



CARTEEH Project Brief (Working Document)

TRANSPORTATION AND HEALTH: A CONCEPTUAL MODEL AND LITERATURE REVIEW

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Problem Statement

Transportation facilitates the movement of people and goods and is key to our everyday lives. Transportation supports health in several 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, also has detrimental impacts on health, through exposures such as air pollution and noise, 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 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. The model builds on existing frameworks 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 framed 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 determinants 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 ultimate impacts on the health of different individuals or population groups.

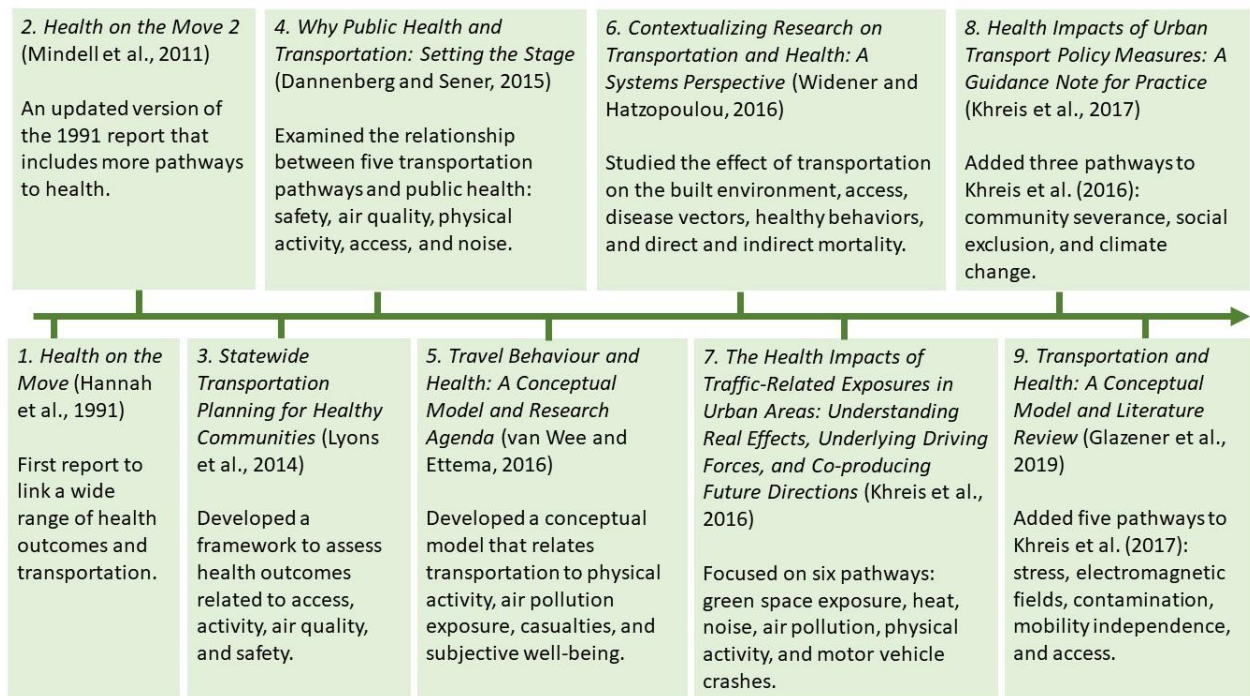


Figure 1. Timeline of Literature on Transportation-Health Frameworks.

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 factors, the 14 pathways, and their impact on health outcomes.

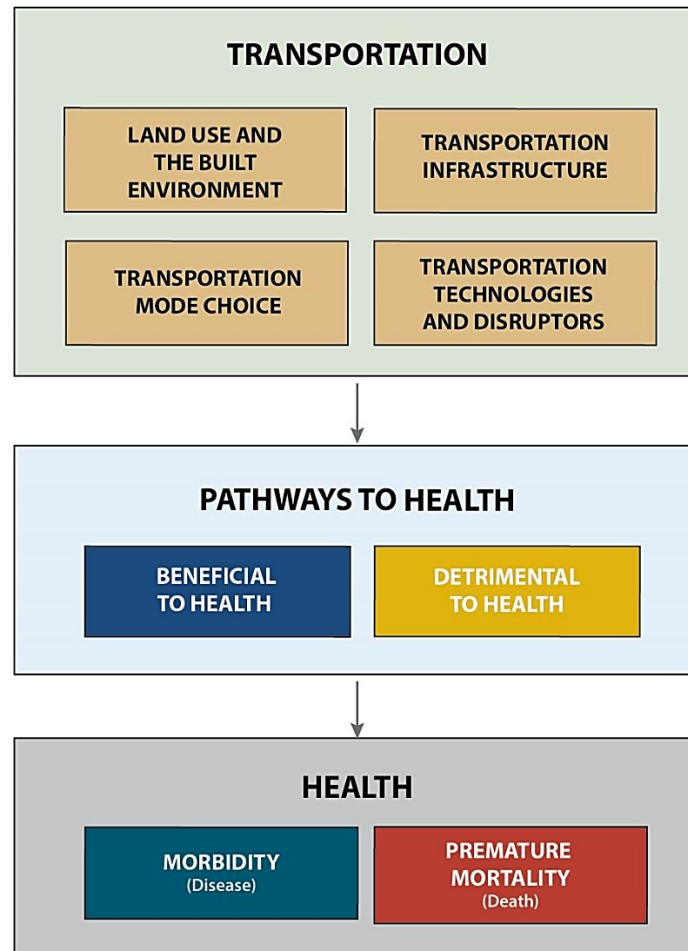


Figure 2. Transportation and Health Conceptual Model.

The key contributions of this framework are the nuanced framing of transportation, 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 factors 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 factors 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).

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, these findings are applicable to other areas as well.

Currently, not all 14 pathways discussed in this brief have been fully recognized as determinants of health outcomes within the public health, transportation, and urban planning fields. However, efforts to quantify individual 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 annually (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, several other pathways, including electromagnetic fields specifically, contamination, and mobility independence, face lack of research and data to determine their overall health impact and

associated costs. These areas warrant future research, and our framework provides the basis for a systematic and holistic approach to quantifying and mitigating the health benefits and adverse 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 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.

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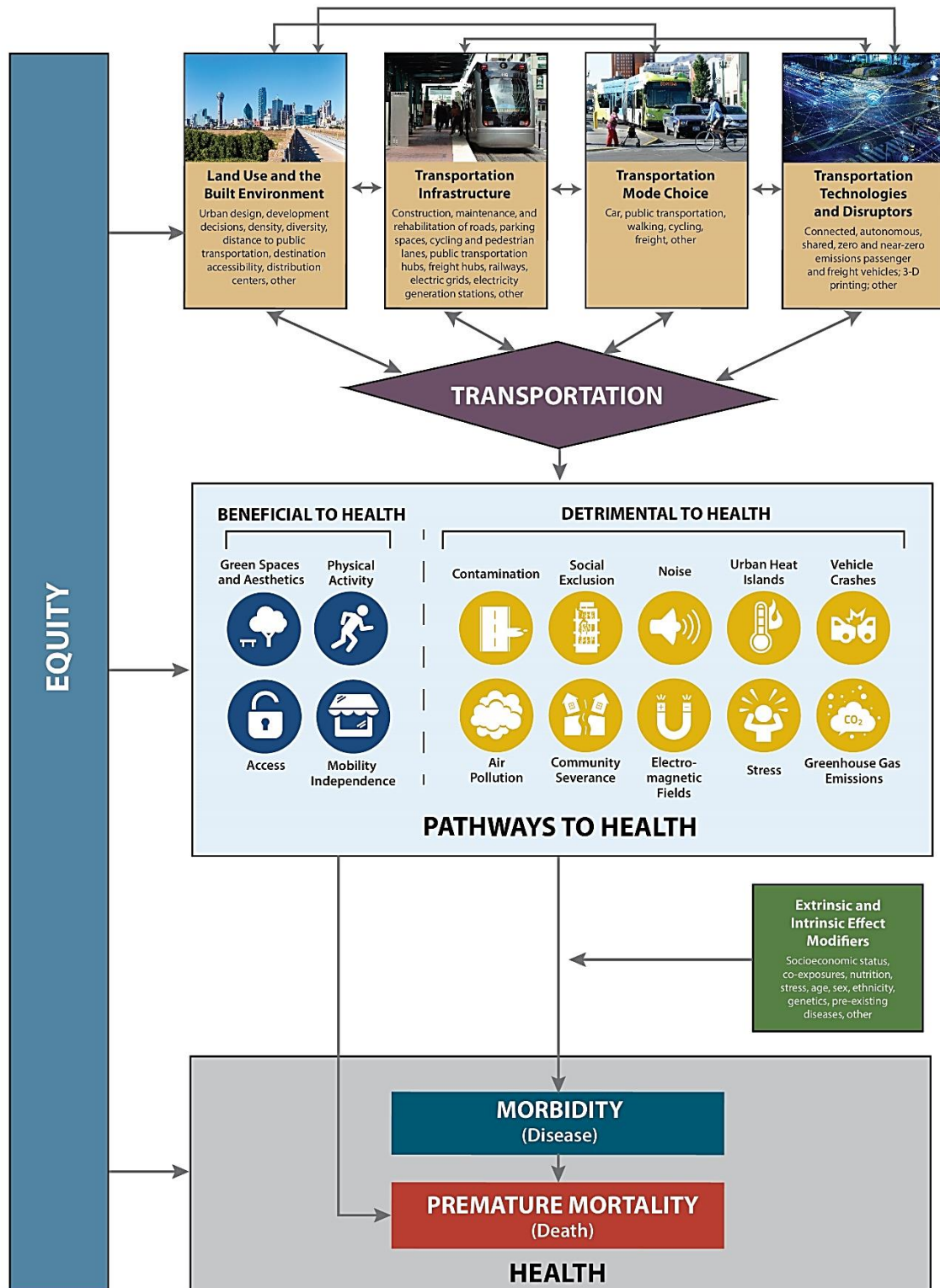
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Appendix A: Transportation and Health Conceptual Model.



Appendix B: Transportation-Health Pathways and Associated Health Outcomes

Definition	Associated Health Outcomes
1. Green Space and Aesthetics	
<p><i>Green space</i> 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, <i>aesthetics</i> 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.</p>	<ul style="list-style-type: none"> • Decreased risk of anxiety • Decreased risk of cardiovascular disease • Decreased risk of high blood pressure • Decreased risk of premature mortality • Decreased risk of respiratory disease • Decreased risk of stress • Decreased risk of stroke • Decreased risk of Type 2 diabetes • Improved cognitive function • Improved mental health • Improved physical activity • Improved pregnancy outcomes • Improved self-reported health • Improved sleep patterns
2. Physical Activity	
<p><i>Physical activity</i> 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).</p>	<ul style="list-style-type: none"> • Decreased risk of Alzheimer’s disease • Decreased risk of cancer • Decreased risk of cardiovascular disease • Decreased risk of cognitive decline • Decreased risk of dementia • Decreased risk of diabetes • Decreased risk of hypertension • Decreased risk of depression and anxiety • Improved mental health and well-being • Decreased risk of premature mortality • Decreased risk of obesity • Decreased risk of stroke • Decreased stress

Definition	Associated Health Outcomes
3. Access	
<p><i>Access</i> 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).</p>	<ul style="list-style-type: none"> • All-cause mortality • Cancer • Cardiovascular disease • Mental health decline • Obesity
4. Mobility Independence	
<p><i>Mobility independence</i> 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).</p>	<ul style="list-style-type: none"> • Increased physical activity • Sustained cognitive ability • Increased self-esteem • Improved mental well-being and motor skills development
5. Contamination	
<p><i>Contamination</i> 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).</p>	<ul style="list-style-type: none"> • Abdominal pain • Arthritis • Depression • Fatigue • Headache • Hypertension • Kidney failure • Liver failure • Low blood pressure • Memory loss • Nausea • Premature birth • Rashes • Reduced birth weight • Renal dysfunction • Sleeplessness • Ulcers

Definition	Associated Health Outcomes
6. Social Exclusion	
<p><i>Social exclusion</i> 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).</p>	<ul style="list-style-type: none"> • Cardiovascular disease • Mental health issues • Physical inactivity • Premature mortality • Stress • Unhealthy diet
7. Noise	
<p><i>Noise</i> 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).</p>	<ul style="list-style-type: none"> • Annoyance • Cognitive impairment • Diabetes • Hypertension • Ischemic heart disease • Low birth weight • Mental health problems • Obesity • Premature birth • Reproductive complications • Sleep disturbance • Stress • Stroke • Disruption to concentration and educational attainment
8. Urban Heat Islands	
<p><i>Urban heat islands</i> (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).</p>	<ul style="list-style-type: none"> • Arrhythmia • Asthma • Cardiorespiratory disease • Cardiovascular disease • Cerebrovascular disease • Chronic obstructive pulmonary disease (COPD) • Diabetes • Heat stress • Hospitalizations • Hypertension • Vehicle crashes • Premature birth • Respiratory disease • Stroke

Definition	Associated Health Outcomes
9. Vehicle Crashes	
<p>A <i>vehicle crash</i> 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).</p>	<ul style="list-style-type: none"> • Crash injury • Premature mortality
10. Air Pollution	
<p><i>Air pollution</i> 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.</p>	<ul style="list-style-type: none"> • Allergies • Arrhythmia • Autism and child behavior problems • Carcinoma • Cardiovascular disease • Childhood asthma • COPD • Congenital anomalies • Congestive heart failure • Deep venous thrombosis • Dementia • Diabetes • Fungal infection • Low birth weight • Lung cancer • Mental health problems • Myocardial infarction (heart attack) • Neurodegenerative diseases • Obesity • Pneumonia • Premature birth

Definition	Associated Health Outcomes
	<ul style="list-style-type: none"> • Reduced sperm quality • Respiratory diseases • Respiratory inflammation • Stroke
11. Community Severance	
<p><i>Community severance</i> 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).</p>	<ul style="list-style-type: none"> • Cardiovascular disease • Increased exposure to air pollution • Increased risk of motor vehicle crashes • Limited social interaction • Mental health problems • Reduced mental well-being • Physical inactivity • Premature mortality • Unhealthy diet • Negative impact on mobility, independence, and access • Stress
12. Electromagnetic Fields	
<p>An <i>electromagnetic field</i> (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).</p>	<ul style="list-style-type: none"> • Adverse and beneficial impacts regarding: <ul style="list-style-type: none"> ○ Cell growth ○ Genes ○ Neural system ○ Immune system ○ Circulatory system ○ Endocrine system • Hindered cognitive development in children • Nerve stimulation • Reproductive complications • Retinal phosphene occurrence
13. Stress	
<p><i>Stress</i> 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).</p>	<ul style="list-style-type: none"> • Anxiety • Depression • Fatigue • Heart disease • High cholesterol • Hypertension • Insomnia • Mental health problems • Obesity • Unhealthy diet • Stroke • Substance abuse

Definition	Associated Health Outcomes
14. Greenhouse Gas Emissions	
<p><i>Greenhouse gas emissions</i> (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).</p>	<ul style="list-style-type: none"> • Adverse mental and physical health outcomes • Change in vector-pathogen relations • Changes in air pollution • Malnutrition • Physical injury • Premature mortality • Health effects from extreme weather events including flooding, hurricanes, etc. with resultant land loss; damage to buildings, infrastructure, and food supplies; etc.

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