transportation.gov/testimony/transportations-role-climate-change-and-greenhouse-gases

Van Schalkwyk, M. C. I., & Mindell, J. S. (2018). Current issues in the impacts of transport on health. *British Medical Bulletin, 125*(1), 67–77. https://doi.org/10.1093/bmb/ldx048

Wahab, S. A., Hassan, A., Latif, M. T., Vadiveel, Y., Jeyabalan, T., Soo, C. I., ... & Hassan, T. (2019). Cluster analysis evaluating $PM_{2.5}$, occupation risk and mode of transportation as surrogates for air-pollution and the impact on lung cancer diagnosis and 1-year mortality. *Asian Pacific Journal of Cancer Prevention, 20*(7), 1959–1965. https://doi.org/10.31557/APJCP.2019.20.7.1959

Wang, T. C., Chang, T. Y., Tyler, R. S., Hwang, B. F., Chen, Y. H., Wu, C. M., Liu, C. S., Chen, K. C., Lin, C. D., & Tsai, M. H. (2021). Association between exposure to road traffic noise and hearing impairment: A case-control study. *Journal of Environmental Health Science & Engineering, 19*(2), 1483–1489. https://doi.org/10.1007/s40201-021-00704-y

Williams, K. M., & Tremblay, N. (2019, June 1). *Improving Transportation Access to Health Care Services*. National Center for Transit Research USF Center for Urban Transportation Research. Report Number: NCTR #79062-20. https://doi.org/10.5038/CUTR-NCTR-RR-2018-09

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning, 125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Wolfe, M. K., McDonald, N. C., & Holmes, G. M. (2020). Transportation barriers to health care in the United States: Findings from the National Health Interview Survey, 1997–2017. *American Journal of Public Health, 110*(6), 815–822. https://doi.org/10.2105/AJPH.2020.305579

World Health Organization (WHO). (2022). *Road Traffic Injuries*. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

Yannis, G., & Chaziris, A. (2022). Transport system and infrastructure. *Transportation Research Procedia, 60*, 6–11. https://doi.org/10.1016/j.trpro.2021.12.002

Yannis, G., Nikolaou, D., Laiou, A., Stürmer, Y. A., Buttler, I., & Jankowska-Karpa, D. (2020). Vulnerable road users: Cross-cultural perspectives on performance and attitudes. *IATSS Research, 44*(3), 220–229. https://doi.org/10.1016/j.iatssr.2020.08.006

Zhou, S., Wu, Z., & Cheng, L. (2013). The impact of spatial mismatch on residents in low-income housing neighbourhoods: A study of the Guangzhou Metropolis, China. *Urban Studies, 50*(9), 1817–1835. https://doi.org/10.1177/0042098012465906

Zietsman, J., Ramani, T., Potter, J., Reeder, V. & DeFlorio, J. *A Guidebook for Sustainability Performance Measurement for Transportation Agencies*. National Cooperative Highway Research Program (NCHRP). Report Number: 708. https://backend.orbit.dtu.dk/ws/portalfiles/portal/155556014/nchrp_rpt_708.pdf