Center for Advancing Research in
**Transportation Emissions, Energy, and Health**
A USDOT University Transportation Center

# Project Brief (Working Document)

# TRANSPORTATION AND HEALTH: A CONCEPTUAL MODEL AND LITERATURE REVIEW

Citation: Khreis, Haneen; Glazener, Andrew; Ramani, Tara; Zietsman, Josias; Nieuwenhuijsen, Mark J.; Mindell, Jennifer S.; Winfree, Gregory D.; Fox, Mary A.; Wunderlich, Robert; and Burke, Thomas A. (2019). *Transportation and Health: A Conceptual Model and Literature Review.* College Station, Texas: Center for Advancing Research in Transportation Emissions, Energy, and Health, May 2019. Available at: https://www.carteeh.org/14-pathways-to-health-project-brief/

## Problem Statement

Transportation facilitates the movement of people and goods and is key to our everyday lives. Transportation affects health in several positive ways, including physical activity through active transportation modes, such as walking and biking, and access to opportunities for people to improve their health and well-being. Transportation, however, can also have detrimental impacts on health, through exposures such as air pollution, noise and crashes, and their disparate impacts on disadvantaged segments of society. These issues are especially relevant in urban areas but are also applicable beyond. These complex interactions merit a thorough analysis to comprehensively frame linkages between transportation and health, and to support analyses, policies, and strategies to improve public health.

### *Highlights*

- Transportation has both beneficial and detrimental impacts on health, through a range of distinct yet interrelated pathways.
- Several of these pathways have been studied in recent years — each with a differing level of evidence.
- In this research, we developed a comprehensive conceptual model of 14 pathways that link transportation to numerous health outcomes.
- This model paves the way for the conceptualization and quantification of the health impacts associated with transportation in a comprehensive manner.

## Technical Objectives

The primary technical objective of this work was to develop a comprehensive transportation-health framework in the form of a conceptual model. Hereafter, the term framework will be used to refer to this conceptual model, which maps the linkages between transportation and numerous health outcomes. The conceptual model builds on existing works but is far more comprehensive and holistic, incorporating the latest research from an ever-growing literature base. Researchers from the Center for Advancing Research in Transportation Emissions, Energy, and Health (CARTEEH) have worked in collaboration with international and national experts on this framework, which is documented in a scientific paper currently under development.

Several existing efforts have examined the relationships between transportation and health, and new frameworks continue to emerge in recent literature (Frank et al., 2019). Figure 1 provides a detailed timeline and overview of existing frameworks on health and transportation. In our work, we built on this existing body of knowledge, to develop a framework that:

- sourced input from experts from a range of disciplines related to both health and transportation;
- employed a comprehensive approach covering the elements of transportation and their linkages to health; and
- discussed the linkages between transportation and health (termed *pathways*) that determine environmental exposures, as well as the extrinsic and intrinsic factors and equity considerations that affect impacts on the health of different individuals or population groups.

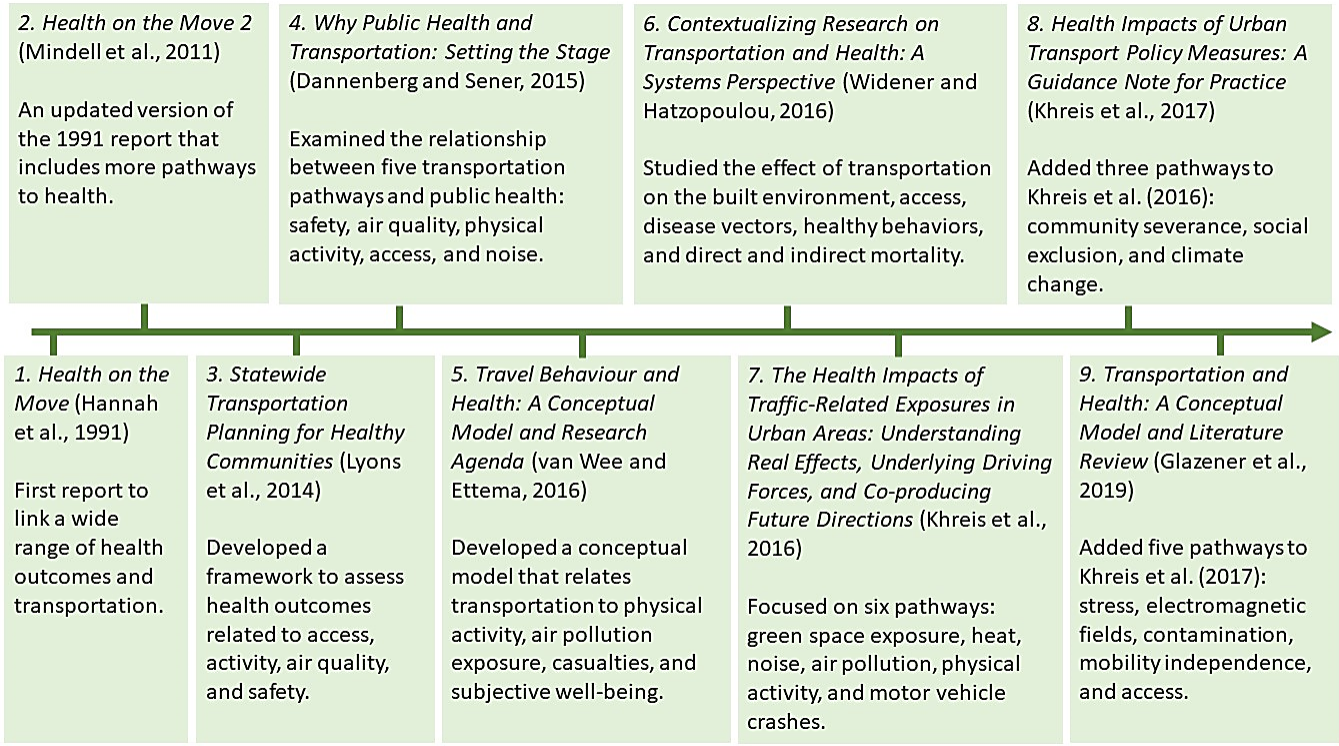



**Figure 1. Timeline of Literature on Transportation-Health Frameworks.**

## Key Findings

Figure 2 shows a simplified version of our conceptual model. Appendix A provides the detailed version. The model depicts the relationships between transportation, its four elements, the 14 pathways (four beneficial and ten detrimental to health), and their impact on health outcomes.

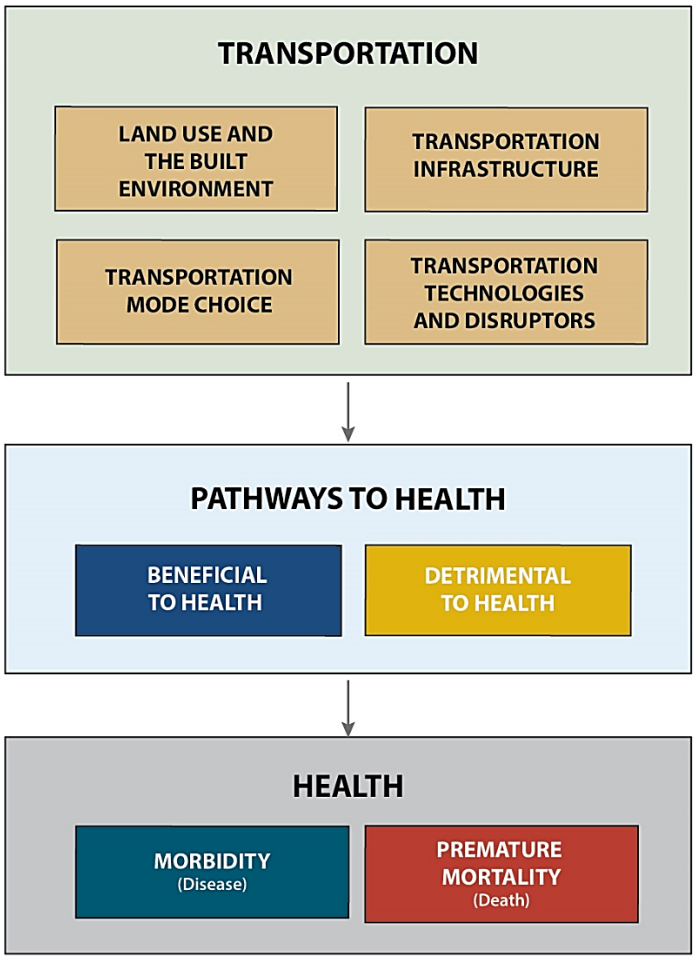



**Figure 2. Transportation and Health Conceptual Model.**

The key contributions of this framework are the nuanced framing of transportation into four elements, and the comprehensive set of pathways between transportation and health. Transportation is shaped by trends in how people live and travel, and policy decisions that determine how transportation systems are funded, whether public transportation is available, and whether alternative modes exist.

We frame the elements that underlie transportation into four categories as shown in Figure 2:

- land use and the built environment,
- transportation infrastructure,
- transportation mode choice, and
- transportation technologies and disruptors.

The effects that these four elements have on transportation determine environmental exposures and lifestyles, what we refer to as the pathways to health. In this framework, the 14 pathways linking transportation to various health outcomes are:

1. green space and aesthetics, *
2. physical activity, *
3. access, *
4. mobility independence, *
5. contamination,
6. social exclusion,
7. noise,
8. urban heat islands,
9. vehicle crashes,
10. air pollution,
11. community severance,
12. electromagnetic fields,
13. stress, and
14. greenhouse gas emissions.

Various levels of literature and evidence support each pathway and its associated health outcomes. The first four pathways (marked with an asterisk) are associated with beneficial health impacts, while the others are associated with detrimental health impacts. Appendix B provides a table defining each of the pathways and summarizing the associated health outcomes for each, as described in the literature. Note that the health outcomes associated with these pathways are broader than conventional morbidity and mortality, and extend to anxiety, stress, mental health and well-being. These latter endpoints are shown in Appendix B.

## Project Impacts

The motivating factor in developing this framework was to guide future research and practice toward more integrated and systematic assessments of transportation and health. While the emphasis is on the urban context because cities are where most people live and travel, our approach is applicable to areas outside of cities as well.

Currently, not all 14 pathways discussed in this brief have been fully recognized or quantified as determinants of health outcomes within the public health, transportation, and urban planning fields. However, research into the impacts of several pathways have shown the significant costs and impacts on health.

For example, motor vehicle crashes have been widely studied. In 2015 alone, more than 37,000 fatalities and 4 million injuries resulted from motor vehicle crashes in the United States (Center for Disease Control and Prevention, 2018). This resulted in $63 billion lost to medical expenses and foregone income (Center for Disease Control and Prevention, 2017).

Additionally, studies show that physical inactivity — a result of sedentary, car-dependent lifestyles — is the fourth largest contributor to mortality (World Health Organization, 2018b), resulting in 3.2 million deaths around the world, each year (World Health Organization, 2018c). Health care costs related to physical inactivity around the world were conservatively estimated at $53.8 billion in 2013 (Ding et al.,

2016). Alternatively, fiscal analysis shows that for each $1 invested in active transportation, there is a $8.41 return in health and economic benefits (Urban Design 4 Health and AECOM, 2016).

However, the overall health impact and associated costs of several other pathways, access, mobility independence, contamination, social exclusion, community severance, stress and specifically electromagnetic fields, are difficult to determine due to the lack of data or research. These areas warrant future research, and our framework provides the basis for a systematic and holistic approach to quantifying the health benefits and mitigating the adverse health impacts of transportation.

## Conclusions

In accordance with our intent to frame the health impacts of transportation and promote work to systematically quantify and track health impacts of transportation, we are currently writing a full paper on this conceptual model (Glazener et al., 2019). We are also working on multiple initiatives to quantify and monetize the impacts of selected pathways for case studies in Texas and beyond. This framework is a first step to promote holistic solutions that enhance the beneficial health impacts of transportation while addressing its detrimental health outcomes. By condensing the existing literature about the health outcomes associated with transportation, we aim to increase awareness of the need to integrate human health into urban and transport planning and policy.

## For Further Information

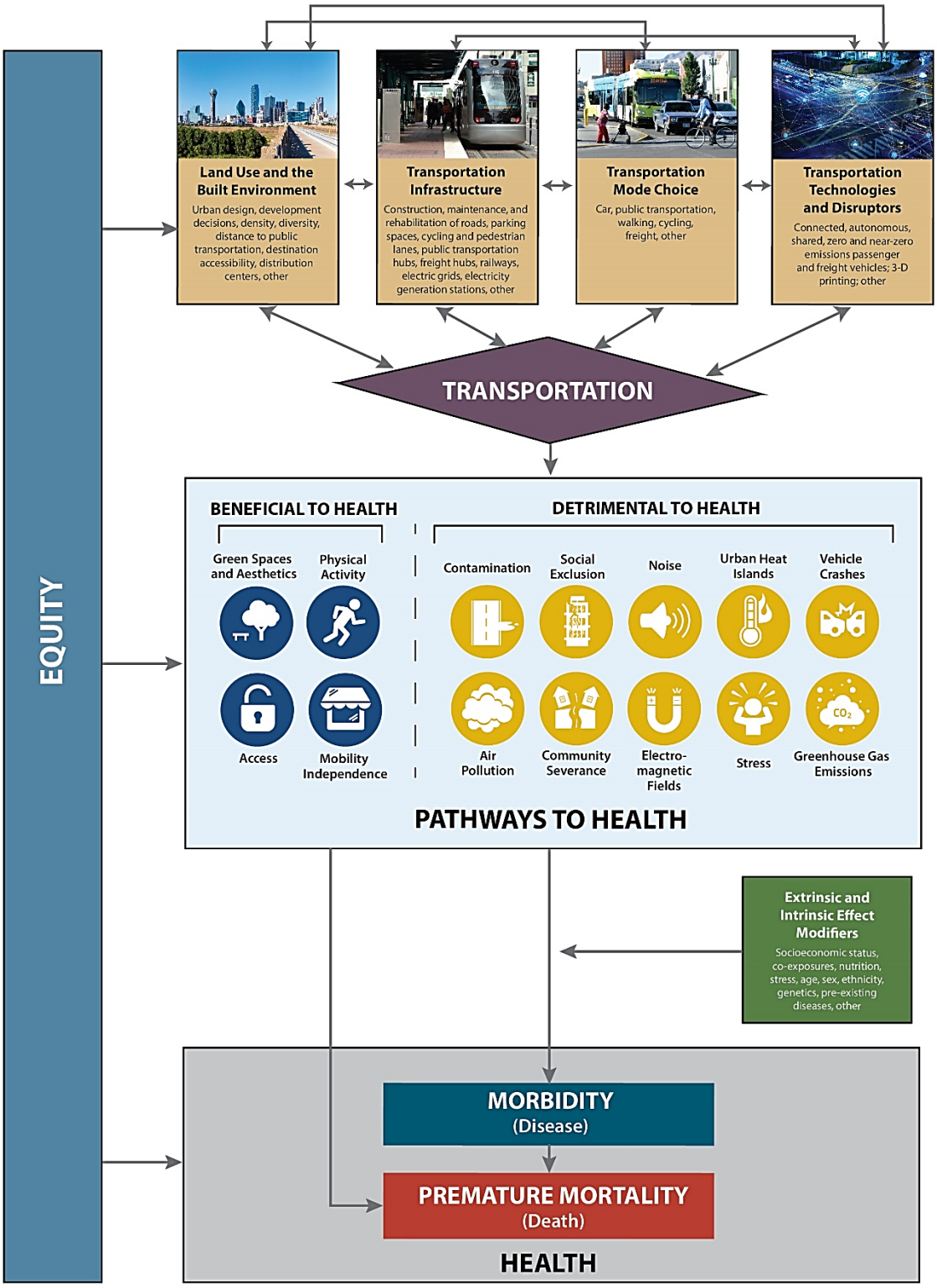
This project brief represents work in progress, with funding from the Texas A&M Transportation Institute's Center for Advancing Research in Transportation Emissions, Energy, and Health, a U.S. Department of Transportation's University Transportation Center. The grant number is 69A3551747128.

For further information, please contact:

**Haneen Khreis, Ph.D.**
*Principal Investigator*, Center for Advancing Research in Transportation Emissions, Energy, and Health
Texas A&M Transportation Institute
1111 RELLIS Parkway, Bryan, TX 77807
Tel. 979.492.1378
https://www.carteeh.org/
http:/tti.tamu.edu

**Josias Zietsman, Ph.D., P.E.**
*Director*, Center for Advancing Research in Transportation Emissions, Energy, and Health
Texas A&M Transportation Institute
1111 RELLIS Parkway, Bryan, TX 77807
Tel. 979.317.2796
https://www.carteeh.org/
http:/tti.tamu.edu

## Appendix A: Transportation and Health Conceptual Model.



## Appendix B: Transportation-Health Pathways and Associated Health Outcomes

| Definition | Associated Health Outcomes |
|---|---|
| **1. Green Space and Aesthetics** | |
| *Green space* is land that is partly or completely covered with grass, trees, shrubs, or other vegetation and accessible to the public in an urban area. Urbanization trends prioritize land use for transportation and related infrastructure over green spaces that have measured health benefits for urban populations. Green spaces contribute to physical activity (Ying et al., 2015) and reduce the likelihood of negative mental health outcomes (Zijlema et al., 2018), diseases, and premature mortality (Gascon et al., 2016). Green spaces also reduce the adverse effects of harmful transportation-induced environmental exposures such as urban heat islands, air pollution, and noise (Hartig et al., 2014; Nieuwenhuijsen, 2016). Within the context of transportation, *aesthetics* is the visual integration of transportation facilities into the surrounding landscape, which can elicit positive and negative health effects depending on the scale of visual integration. There is also increasing evidence for similar benefits for blues spaces (Gascon et al., 2017), although the link between transportation and blue spaces is less clear. | • Decreased risk of anxiety<br>• Decreased risk of cardiovascular disease<br>• Decreased risk of high blood pressure<br>• Decreased risk of premature mortality<br>• Decreased risk of respiratory disease<br>• Decreased risk of stress<br>• Decreased risk of stroke<br>• Decreased risk of Type 2 diabetes<br>• Improved cognitive function<br>• Improved mental health<br>• Improved physical activity<br>• Improved pregnancy outcomes<br>• Improved self-reported health<br>• Improved sleep patterns |
| **2. Physical Activity** | |
| *Physical activity* is body movement that requires energy expenditure. The lack of physical activity is considered a health crisis due to its role in the obesity epidemic and contribution to numerous other diseases (Khreis et al., 2016). Land use policies that promote high density, connectivity, and active transportation infrastructure can boost physical activity (Panter et al., 2016; Rafiemanzelat et al., 2017). Physical inactivity is the fourth largest contributor to global mortality (World Health Organization, 2018b), resulting in 3.2 million global deaths annually (World Health Organization, 2018c). Health care costs related to physical inactivity around the world were estimated at $53.8 billion in 2013 (Ding et al., 2016). Additionally, analyses have shown that for each $1 spent on active transportation, there is a $8.41 return on investment (Urban Design 4 Health and AECOM, 2016). | • Decreased risk of Alzheimer's disease<br>• Decreased risk of cancer<br>• Decreased risk of cardiovascular disease<br>• Decreased risk of cognitive decline<br>• Decreased risk of dementia<br>• Decreased risk of diabetes<br>• Decreased risk of hypertension<br>• Decreased risk of depression and anxiety<br>• Improved mental health and well-being<br>• Decreased risk of premature mortality<br>• Decreased risk of obesity<br>• Decreased risk of stroke<br>• Decreased stress |

| Definition | Associated Health Outcomes |
|---|---|
| **3. Access** | |
| *Access* is the ability for individuals to reach destinations to protect and improve their health, including health facilities and services, healthy food (eradicating food deserts), green space, physical activity facilities, jobs, and education (Litman, 2015b). Several strategies to increase access include development practices like complete streets (Litman, 2015a), densification, and transit-oriented development (Renne et al., 2016). These strategies can decrease distance to public transportation and increase active transportation, reducing morbidity and mortality (Nieuwenhuijsen, 2018). Accessibility poverty is a product of increased transit time and costs that limit access and lead to the exacerbation of issues like social exclusion and community severance (Lucas et al., 2016), which can cause adverse mental health outcomes (Cohen et al., 2014). | • All-cause mortality<br>• Cancer<br>• Cardiovascular disease<br>• Mental health decline<br>• Obesity |
| **4. Mobility Independence** | |
| *Mobility independence* is the ability to use various transportation modes to access commodities and neighborhood facilities, and to participate in meaningful social, cultural, and physical activities without assistance or supervision (Rantanen, 2013). The elderly and children are population cohorts that are dependent on capable individuals for transportation assistance due to declining/developing motor skills and awareness. Mobility independence may promote healthy aging through physical activity and engagement in community activities, which sustain cognitive function (Rantanen, 2013). Lack of mobility independence in children impairs self-esteem and physical and mental development (Mindell et al., 2012). | • Increased physical activity<br>• Sustained cognitive ability<br>• Increased self-esteem<br>• Improved mental well-being and motor skills development |
| **5. Contamination** | |
| *Contamination* is caused by oils, gasoline, heavy metals, particulate matter, and polycyclic aromatic hydrocarbons that can be found on roadway surfaces due to motor vehicle traffic (Burant et al., 2018; Gaffield et al., 2003; Khan and Strand, 2018). These chemicals can contaminate water sources, soils, and the air, potentially ending up in what humans consume (Adamiec et al., 2016). Minimizing the number of vehicle trips and the associated infrastructure by supporting alternative modes of transportation could reduce the overall presence of these harmful substances. Similarly, the provision of green spaces and the development of biodegradable and environmentally conservative vehicle and road surface materials could mitigate the effects of roadway contamination (Federal Highway Administration, 2016; Asphalt Pavement Association of Oregon, 2013). | • Abdominal pain<br>• Arthritis<br>• Depression<br>• Fatigue<br>• Headache<br>• Hypertension<br>• Kidney failure<br>• Liver failure<br>• Low blood pressure<br>• Memory loss<br>• Nausea<br>• Premature birth<br>• Rashes<br>• Reduced birth weight<br>• Renal dysfunction<br>• Sleeplessness<br>• Ulcers |

| Definition | Associated Health Outcomes |
|---|---|
| **6. Social Exclusion** | |
| *Social exclusion* is the culmination of transportation-related inhibitions and/or deprivations — affordability, accessibility, availability, geographical location, time, and fear — that limit the opportunity to socially participate in community activities. The inability to engage in community or social activities contributes to negative health outcomes (Julien et al., 2015). Social isolation, loneliness, and living alone result in a 29%, 26%, and 32% increase in mortality, respectively (Holt-Lunstad et al., 2015). | • Cardiovascular disease<br>• Mental health issues<br>• Physical inactivity<br>• Premature mortality<br>• Stress<br>• Unhealthy diet |
| **7. Noise** | |
| *Noise* is motorized vehicle sounds at levels detrimental to health. Noise level is dependent on factors like road networks, junctions, traffic flow and speed, acoustics, and meteorological conditions (Zuo et al., 2014; Bell et al., 2014; Foraster et al., 2011). Encouraging smart growth — mixed-use, dense, and connected — developments could lead to increased active transportation and decreased vehicle miles traveled, vehicle speeds, and vehicle usage, potentially reducing overall noise levels (Nieuwenhuijsen, 2016; U.S. Department of Transportation, 2015; Environmental Protection Agency, 2018). Other feasible traffic noise reduction strategies include physical barriers (Federal Highway Administration, 2017), low-noise tires and road surfaces (European Commission, 2017), and vegetation near roadways (Hyung Suk Jang, 2015; Peng et al., 2014). | • Annoyance<br>• Cognitive impairment<br>• Diabetes<br>• Hypertension<br>• Ischemic heart disease<br>• Low birth weight<br>• Mental health problems<br>• Obesity<br>• Premature birth<br>• Reproductive complications<br>• Sleep disturbance<br>• Stress<br>• Stroke<br>• Disruption to concentration and educational attainment |
| **8. Urban Heat Islands** | |
| *Urban heat islands* (UHIs) are urban spaces with greater surface and air temperatures than surrounding rural areas (Coseo and Larsen, 2014). UHIs are becoming more prominent in cities as the built environment and transportation infrastructure, composed of heat-absorbing concretes and asphalts, continue to expand and replace trees, vegetation, and green spaces (Khreis et al., 2017; Nieuwenhuijsen, 2016), which can cool temperatures (Doick et al., 2014; Petralli et al., 2014). On several occasions, heat waves have proved fatal, including the 2003 Paris heat wave, which killed 15,000 people (Fouillet et al., 2006), and the 2006 California heat wave, which killed 600 people and caused 16,000 emergency room visits (Ostro et al., 2009; Knowlton et al., 2009). Heat waves are expected to become more frequent and intense throughout the 21st century (Lemonsu et al., 2014). A study on heat wave intensity found that for every 1°C increase in heat wave intensity, there is a 4.5% increase in mortality risk (Anderson and Bell, 2011). | • Arrhythmia<br>• Asthma<br>• Cardiorespiratory disease<br>• Cardiovascular disease<br>• Cerebrovascular disease<br>• Chronic obstructive pulmonary disease (COPD)<br>• Diabetes<br>• Heat stress<br>• Hospitalizations<br>• Hypertension<br>• Vehicle crashes<br>• Premature birth<br>• Respiratory disease<br>• Stroke |

| Definition | Associated Health Outcomes |
|---|---|
| **9. Vehicle Crashes** | |
| A *vehicle crash* is any incident involving a vehicle that may result in death, injury, or disability. Those most affected by motor vehicle crashes are vulnerable road users like pedestrians, bicyclists, and motorcyclists, who account for over 50% of all traffic deaths worldwide (World Health Organization, 2018a). The frequency of motor vehicle crash fatalities per vehicle mile decreased in the United States for 40 years; however, in 2016 that number increased to the highest it has been since 2008, mirroring an increase in vehicle miles traveled (National Highway Transportation Safety Administration, 2017). Motor vehicle crash fatalities per capita in the United States had decreased steadily since 2000 but increased by 6.8% from 2014 to 2015 (Organisation for Economic Co-ordination and Development, 2018). Motor vehicle crashes are ranked as the eighth leading cause of death in the world and the leading cause of death among those aged 5–29 (World Health Organization, 2018a). Annually, motor vehicle crashes are responsible for 1.35 million deaths and up to 50 million injuries globally (World Health Organization, 2018a). In the United States in 2015, more than 36,000 motor vehicle crash fatalities occurred, and 2.5 million people were treated for injuries due to motor vehicle crashes, resulting in $63 billion lost to medical expenses and missed income (Center for Disease Control and Prevention, 2017). Road travel injuries also occur frequently through falls when walking or cycling and, rarely, from collisions between cyclists and pedestrians. For pedestrians, falls are a more common cause of hospitalization in many countries than being hit by a motor vehicle (Methorst et al., 2017). | • Crash injury<br>• Premature mortality |
| **10. Air Pollution** | |
| *Air pollution* results from the emission and dispersion of toxic substances in the air we breathe. Conservative estimates from the World Bank in 2014 attribute 184,000 annual deaths worldwide to traffic-related air pollution (Bhalla, 2014), although a different study attributed 137,400 deaths in China just to traffic-related particulate matter ($PM_{2.5}$) in 2013 (Global Burden of Disease Working Group, 2016). Another study reported that vehicle emissions are responsible for almost 20% of all ambient $PM_{2.5}$ and ozone-related mortality in Germany, the United States, and the United Kingdom (Lelieveld et al., 2015). Air pollution is also linked to a wide spectrum of global and chronic diseases. | • Allergies<br>• Arrhythmia<br>• Autism and child behavior problems<br>• Carcinoma<br>• Cardiovascular disease<br>• Childhood asthma<br>• COPD<br>• Congenital anomalies<br>• Congestive heart failure<br>• Deep venous thrombosis<br>• Dementia<br>• Diabetes<br>• Fungal infection<br>• Low birth weight<br>• Lung cancer<br>• Mental health problems<br>• Myocardial infarction (heart attack)<br>• Neurodegenerative diseases<br>• Obesity<br>• Pneumonia<br>• Premature birth |

| Definition | Associated Health Outcomes |
|---|---|
| | • Reduced sperm quality<br>• Respiratory diseases<br>• Respiratory inflammation<br>• Stroke |
| **11. Community Severance** | |
| *Community severance* results from transportation infrastructure and/or motorized traffic (speed or volume of traffic) that separates places and people, interfering with the ability of individuals to access goods, services, and personal networks (Mindell et al., 2017). This barrier effect is associated with limited social interaction, mental health problems, reduced mental well-being, and premature mortality (Anciaes et al., 2019). Community severance can also increase the risk of motor vehicle crashes and may restrict access to public transportation and physical activity (James et al., 2005). | • Cardiovascular disease<br>• Increased exposure to air pollution<br>• Increased risk of motor vehicle crashes<br>• Limited social interaction<br>• Mental health problems<br>• Reduced mental well-being<br>• Physical inactivity<br>• Premature mortality<br>• Unhealthy diet<br>• Negative impact on mobility, independence, and access<br>• Stress |
| **12. Electromagnetic Fields** | |
| An *electromagnetic field* (EMF) is composed of moving electrically charged particles. EMFs can be created by differences in voltage and can be present near electricity generation stations, electric grids, and other similar infrastructure used to accommodate transportation technologies and disrupters (autonomous, connected, electric, and shared vehicles) (World Health Organization, 2018d). Studies have linked EMF exposure to pregnancy complications (Li et al., 2017) and hindered cognitive development (Calvente et al., 2016). | • Adverse and beneficial impacts regarding:<br>o Cell growth<br>o Genes<br>o Neural system<br>o Immune system<br>o Circulatory system<br>o Endocrine system<br>• Hindered cognitive development in children<br>• Nerve stimulation<br>• Reproductive complications<br>• Retinal phosphene occurrence |
| **13. Stress** | |
| *Stress* is the body's response to any demand. It was labeled the "health epidemic of the 21st century" and was estimated to cost Americans $300 billion annually (Fink, 2017). Stress is associated with travel and might result from increased travel times, congestion, searching for parking, interaction with other drivers, and safety (Ding et al., 2014). Traffic congestion costs the average U.S. driver $1,400 per year (INRIX, 2016). | • Anxiety<br>• Depression<br>• Fatigue<br>• Heart disease<br>• High cholesterol<br>• Hypertension<br>• Insomnia<br>• Mental health problems<br>• Obesity<br>• Unhealthy diet<br>• Stroke<br>• Substance abuse |

| Definition | Associated Health Outcomes |
|---|---|
| **14. Greenhouse Gas Emissions** | |
| *Greenhouse gas emissions* (GHGs) are gases — carbon dioxide, methane, nitrous oxide, and fluorinated gases — that trap heat in the atmosphere (Environmental Protection Agency, 2016). In the United States, 81% of GHG emissions are carbon dioxide (Environmental Protection Agency, 2016), 30% of which are produced by motor vehicles (Energy Information Administration, 2017). The transportation sector is the largest contributor of GHGs (30%) in the United States (Kay et al., 2014) and accounts for 23% of GHG emissions globally (Edenhofer et al., 2014). While carbon dioxide and other GHGs are not directly threatening to human health, a 2°C increase in global mean temperature from levels recorded during pre-global industrialization would result in harmful effects for human populations and the ecosystems that sustain them, such as increase flooding or extreme heat events and is expected to occur by the end of the century (Watts et al., 2018; Patz et al., 2014). | • Adverse mental and physical health outcomes<br>• Change in vector-pathogen relations<br>• Changes in air pollution<br>• Malnutrition<br>• Physical injury<br>• Premature mortality<br>• Health effects from extreme weather events including flooding, hurricanes, etc. with resultant land loss; damage to buildings, infrastructure, and food supplies; etc. |

## References


Adamiec, E., Jarosz-Krzemińska, E., and Wieszała, R. (2016). Heavy Metals from Non-exhaust Vehicle Emissions in Urban and Motorway Road Dusts. *Environmental Monitoring and Assessment* 188: 369.

Anciaes, P. R., Stockton, J., Ortegon, A., & Scholes, S. (2019). Perceptions of Road Traffic Conditions Along with Their Reported Impacts on Walking Are Associated with Wellbeing. *Travel Behaviour and Society* 15: 88-101.Anderson, G.B., and Bell, M.L. (2011). Heat Waves in the United States: Mortality Risk during Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. Communities. *Environmental Health Perspectives* 119: 210-218.

Asphalt Pavement Association of Oregon (2013). *Asphalt — Environmentally Friendly, Sustainable Pavement Material.*

Bell, M.L., Ebisu, K., Leaderer, B.P., Gent, J.F., Lee, H.L., Koutrakis, P., Peng, R.D., et al. (2014). Associations of $PM_{2.5}$ Constituents and Sources with Hospital Admissions: Analysis of Four Counties in Connecticut and Massachusetts for Persons ≥ 65 Years of Age. *Environmental Health Perspectives* 122: 138-144.

Bhalla, K., Shotten, M., Cohen, A., Brauer, M., Shahraz, S., Burnett, R., Murray, C.J.L., et al. (2014). *Transport for Health: The Global Burden of Disease from Motorized Road Transport.* World Bank Group.

Burant, A., Selbig, W., Furlong, E.T., and Higgins, C.P. (2018). Trace Organic Contaminants in Urban Runoff: Associations with Urban Land-Use. *Environmental Pollution* 242: 2068-2077.

Calvente, I., Pérez-Lobato, R., Núñez, M.-I., Ramos, R., Guxens, M., Villalba, J., Fernandez, M.F., et al. (2016). Does Exposure to Environmental Radiofrequency Electromagnetic Fields Cause Cognitive and Behavioral Effects in 10-Year-Old Boys? *Bioelectromagnetics* 37: 25-36.

Center for Disease Control and Prevention (2017). Cost Data and Prevention Policies. Available at https://www.cdc.gov/motorvehiclesafety/costs/index.html. Accessed April 10, 2019.

Center for Disease Control and Prevention (2018). WISQARS (Web-Based Injury Statistics Query and Reporting System). Available at https://www.cdc.gov/injury/wisqars. Accessed April 10, 2019.

Cohen, J.M., Boniface, S., and Watkins, S. (2014). Health Implications of Transport Planning, Development and Operations. *Journal of Transport and Health* 1: 63-72.

Coseo, P., and Larsen, L. (2014). How Factors of Land Use/Land Cover, Building Configuration, and Adjacent Heat Sources and Sinks Explain Urban Heat Islands in Chicago. *Landscape and Urban Planning* 125: 117-129.

Dannenberg, A.L., and Sener, I.N. (2015). *Why Public Health and Transportation: Setting the Stage.*

Ding, D., Gebel, K., Phongsavan, P., Bauman, A.E., and Merom, D. (2014). Driving: A Road to Unhealthy Lifestyles and Poor Health Outcomes. *PLOS ONE* 9: e94602.

Ding, D., Lawson, K.D., Kolbe-Alexander, T.L., Finkelstein, E.A., Katzmarzyk, P.T., van Mechelen, W., Pratt, M., et al. (2016). The Economic Burden of Physical Inactivity: A Global Analysis of Major Non-communicable Diseases. *The Lancet* 388: 1311-1324.

Doick, K.J., Peace, A., and Hutchings, T.R. (2014). The Role of One Large Greenspace in Mitigating London's Nocturnal Urban Heat Island. *Science of The Total Environment* 493: 662-671.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Minx, J.C., et al. (2014). *Climate Change 2014: Mitigation of Climate Change.* Contribution of Working Group III to the Fifth Assessment.

Energy Information Administration (2017). How Much Carbon Dioxide Is Produced from Burning Gasoline and Diesel Fuel? Available at https://www.eia.gov/tools/faqs/faq.php?id=307&t=11. Accessed April 10, 2019.

Environmental Protection Agency (2016). Sources of Greenhouse Gas Emissions. Available at https://www.epa.gov/ghgemissions/overview-greenhouse-gases. Accessed April 10, 2019.

Environmental Protection Agency (2018). *About Smart Growth.*

European Commission (2017). *Science for Environment Policy — Future Brief: Noise Abatement Approaches.*

Federal Highway Administration (2016). *Strategies for Improving Sustainability of Asphalt Pavements.*

Federal Highway Administration (2017). *The Audible Landscape: A Manual for Highway Noise and Land Use.*

Fink, G. (2017). Stress: Concepts, Definition and History. *Reference Module in Neuroscience and Biobehavioral Psychology.*

Foraster, M., Deltell, A., Basagaña, X., Medina-Ramón, M., Aguilera, I., Bouso, L., Künzli N., et al. (2011). Local Determinants of Road Traffic Noise Levels versus Determinants of Air Pollution Levels in a Mediterranean City. *Environmental Research* 111: 177-183.

Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Clavel, J., Hémon, D., et al. (2006). Excess Mortality Related to the August 2003 Heat Wave in France. *International Archives of Occupational and Environmental Health* 80: 16-24.

Frank, L.D., Iroz-Elardo, N., MacLeod, K.E., and Hong, A. (2019). Pathways from Built Environment to Health: A Conceptual Framework Linking Behavior and Exposure-Based Impacts. *Journal of Transport and Health* 12: 319-335.

Gaffield, S.J., Goo, R.L., Richards, L.A., and Jackson, R.J. (2003). Public Health Effects of Inadequately Managed Stormwater Runoff. *American Journal of Public Health* 93: 1527-1533.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., and Nieuwenhuijsen, M.J. (2016). Residential Green Spaces and Mortality: A Systematic Review. *Environment International* 86: 60-67.

Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor Blue Spaces, Human Health and Well-Being: A Systematic Review of Quantitative Studies. *International Journal of Hygiene and Environmental Health*, 220(8), 1207-1221.

Glazener, A., Khreis, H., Ramani, T., Zietsman, J., Nieuwenhuijsen, M.J., Mindell, J. Winfree, G.D., and Burke, T.A. (2019). *Transportation and Health: A Conceptual Model and Literature Review.* In preparation.

Global Burden of Disease Working Group (2016). *Burden of Disease Attributable to Coal-Burning and Other Air Pollution Sources in China.*

Hannah, J., Morton, S., and Watkins, S.J. (1991). *Health on the Move: Policies for Health Promoting Transport.*

Hartig, T., Mitchell, R., Vries, S.D., and Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health* 35: 207-228.

Holt-Lunstad, J., Smith, T.B., Baker, M., Harris, T., and Stephenson, D. (2015). Loneliness and Social Isolation as Risk Factors for Mortality: A Meta-analytic Review. *Perspectives on Psychological Science* 10: 227-237.

INRIX (2016). INRIX 2016 Traffic Scorecard. Available at http://inrix.com/resources/inrix-2016-traffic-scorecard-us/. Accessed April 10, 2019.

James, E., Millington, A., and Tomlinson, P. (2005). *Understanding Community Severance. Part 1: Views of Practitioners and Communities.* Report for the U.K. Department for Transport.

Jang, H.S., Lee, S., Jeon, J.Y., and Kang, J. (2015). Evaluation of Road Traffic Noise Abatement by Vegetation Treatment in a 1:10 Urban Scale Model. *The Journal of the Acoustical Society of America* 138: 3884-3895.

Julien, D., Richard, L., Gauvin, L., Fournier, M., Kestens, Y., Shatenstein, B., Payette, H., et al. (2015). Transit Use and Walking as Potential Mediators of the Association between Accessibility to Services and Amenities and Social Participation among Urban-Dwelling Older Adults: Insights from the VoisiNuAge Study. *Journal of Transport and Health* 2: 35-43.

Kay, A.I., Noland, R.B., and Rodier, C.J. (2014). Achieving Reductions in Greenhouse Gases in the US Road Transportation Sector. *Energy Policy* 69: 536-545.

Khan, R.K., and Strand, M.A. (2018). Road Dust and Its Effect on Human Health: A Literature Review. *Epidemiology and Health* 40: e2018013.

Khreis, H., May, A.D., and Nieuwenhuijsen, M.J. (2017). Health Impacts of Urban Transport Policy Measures: A Guidance Note for Practice. *Journal of Transport and Health* 6: 209-227.

Khreis, H., Warsow, K., Verlinghieri, E., Guzman, A., Pellecuer, L., Ferreira, A., Nieuwenhuijsen, M., et al. (2016). The Health Impacts of Traffic-Related Exposures in Urban Areas: Understanding Real Effects, Underlying Driving Forces and Co-producing Future Directions. *Journal of Transport and Health* 3: 249-267.

Knowlton, K., Rotkin-Ellman, M., King, G., Margolis, H.G., Smith, D., Solomon, G., English, P., et al. (2009). The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits. *Environmental Health Perspectives* 117: 61-67.

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., and Pozzer, A. (2015). The Contribution of Outdoor Air Pollution Sources to Premature Mortality on a Global Scale. *Nature* 525: 367.

Lemonsu, A., Beaulant, A.L., Somot, S., and Masson, V. (2014). Evolution of Heat Wave Occurrence over the Paris Basin (France) in the 21st Century. *Climate Research* 61: 75-91.

Li, D.-K., Chen, H., Ferber, J.R., Odouli, R., and Quesenberry, C. (2017). Exposure to Magnetic Field Non-ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study. *Scientific Reports* 7: 17541.

Litman, T. (2015a). *Evaluating Complete Streets: The Value of Designing Roads for Diverse Modes, Users and Activities.* Victoria Transport Policy Institute.

Litman, T. (2015b). *Evaluating Public Transportation Health Benefits.* American Public Transportation Association.

Lucas, K., Mattioli, G., Verlinghieri, E., and Guzman, A. (2016). Transport Poverty and Its Adverse Social Consequences. *Proceedings of the Institution of Civil Engineers — Transport* 169: 353-365.

Lyons, W., Morse, L., Nash, L., and Strauss, R. (2014). *Statewide Transportation Planning for Healthy Communities.* Federal Highway Administration.

Methorst, R., Schepers, P., Christie, N., Dijst, M., Risser, R., Sauter, D., & Van Wee, B. (2017). 'Pedestrian falls' as Necessary Addition to The Current Definition of Traffic Crashes for Improved Public Health Policies. *Journal of Transport and Health* 6: 10-12.

Mindell, J.S., Anciaes, P.R., Dhanani, A., Stockton, J., Jones, P., Haklay, M., Vaughan, L., et al. (2017). Using Triangulation to Assess a Suite of Tools to Measure Community Severance. *Journal of Transport Geography* 60: 119-129.

Mindell, J.S. (2011). Health on the Move 2. Policies for Health-Promoting Transport. *Journal of Transport and Health* 1: 2-2.

Mindell, J.S., and Saffron K (2012). Community Severance and Health: What Do We Actually Know? *Journal of Urban Health* 89, no. 2: 232-246.

National Highway Transportation Safety Administration (2017). Fatality Analysis Reporting System. Available at https://www-fars.nhtsa.dot.gov/Main/index.aspx. Accessed April 10, 2019.

Nieuwenhuijsen, M.J. (2016). Urban and Transport Planning, Environmental Exposures and Health — New Concepts, Methods and Tools to Improve Health in Cities. *Environmental Health* 15: S38.

Nieuwenhuijsen, M.J. (2018). Influence of Urban and Transport Planning and the City Environment on Cardiovascular Disease. *Nature Reviews: Cardiology, 1*.

Organisation for Economic Co-ordination and Development (2018). Road Accidents. Available at https://data.oecd.org/transport/road-accidents.htm. Accessed April 10, 2019.

Ostro, B.D., Roth, L.A., Green, R.S., and Basu, R. (2009). Estimating the Mortality Effect of the July 2006 California Heat Wave. *Environmental Research* 109: 614-619.

Panter, J., Heinen, E., Mackett, R., and Ogilvie, D. (2016). Impact of New Transport Infrastructure on Walking, Cycling, and Physical Activity. *American Journal of Preventive Medicine* 50: e45-e53.

Patz, J.A., Grabow, M.L., and Limaye, V.S. (2014). When It Rains, It Pours: Future Climate Extremes and Health. *Annals of Global Health* 80: 332-344.

Peng, J., Bullen, R., and Kean, S. (2014). *The Effects of Vegetation on Road Traffic Noise*.

Petralli, M., Massetti, L., Brandani, G., and Orlandini, S. (2014). Urban Planning Indicators: Useful Tools to Measure the Effect of Urbanization and Vegetation on Summer Air Temperatures. *International Journal of Climatology* 34: 1236-1244.

Rafiemanzelat, R., Emadi, M.I., and Kamali, A.J. (2017). City Sustainability: The Influence of Walkability on Built Environments. *Transportation Research Procedia* 24: 97-104.

Rantanen, T. (2013). Promoting Mobility in Older People. *Journal of Preventive Medicine and Public Health = Yebang Uihakhoe chi* 46 Suppl 1: S50-S54.

Renne, J.L., Hamidi, S., and Ewing, R. (2016). Transit Commuting, the Network Accessibility Effect, and the Built Environment in Station Areas across the United States. *Research in Transportation Economics* 60: 35-43.

Taylor, R. (2018). 2017 *Urban Congestion Trends — Measuring, Managing, and Improving Operations in the 21st Century.* U.S. Department of Transportation.

U.S. Department of Transportation (2015). *Integrate Health and Transportation Planning*.

Urban Design 4 Health and AECOM (2016). *Active Transportation, Health, and Economic Benefit Study.*

Van Wee, B., and Ettema, D. (2016). Travel Behaviour and Health: A Conceptual Model and Research Agenda. *Journal of Transport and Health* 3(3): 240-248.

Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., Costello, A., et al. (2018). The Lancet Countdown on Health and Climate Change: From 25 Years of Inaction to a Global Transformation for Public Health. *The Lancet* 391: 581-630.

Widener, M.J., and Hatzopoulou, M. (2016). Contextualizing Research on Transportation and Health: A Systems Perspective. *Journal of Transport and Health* 3(3): 232-239.

World Health Organization (2018a). *Global Status Report on Road Safety 2018*. Available at https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/. Accessed April 10, 2019.

World Health Organization (2018b). Global Strategy on Diet, Physical Activity and Health. Available at https://www.who.int/dietphysicalactivity/pa/en/. Accessed April 10, 2019.

World Health Organization (2018c). Physical Inactivity: A Global Public Health Problem. Available at http://www.who.int/dietphysicalactivity/factsheet_inactivity/en/. Accessed April 10, 2019.

World Health Organization (2018d). What Are Electromagnetic Fields? Available at http://www.who.int/peh-emf/about/WhatisEMF/en/. Accessed April 10, 2019.

Ying, Z., Ning, L.D., and Xin, L. (2015). Relationship between Built Environment, Physical Activity, Adiposity, and Health in Adults Aged 46–80 in Shanghai, China. *Journal of Physical Activity and Health* 12: 569-578.

Zijlema, W.L., Avila-Palencia, I., Triguero-Mas, M., Gidlow, C., Maas, J., Kruize, H., Nieuwenhuijsen, M.J., et al. (2018). Active Commuting through Natural Environments Is Associated with Better Mental Health: Results from the PHENOTYPE Project. *Environment International* 121: 721-727.

Zuo, F., Li, Y., Johnson, S., Johnson, J., Varughese, S., Copes, R., Chen, H., et al. (2014). Temporal and Spatial Variability of Traffic-Related Noise in the City of Toronto, Canada. *Science of The Total Environment* 472: 1100-1107.