# ADVANCES IN TRANSPORTATION AND HEALTH

## TOOLS, TECHNOLOGIES, POLICIES, AND DEVELOPMENTS

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EDITED BY
MARK J. NIEUWENHUIJSEN AND HANEEN KHREIS

# Advances in Transportation and Health

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Edited by

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PART I

# Introduction and setting

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CHAPTER ONE

# Transport and health; an introduction

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## Introduction

Transport is an essential component of economic activity and is often envisioned as a driver for urban development and a key contributor to economic returns. It is important for moving goods and people and provides "the right connections in the right places" (Eddington, 2006). Urban transport networks facilitate the economic competitiveness, social progress, and cultural diversity of urban areas (Eddington, 2006; Hall et al., 2014). Transport also has direct (negative and potentially positive) impacts on the health of a population. For example, the car industry is a large employer and exports products in countries such as Germany and Spain and therefore boosts the economy, which is generally good for health and health care, for example, because of better income for workers. Road construction and maintenance is also a large

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employer and responsible for many jobs. Motorized mobility is a criterion for measuring country-level economic success, and the level of automobility is often seen as a function of income and/or social status (Ecola et al., 2014). However, there are also many negative health impacts of transport, particularly motorized transport in cities. These impacts, as shown later in this chapter and book, are particularly connected to the use and prevalence of motorized transport. In developed countries, there is a cultural and economic dependence on motor vehicles as the primary mode of transport dominates urban transport design and planning and reduces the opportunity of other and healthier transport modes (Jeekel, 2013). Though mass motorization started later in developing countries, it is growing rapidly, causing similar problems in many developing cities (Dargay et al., 2007).

The adverse health impacts of motor vehicle traffic are striking, with over 1.3 million deaths and 78 million injuries warranting medical care are due to motor vehicle crashes (MVCs), each year globally (Bhalla et al., 2014). Traffic-related exposures, including air pollution, greenhouse gases (GHGs), noise, dwindling green space, and urban heat islands (UHIs), contribute to the climate crisis, environmental pollution, and degradation, which, in turn, impacts negatively on the population's health and is responsible for millions of deaths and cases of disease each year (Nieuwenhuijsen, 2016). Mass motorization and the associated lack of physical activity (PA) have resulted in a large disease burden and contribute to a large number of annual deaths due to physical inactivity. Current urban forms and lack of infrastructure for active travel are furthermore reinforcing the excessive use of motorized transport for short-distance trips (Cervero and Duncan, 2003; Giles-Corti and Donovan, 2002), further contributing to increased traffic-related environmental exposures and reduced opportunities for PA. Outdoor air pollution and decreases in PA, both to some extent caused by motorized traffic, are associated with annual estimates of 4.2 million and 2.1 million global deaths, respectively (Forouzanfar et al., 2015). There is, however, emerging evidence that sustainable transport infrastructure and modes such as cycling, walking, and public transport/transit can be effective in promoting an increase in active commuting (Heinen et al., 2015; Panter et al., 2016; Heath et al., 2006), thereby also having the potential to reduce deleterious traffic-related environmental exposures (Woodcock et al., 2009; Grabow et al., 2012).

## Trends

There are two key trends of development that are responsible for the negative health impacts of traffic; rapid urbanization and mass motorization. The urban population is still expected to rise from 50% at the moment to 70% in the next 20 years (Rydin et al., 2012), while the number of cars is expected to rise from the current 1 to 1.6 billion in 2040 (Bloomberg New Energy Finance, 2017). Rapid urbanization coupled with excessive catering for car use in these areas has led to dominance of the car in many places. Even though private motorized transport may not be the predominant mode choice in many cities, cars still occupy a large proportion of public space due to the infrastructure needed for them such as roadways and parking spaces. And although some cities in the developed world are recognizing the negative impacts, car-centered urban models are still the widespread norm (United Nations Human Settlements Programme (UN-HABITAT), 2012). Car-centric urban models allowed and have led to urban sprawl as car travel enables traveling for longer distances between residences and work (United Nations Human Settlements Programme (UN-HABITAT), 2012). A large proportion of the population lives and works in close proximity to highways and roads, including children, as schools are often located in high traffic pollution exposure areas (Health Effects Institute (HEI), 2010; Brandt et al., 2015). Exposures to heat, air pollution, and radiation are often enhanced in urban areas (Vanos, 2015) because of traffic density and the formation of the so-called UHIs, due to the excessive asphalt and concrete infrastructures needed for car traffic. The development of streets flanked by buildings are also causing canyon effects where ventilation is reduced and air flow structures are modified significantly increasing levels of and exposure to traffic-related air pollution (Vardoulakis et al., 2003). Similarly, the levels of ambient noise in urban cores are indicative of building density, roadway network, and intersections/junctions (Foraster et al., 2011; Bell and Galatioto, 2013; Zuo et al., 2014). The expanding density of the roadway infrastructure accompanied by general increases in development structures is also contributing to increases in local temperature via the UHI effect (O'Neill and Ebi, 2009). Finally, increases in traffic-related infrastructure require right of way land acquisition depleting green space in many cities.

Mass motorization also played a major role in exacerbating the adverse health impacts of traffic simply by increasing the number of vehicles on the road and the associated infrastructure that manifested most obviously in increasing MVC. Motorized traffic in developed countries grew more or less according to an S-shaped saturation curve (Oppe, 1989). Motor vehicle kilometers in many developed countries indeed followed such a path.

Finally, the use of the private car had been associated with a reduction in PA and an increase in sedentary behavior in the general population as people step easily into the car to go to work, shops, or other destination without having to move much.

## Adverse health impacts

In most countries, particularly with old cities, the roadway network was not designed to safely accommodate the rapid increases witnessed during the early stages of motorization, both in terms of infrastructure demands and road user experience (Oppe, 1989). Mass motorization led to a substantial number of deaths due to MVCs. Generally, developed countries have experienced gradual reductions of road deaths per motor vehicle kilometer, but only after the pace of growth of motor vehicle kilometers decreased and legislation improved in the 1970s was the risk decrease sufficient to achieve reductions of the number of road deaths per capita (Oppe, 1989). There were government policies with regard to vehicle crash testing and mandate of seat belts alongside other safety-oriented technologies that have helped further. Developing countries are still, however, experiencing a high rate of fatalities due to MVC.

Although the number of deaths in MVC is still too high in both developed and developing countries, developed countries have proved to be able to combine a substantial improvement of road safety with mass motorization. There are important differences, however, in how successful countries were and how safe conditions have become for using active travel modes, highlighting some potential causal explanations of what policies and underlying positions seem to work for mitigating adverse health impacts of traffic. Examples of successful countries are Sweden and The Netherlands with reductions in road deaths of 70% and 82%, respectively, between 1970 and 2006 versus only 43% in the United States. In 2006 the number of road deaths per 100,000 population was over three times as high in the United States as in Sweden and The Netherlands (5.0 in Sweden, 4.4 in The

Netherlands, and 15.4 in the United States; Organisation for Economic Co-ordination and Development (OECD), 2018).

Interestingly, Sweden and The Netherlands are two countries that were first to base their traffic safety policies on a *systems approach* [e.g., Vision Zero initiated by Sweden and Sustainable Safety in The Netherlands (Koornstra et al., 2002, PIARC, 2012)]. A systems approach is based on an ethical position in which it is unacceptable to have people seriously injured or killed on the transport network, and where transport professionals are given clearly defined responsibility for designing the road system on the basis of actual human capabilities. As such, the transport infrastructure design is inherently conceived to drastically reduce crash risk. Sweden and The Netherlands have among the lowest number of cyclist deaths per kilometer cycled in the world (Schepers et al., 2015). The Dutch cyclist fatality rate per kilometer cycled is about five times lower than in the United States (Pucher and Buehler, 2008). This is due in part to a dense Dutch motorway network that excludes cyclists and accommodates for about half of all motor vehicle kilometers in The Netherlands. On the other end of the road hierarchy, there are large traffic calmed areas where cyclist and pedestrian exposure to high-speed motor vehicles, traffic-related air pollution, and noise is reduced (Schepers et al., 2013). In its turn, a high volume of cyclists and pedestrians further helps to reduce crash risk due to heightened awareness by motor vehicle drivers to cyclists and pedestrians, the so-called safety in numbers effect (Jacobsen, 2003; Elvik, 2009; Schepers and Heinen, 2013).

While countries such as The Netherlands and Sweden were successful in safeguarding vulnerable road users from motorized transport due to these measures, metropolitan areas built on a combination of transit and walking seem relatively safe as well and could mitigate traffic-related environmental exposures. For comparison, the four largest Dutch cities, Amsterdam, The Hague, Rotterdam, and Utrecht (all with a very high bicycle modal share by international standards), had 2.0 recorded road deaths per 100,000 people between 2010 and 2014 (SWOV, 2016). Cities centered around mass transit such as Hong Kong and Paris had between 1.5 and 1.6 road deaths per 100,000 people in the same period (Transport Department Hong Kong, 2016; Préfecture de Police, 2013). Excluding walking, modal share of public transport accounts for 80% in Hong Kong and 65% in Paris (Sun et al., 2014).

Although MVCs have often received the most attention as a negative impact of motorized traffic, there are nowadays many more pathways and impacts that are recognized, as was mentioned previously, including effects of (Table 1.1 and Fig. 1.1) the following:

1. green space and aesthetics
2. PA
3. access
4. mobility independence
5. contamination
6. social exclusion
7. noise
8. UHIs
9. vehicle crashes
10. air pollution
11. community severance
12. electromagnetic fields (EMFs)
13. stress
14. GHG emissions

All these pathways (or factors) have been associated with a wide variety of adverse health impacts, including premature death, cardiovascular and respiratory disease, cancer, cognitive decline, and adverse birth outcomes, and will be discussed in more detail in Table 1.1 and the rest of this book.

## Land use, transport, and health

It is now well recognized that there is a relationship between land use, transport, and health, and to change transport and health, one has to change land use (Fig. 1.2). Land use can be described in terms of the five Ds: density, diversity, design, destination accessibility, and distance to transit (Ewing and Cervero, 2010). Higher population and development density often leads to shorter travel distances because destinations become closer to origins. Shorter distances are easier and more convenient to walk or cycle and this may reduce the use of the private car (Grasser et al., 2013; Wang et al., 2016). Destination accessibility is a measure of how accessible places are, whereas distance to transit expresses the shortest distance to a bus stop or railway station. When the destination accessibility is higher and the distance to public transport is shorter, the use of public and active transportation may be encouraged (Wang et al., 2016). Design

**Table 1.1** Transportation-health pathways and 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 UHIs, 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). In addition, | • 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 |

(*Continued*)

**Table 1.1** (Continued)

| | |
|---|---|
| analyzes 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 premature mortality<br>• Decreased risk of obesity<br>• Decreased risk of stroke<br>• Decreased stress |
| 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, PM, 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 |
| 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 | |

(*Continued*)

**Table 1.1** (Continued)

| | |
|---|---|
| *Noise* is motorized vehicle sounds at levels detrimental to health. Noise level is dependent on factors such as 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. UHIs | |
| *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 | • Arrhythmia<br>• Asthma<br>• Cardiorespiratory disease<br>• Cardiovascular disease<br>• Cerebrovascular disease<br>• COPD<br>• Diabetes<br>• Heat stress<br>• Hospitalizations<br>• Hypertension<br>• Vehicle crashes |

| | |
|---|---|
| for every 1°C increase in heat wave intensity, there is a 4.5% increase in mortality risk (Anderson and Bell, 2011) | • Premature birth<br>• Respiratory disease<br>• Stroke |
| 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 such as 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 (OECD), 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 |

(*Continued*)

**Table 1.1** (Continued)

| | |
|---|---|
| 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 $PM_{2.5}$ 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<br>• Reduced sperm quality<br>• Respiratory diseases<br>• Respiratory inflammation<br>• Stroke |

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| 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. EMFs | |
| An 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>◦ Cell growth<br>◦ Genes<br>◦ Neural system<br>◦ Immune system<br>◦ Circulatory system<br>◦ Endocrine system<br>• Hindered cognitive development in children<br>• Nerve stimulation<br>• Reproductive complications<br>• Retinal phosphene occurrence |

(*Continued*)

**Table 1.1** (Continued)

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|---|---|
| 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 US driver $1400 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 |
| 14. GHG emissions | |
| *GHG* emissions 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 preglobal 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 and hurricanes, with resultant land loss; damage to buildings, infrastructure, and food supplies, etc. |

*COPD*, Chronic obstructive pulmonary disease; *EMF*, electromagnetic field; *GHG*, greenhouse gas; *PM*, particulate matter; *UHIs*, urban heat islands.
*Source:* From Khreis, H., Glazener, A., Ramani, T., Zietsman, J., Nieuwenhuijsen, M. J., Mindell, J.S., et al., 2019. *Transportation and Health: A Conceptual Model and Literature Review*. College Station, Texas: Center for Advancing Research in Transportation Emissions, Energy, and Health.

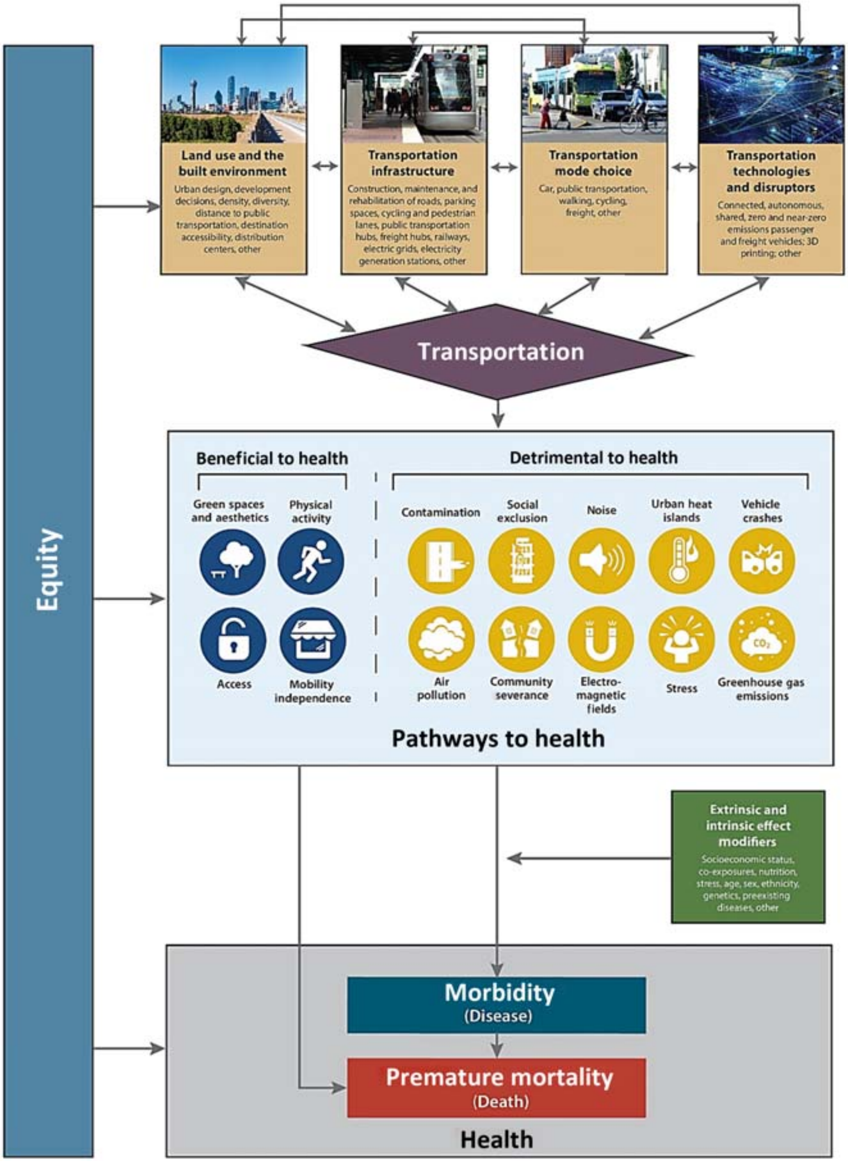


**Figure 1.1** Transportation and health conceptual model. *Source: From Khreis, H., Glazener, A., Ramani, T., Zietsman, J., Nieuwenhuijsen, M. J., Mindell, J.S., et al., 2019.* Transportation and Health: A Conceptual Model and Literature Review. *College Station, Texas: Center for Advancing Research in Transportation Emissions, Energy, and Health.*

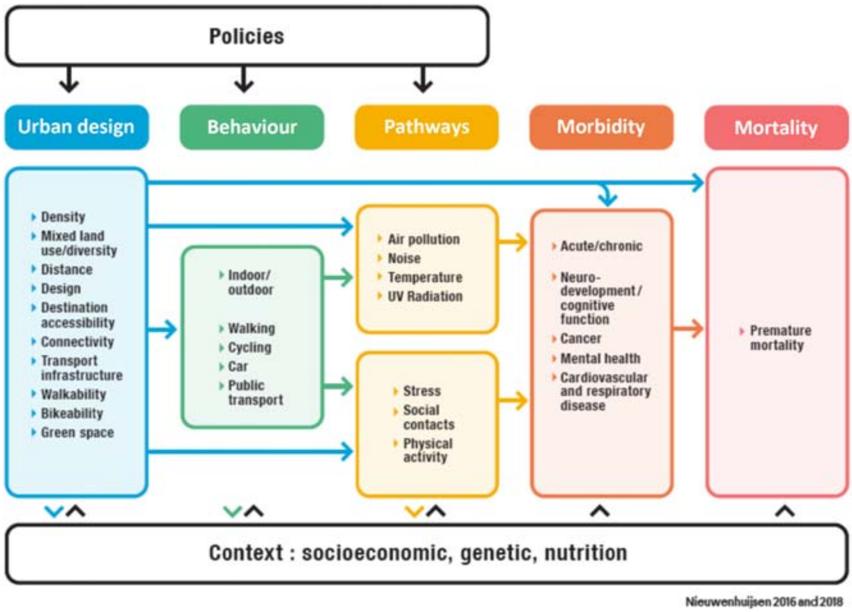


**Figure 1.2** The relationship between urban design, behavior, environmental pathways, and morbidity and mortality.

describes the overall infrastructure and connectivity, and a good design encourages public and active transportation and discourages the use of cars. Diversity is a measure of the land use mix, which is characterized by a mix homes, shops, schools, and work places in an area; greater diversity encourages walking and cycling (Grasser et al., 2013; Wang et al., 2016).

Greater density, diversity, and destination accessibility, better design, and shorter distance to transit are characteristics of the so-called compact cities, an example of which is Barcelona, Spain, where the density, diversity, and destination accessibility are high and distance to transit is short. Conversely, cities such as Atlanta, GA, United States, or Houston, TX, United States are sprawling cities, where the opposite is true. Compact cities have great potential benefits in terms of increased walking, cycling, and public transport use, reduced residential energy consumption, reduced pedestrian and vehicle fatalities, increased PA and reduced obesity, reduced household transportation cost, increased traffic safety, increased sense of community, and increased social interaction and social capital (Ewing and Cervero, 2017).

There is now good evidence that there is a direct relationship between urban design, how people get around, and how this affects environmental exposure and lifestyle factors and morbidity and mortality (Nieuwenhuijsen, 2016, 2018). In a city designed for and with large investment in infrastructure for cars, many people will use the car. This will lead to high air pollution, noise and stress levels, heat island effects, lack of PA, social contacts and green space and to increased, for example, cardiovascular and respiratory morbidity, reduced cognitive functioning and cancer and thereby premature mortality (Nieuwenhuijsen, 2016, 2018). On the other hand, in a city designed for and with large investment in infrastructure for active transportation such as cycling, more people will cycle. This will lead to lower air pollution, noise and stress levels, less heat island effects, more PA, social contacts and green space and to decreased, for example, cardiovascular and respiratory morbidity, better cognitive functioning and less cancer and thereby less premature mortality (Fig. 1.2) (Nieuwenhuijsen, 2016, 2018).

Some ways to improve transport to protect and promote public health are described next.

## Reduce car dependency and move toward public and active transportation

As mentioned before, currently there are around 1 billion cars in the world and this number is likely to rise to 1.6 billion in 2040 (Bloomberg New Energy Finance, 2017). An estimated 33% of cars in 2040 are expected to be electric. Changes in technology have been proposed as solutions to our current problems in cities. For example, the electric car is often portrayed as the solution to the current air pollution and climate change problems in our cities, but it provides only a partial solution. Electric cars may reduce $CO_2$ emissions, tailpipe $NO_2$, and particulate matter (PM) emissions and engine noise, but there are still non-tailpipe PM emissions from tear ware of brakes and tires, noise from tires, occupation of the same amount of space as fossil fuel cars, and no addressing of physical inactivity. The $CO_2$ reductions are also contingent upon the production of clean energy. Unfortunately, fossil fuels are still widely used in electricity generation and the use of coal, for example, constitutes 40% of global electricity generation (Smith et al., 2013). Generally, there is a lack of progress with electricity decarbonization which significantly limits the emission and air quality benefits of electric vehicles (Energy Research Centre, 2016). Finally, the air quality benefits of electric vehicles have also been under scrutiny. A state-of-the-art review by Timmers and Achten (2016) investigated the effects of fleet electrification on nonexhaust PM emissions and found that total $PM_{10}$ emissions from electric vehicles—originating from power plant emissions—are likely to be higher than their nonelectric counterparts, while the reduction in $PM_{2.5}$ emissions from electric vehicles is estimated to be negligible (1%–3%), partly due to increased weight related to accommodating the vehicles' battery.

Autonomous vehicles have also been suggested as a future solution and predictions suggest a quick and extensive market penetration (LexInnova, 2016), but it is currently unclear to what lifestyle and behavioral changes autonomous vehicles may lead. They may reduce accidents, as 90% of accidents are due to human error. If they are shared, they could lead to a large reduction of vehicles on the road and parked vehicles. However, people may choose to live further away from work, if, for example, they can work on their commute to work, which means that this technology may increase the total number of kilometers driven and lead to urban sprawl. They may also pull people from active and public transport modes, if the cost of trips is low. Although controversial, both autonomous and electric vehicles may increase EMFs in urban areas, human exposure, and associated adverse health effects. On the other side, electric-shared autonomous vehicles could be beneficial for public health, if the number and types of current vehicle trips would stay the same, but the number of vehicles was to be reduced.

A large number of car trips are less than 5 km (as high as 50%) and these could easily be replaced by other modes of transport such as cycling (Khreis et al., 2016). Cycling has many advantages as it reduces, for example, premature mortality, it combines transport with the gym, it does not cause air and noise pollution, it emits zero $CO_2$ and air pollution, it uses much less space than the car and cyclists tend to be happier than other transport users (Mueller et al., 2015; Götschi et al., 2016; ISGlobal, 2019). Countless studies have also shown that the health benefits of PA well outweigh the risk of increased inhalation of air pollution due to increased PA and of fatal accidents (Mueller et al., 2015). Also, cost benefit analyzes (CBAs) show that the costs of cycling are generally much lower than car use; for example, the cost of car driving is more than six times higher (Euro 0.50/km) than cycling (Euro 0.08/km) in Copenhagen (Gössling and Choi, 2015). New technologies such as bike sharing systems have greatly increased the number of cycling trips and improved health in the cities where they were introduced (Otero et al., 2018). Similarly, electric bikes allow for longer distance cycling rides and rides uphill, which otherwise would not have been possible, especially in subpopulations such as the elderly or disabled (Bourne et al., 2018).

An important prerequisite for cycling, though, is the availability of safe cycling infrastructure, including segregated cycling lanes. A recent large European study in 168 cities (75 million people) found that there was an almost linear relationship between the availability of segregated cycling infrastructure and the percentage cycling as total number trips increase to 25% of transport mode share (Mueller et al., 2018) (Fig. 1.3). Over 25% of transport mode share, there was no relationship anymore and other factors may become more important. The authors also estimated that just over 10,000 premature deaths could be prevented in these 168 cities, if they all had a 25% transport mode share of cycling.

Other studies have evaluated specific transport policy measures in cities. Woodcock et al. (2009) estimated the health impacts of alternative urban land transport scenarios for two settings: London, the United

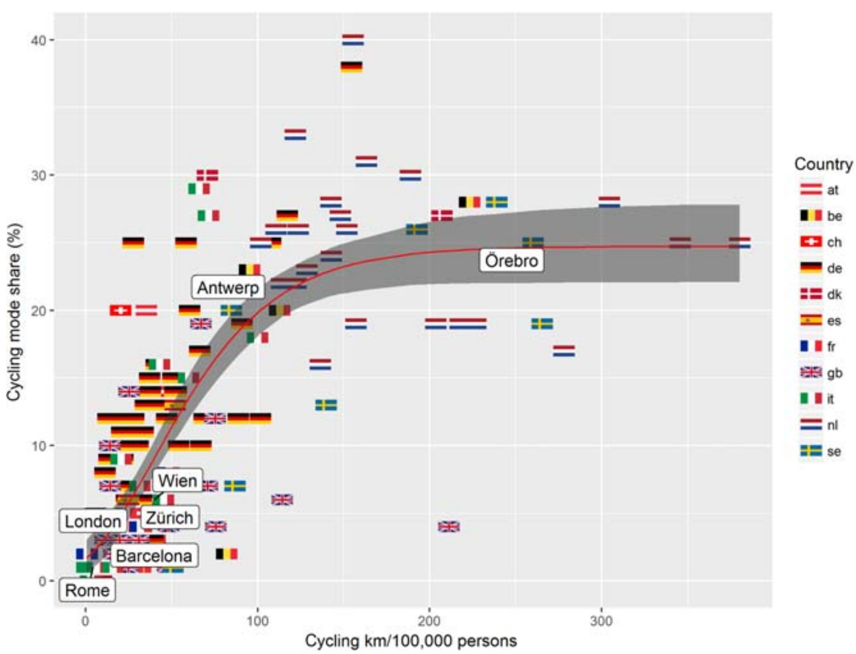


**Figure 1.3** Cycling infrastructure provision against mode share of cycling in Europe. *Mueller, N., Rojas-Rueda, D., Salmon, M., Martinez, D., Ambros, A., Brand, C., et al., 2018. Health impact assessment of cycling network expansions in European cities. Prev. Med. 109, 62–70. pii: S0091-7435(17)30497-8*

Kingdom, and Delhi, India. The authors found that a combination of active travel and lower-emission motor vehicles would give the largest benefits [7439 prevented disability adjusted life years (DALYs) in London and 12,995 in Delhi].

Although less new technology is being introduced, public transport also provides many environmental, climate change, and health benefits and could cover longer journeys that cannot be covered by cycling (Kwan and Hashim, 2016). Therefore a general shift away from car use toward active and public transportation can have significant environmental, climate change, health, and economic benefits (Creutzig et al., 2012; Rojas-Rueda et al., 2012, 2013).

There is a substantial urban and transport literature on how to implement urban transport policy measures and what the likely effects on health will be. For example, Khreis et al. (2017) qualitatively reviewed 64 different transport policy measures indexed in the Knowledgebase on Sustainable Urban Land use and Transport and provided an indication of their potential health impacts, based on expert judgment via pathways of MVCs, traffic-related air pollution, noise, heat islands, lack of green space, physical inactivity, climate change, social exclusion, and community severance. Further reviews overview the effect of, for example, vehicle technologies, emission reduction, low emission zones on health (Glazener and Khreis, 2019). An aspect which has been addressed less above, but which has been successful, is the use of legal instruments to make changes and, for example, reduce air pollution in cities via the introduction of euro emission standards (Kuklinska et al., 2015; Glazener and Khreis, 2019).

## Land use changes

More compact cities may reduce the dependency on cars and increase public and active transportation. Stevenson et al. (2016) modeled land use changes to reflect a compact city in which land-use density and diversity were increased and distances to public transport were reduced to produce low motorized mobility, namely, a modal shift from private motor vehicles to walking, cycling, and public transport. The modeled compact city scenario resulted in health gains for all cities (for diabetes, cardiovascular disease, and respiratory disease) with overall health gains of 420–826 DALYs per 100,000 population. However, for moderate to highly motorized cities, such as Melbourne, London, and Boston, the compact city scenario predicted a small increase in road trauma for cyclists and pedestrians (health loss between 34 and 41 DALYs per 100,000 population). The findings suggested that government policies need to actively pursue land-use elements, with a particular focus toward compact cities, to support a modal shift away from private motor vehicles toward walking, cycling, and low-emission public transport. And that at the same time, these policies need to ensure the provision of safe walking and cycling infrastructure.

The Barcelona Superblock model is an innovative urban and transport planning strategy that aims to reclaim public space for people, reduce motorized transport, promote sustainable mobility and active lifestyles, provide urban greening, and mitigate effects of climate change. It cuts through traffic in a grid system by assigning junctions to other activities (Fig. 1.4) (Rueda, 2018). Mueller et al. (2019) estimated the health impacts of implementing this urban model across Barcelona. They (1) estimated expected changes in (a) transport-related PA, (b) air pollution ($NO_2$), (c) road traffic noise, (d) green space, and (e) reduction of the UHI effect through heat reductions; (2) scaled available risk estimates; and (3) calculated attributable health impact fractions. They found that 667 premature deaths (95% confidence interval (CI): 235−1098) could be prevented annually through implementing the 503 Superblocks across Barcelona. The greatest number of preventable deaths could be attributed

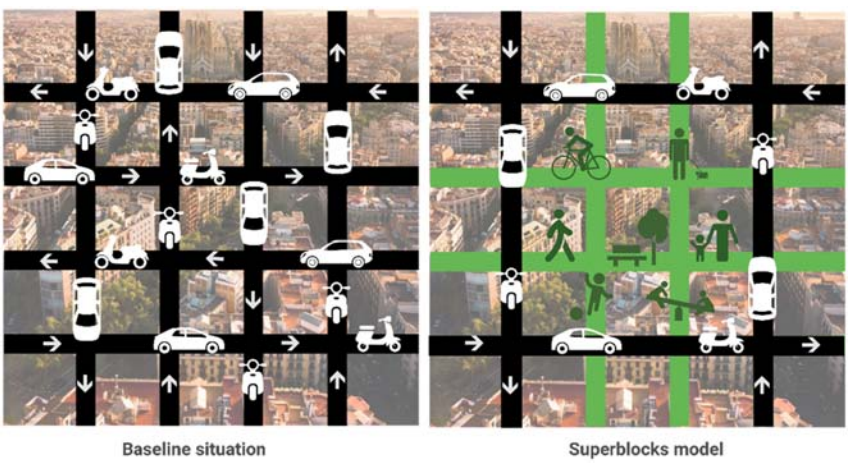


**Figure 1.4** The Super block model—before and after. *Mueller, N., Rojas-Rueda, D., Khreis, H., Cirach, M., Andrés, D., Ballester, J., et al., 2019. Changing the urban design of cities for health: the superblock model. Environ. Int. 134, 105132*

to reductions in $NO_2$ (291, 95% CI: 0−838), followed by noise (163, 95% CI: 83−246), heat (117, 95% CI: 101−137), and green space development (60, 95% CI: 0−119). Increased PA for an estimated 65,000 persons shifting car/motorcycle trips to public and active transport resulted in 36 preventable deaths (95% CI: 26−50). The Superblocks were estimated to result in an average increase in life expectancy for the Barcelona adult population of almost 200 days (95% CI: 99−297), and result in an annual economic impact of 1.7 billion EUR (95% CI: 0.6−2.8).

## Policy assessment changes

Finally, a key driver for policy favoring car use is the nature of the investment appraisal instruments that transport planning and policy typically employs. These instruments are produced with a great focus on economic appraisal and an emphasis on the CBA method as the most reliable and most used instrument to determine whether a certain transport project is better than another. The CBA method attempts to quantify effects expected from a transport project and assign those a monetary value to include in the overall economic appraisal of the total value of the project in monetary terms. Monetized items include changes in travel times and related consumers' surplus, changes in employment and business activity and earnings, accidents, carbon emissions, and noise impacts, and are input for a partial CBA to estimate a benefit-to-cost ratio (Geurs et al., 2009). As such, CBA and similar instruments *attempt* to measure all the aspects of new transport projects in terms of financial gains or costs to society.

Despite having provided a powerful and practical mean to assess investments based on a strong welfare economics perspective, the logic behind these tools could be argued as flawed at its fundamental level (not everything can be or should be equated to money), while at its practical and technical level, there are also substantial issues regarding which of the impacts associated with transport actually make it into the appraisal (practitioners with a solely engineering and/or economical education might be incapable of capturing the whole complexity of possible societal impacts of a transport planning scheme). For example, the PA benefits of more sustainable modes of transport such as walking and cycling are currently overlooked in some CBAs and it is only a few years ago that experts started thinking about including health benefits of more cycling and walking in CBAs. Therefore a key point needs to be addressed in that the use of CBA and similar tools is currently not accounting for the full range of short- and long-term health impacts that are, however, as we show, a major contemporary societal issue. This feasibly often results in positive evaluation of transport development schemes that would otherwise fail in their economic appraisal and suggests that the costs incurred due to current practices and policies are very likely to be higher than previously imagined. Taking inspiration from the examples mentioned before, it may also be time to consider the possibility, as partially practiced in The Netherlands and the Swedish context, to submit CBAs and other appraisal tools to certain fundamental ethical principles, for example, considering adverse health impacts unacceptable.

This book brings together a large number of transport and health experts that described in more details the issues discussed here and also expand to other areas. The second chapter describes the well-recognized issue of road traffic injuries and this is followed by chapters on transport and air pollution, noise, PA, and health and chapters around community severance and inequalities. Following these chapters, there are a number of chapters focusing on new technologies in transport, bike-sharing systems, electric bikes and active school commuting, and health as these are important and have emerged as important issues over the recent years. The next section of chapters focuses on tools and designs, including novel intervention studies, health impact assessment tools, and community and street designs. The final section deals with policies and education, including the carriers and facilitators of policy changes, how to move forward and the educational requirements and provisions. The last chapter provides a general overview.

## Conclusion

Transport and health are strongly connected. Current transport systems bring not only large economic benefits but also large negative impacts on health. The negative impacts are partly due to strong car dependency in many cities in the world that could be mitigated by a move toward public and active transportation options. Changes in urban planning and land use may be essential to make this possible. In the rest of this book, there will be a more in-depth discussion of the different aspects of transport and health, and how we can achieve changes aimed at protecting and promoting public health.

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PART II

# Transport and effects on health

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CHAPTER TWO

# Perspectives on road safety through the lens of traffic crashes in the United States

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## Contents



## Traffic crash fatalities: a global comparison

Traffic crashes are one of the leading causes of preventable death in the world and the leading cause of death for children and young adults (World Health Organization (WHO), 2018). In the United States, approximately 24% of all fatal injuries are due to traffic crashes. The proportion in the United States is higher than Australia, Canada, and the Western European countries. Table 2.1 illustrates this point and displays

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**Table 2.1** Percent of all fatal injuries that are traffic-related and the traffic fatality rate per 100,000 population for selected countries.

| Country | Proportion of all fatal injury that is traffic related (2016) (%)[a] | Traffic fatality rate per 100,000 population (2016)[b] |
|---|---|---|
| Indonesia | 42 | 12.2 |
| China | 37 | 18.2 |
| South Africa | 34 | 25.9 |
| Brazil | 29 | 19.7 |
| Mexico | 25 | 13.1 |
| **United States** | **24** | **12.4** |
| Nigeria | 24 | 21.4 |
| India | 23 | 22.6 |
| South Korea | 21 | 9.8 |
| Poland | 19 | 9.7 |
| Australia | 18 | 5.6 |
| Canada | 16 | 5.8 |
| Russia | 16 | 18.0 |
| United Kingdom | 14 | 3.1 |
| Germany | 13 | 4.1 |
| France | 11 | 5.5 |
| Japan | 11 | 4.1 |
| Sweden | 9 | 2.8 |

[a]Data source: Institute for Health Metrics and Evaluation (2019).
[b]Data source: World Health Organization (WHO) (2018).

the proportion of all fatal injuries that are related to traffic crashes for 18 countries in 2016. The proportions range from 9% to 42%. The United States' value (24%) is approximately in the upper third of this range. France, Germany, Japan, the United Kingdom, and Sweden all have percentages that are substantially lower than the United States. Countries with values above the United States include Indonesia, China, South Africa, Brazil, and Mexico. Countries with lowest values include the United Kingdom, Germany, France, Japan, and Sweden. Table 2.1 also presents the traffic fatality rates for the same countries in 2016. The rates range from 2.8 per 100,000 population to 25.9 per 100,000 population with the rate (12.4 per 100,000 population) for the United States being approximately in the middle. The countries with rates exceeding the United States include South Africa, India, Nigeria, Brazil, China, Russia, and Mexico. The countries with the lowest rates are the same as those observed for the proportion values.

## Traffic crash trends in the United States

In the United States the frequency of fatalities has varied considerably over time. Fig. 2.1 depicts the number of traffic crash deaths since the year 2000, based on data from the Fatality Analysis Reporting System (FARS) (National Highway Traffic Safety Administration (NHTSA), 2019a). Unless otherwise noted, the remaining figures in the chapter are based on data from FARS. In general, traffic fatalities rose from 2000 until 2005 to a level of 43,510 annual deaths. Since 2005 the number of fatalities began to decline until 2014 when annual fatalities fell to 32,675, a decrease of over 30%. Then fatalities began to rise again to a level of 37,678 in 2016. More recently in 2017 and 2018, fatalities are again declining and now stand approximately 20% lower than the peak in 2005.

Historically, rural traffic fatalities have exceeded urban traffic fatalities in the United States. However, between 2015 and 2016, this reversed, and since that time rural fatalities have declined and urban fatalities have remained relatively constant, as shown in Fig. 2.2. In fact, the decrease in deaths since 2005 has occurred primarily in rural areas.

The number of traffic fatalities over time in the United States also differs by the number of vehicles involved in the crash. Changes over time are illustrated in Fig. 2.3, which depicts the number of fatalities by single versus multivehicle crashes. Crashes involving only a single vehicle by

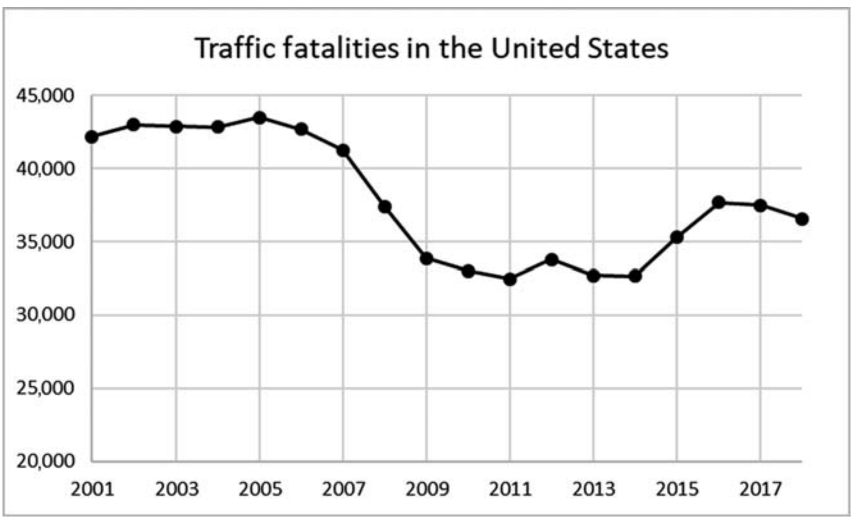


**Figure 2.1** Frequency of traffic fatalities in the United States from 2001 to 2018.

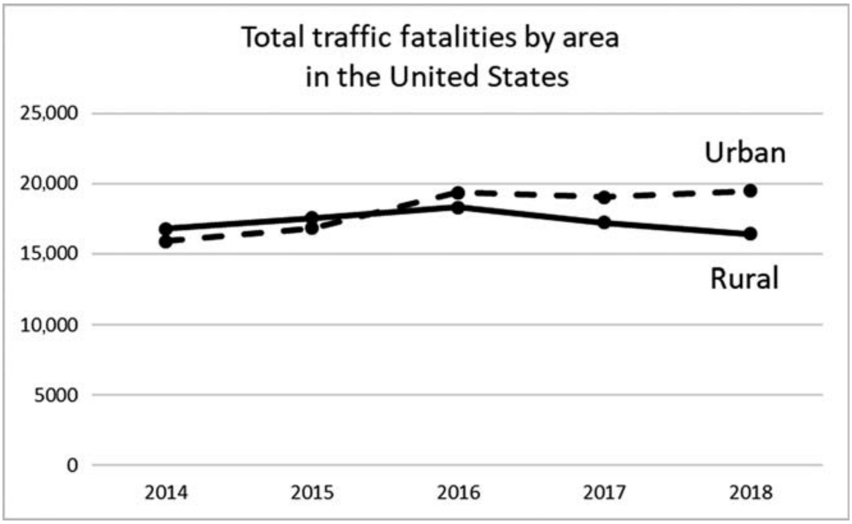


**Figure 2.2** Rural and urban traffic fatalities in the United States, 2014–18.

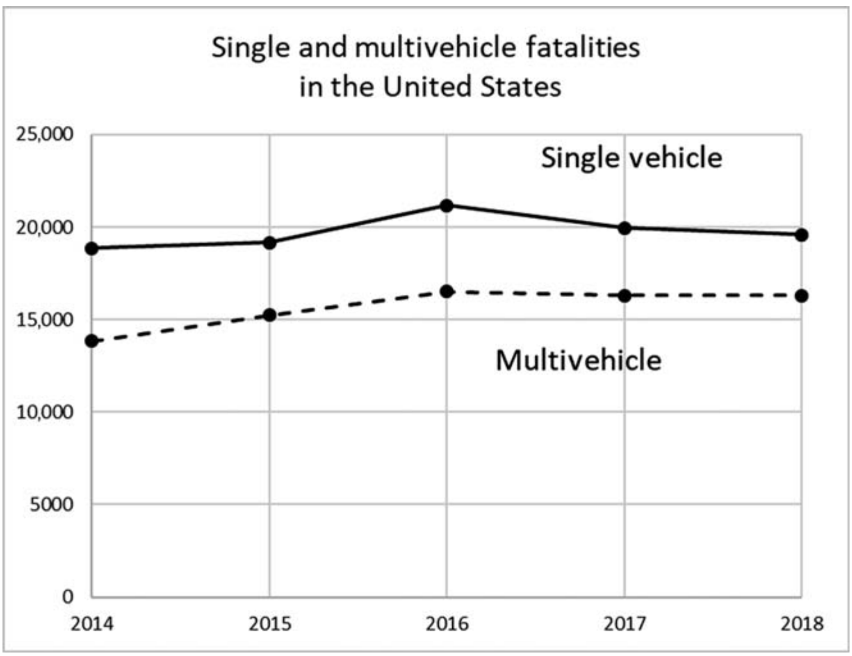


**Figure 2.3** Traffic fatalities due to single and multivehicle crashes in the United States, 2014–18.

itself or that involved striking only a pedestrian or bicyclist are classified as single vehicle crashes. Single vehicle crashes and fatalities have risen and fallen during the period from 2014 to 2018, and about 700 more people died in single vehicle crashes in 2018 than 2019. In contrast, fatalities due to multivehicle crashes have risen substantially over this period, and almost 2500 more people died in multivehicle crashes in 2018 than 2014.

Fig. 2.4 depicts the trends in single and multivehicle fatalities indexed to the levels in 2014. Indexed values simplify the examination of percent change over time. An indexed value is computed by designating a base year and dividing all other years by the base year. The frequency of crashes in each year is then, "indexed" to the value of the base year. As shown in Fig. 2.4, multivehicle fatalities increased 19% from 2014 to 2016 and have remained at about that level. Single vehicle fatalities increased in 2016, by 12% over the number in 2014, but have since decreased to 4% above the number of fatalities in 2014.

More than half of traffic fatalities in the United States are associated with single vehicle crashes. These crashes include collisions between a motor vehicle and a pedestrian or bicyclist. In 2018 crashes involving pedestrians and bicyclists accounted for nearly a third of all single vehicle crash fatalities, and pedestrian crashes accounted for nearly 90% of the pedestrian and bicyclist fatalities.

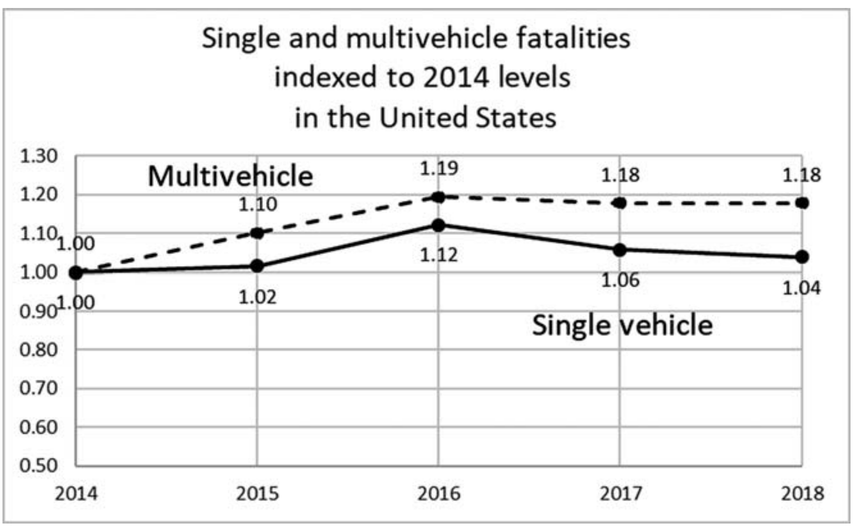


**Figure 2.4** Traffic fatalities due to single and multivehicle crashes indexed to 2014 levels in the United States, 2014–18.

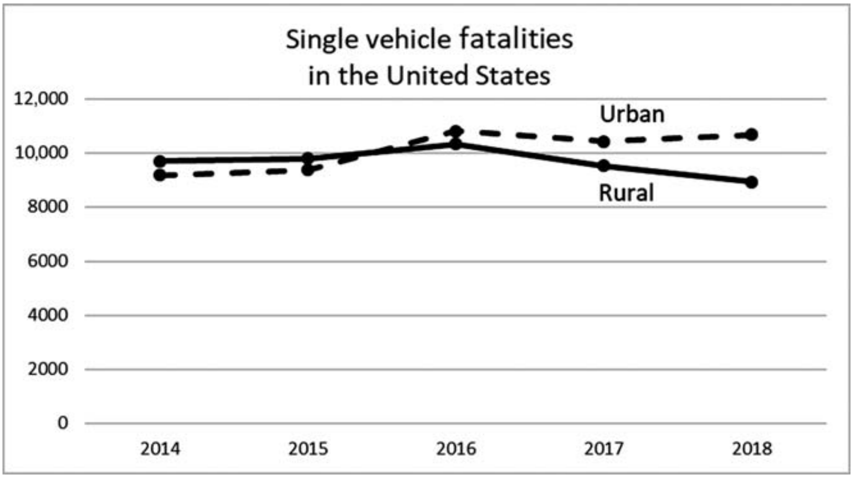


**Figure 2.5** Rural and urban single vehicle fatalities in the United States, 2014–18.

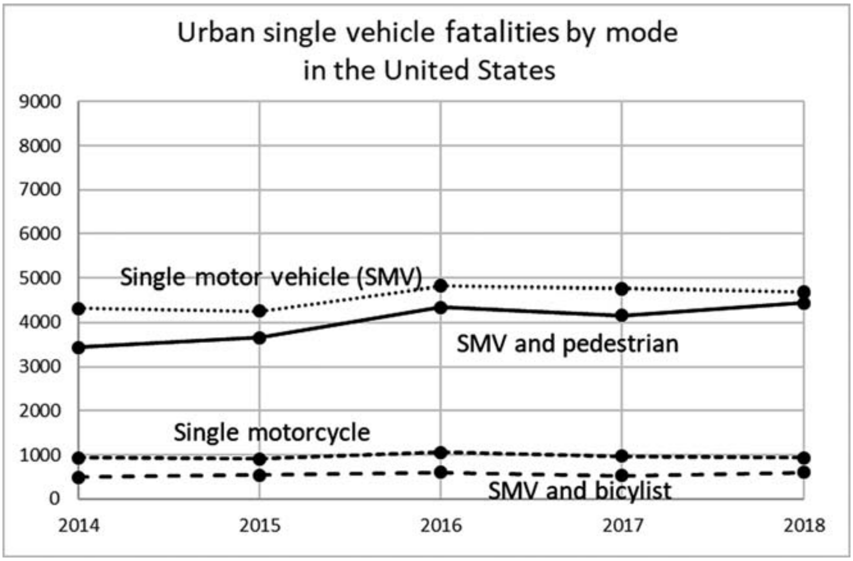


**Figure 2.6** Urban single vehicle fatalities by mode in the United States, 2014–18.

In 2014 there were more single vehicle fatalities in rural areas than urban areas, as shown in Fig. 2.5. Between 2015 and 2016 this relationship changed and since then single vehicle fatalities in urban areas. Single vehicle fatalities in rural areas have declined since 2016.

Fig. 2.6 depicts the trends in urban single vehicle fatalities in the United States since 2014. Separate trends are shown for crashes that

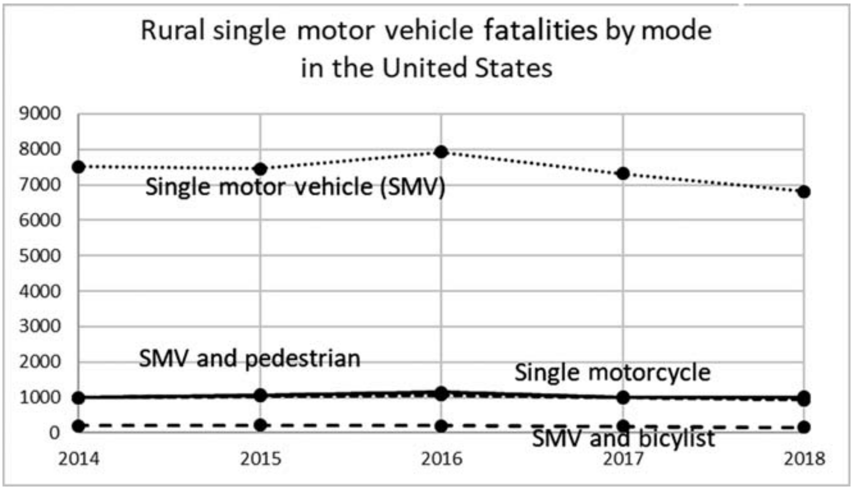


**Figure 2.7** Rural single vehicle fatalities by mode in the United States, 2014–18.

involve a single vehicle, a single motorcycle, and those where a single vehicle struck a pedestrian or bicyclist. Fig. 2.7 depicts the same information for rural single vehicle crashes.

Rural single vehicle fatalities have declined over this period, while rural single motorcyclist fatalities and bicycle and pedestrian fatalities have stayed fairly constant. The number of motorcyclist and pedestrian fatalities are about equal in rural areas. In contrast, single vehicle fatalities with pedestrians have increased significantly in urban areas, but single motorcycle and bicycle fatalities are fairly stable.

### *Fatal crashes involving single motor vehicles*

Crashes involving more than one motor vehicle accounted for between 42% and 45% of all fatalities in the United States from 2014 to 2018. The overall trend in urban and rural multivehicle fatalities is shown in Fig. 2.8. Urban fatalities involving more than one motor vehicle rose about 30% during this time while rural fatal crashes rose until 2016, and then fell to a level just 5% more than in 2014.

Fig. 2.9 provides a breakdown of fatalities involving more than one vehicle. Fatalities due to multivehicle crashes have risen about 30% over this period. Multivehicle fatalities which include a motorcycle are up about 25% but have remained fairly constant from 2016 to 2018. Multivehicle fatalities that also involve a bicyclist or pedestrian make up about 6% of all multivehicle fatalities.

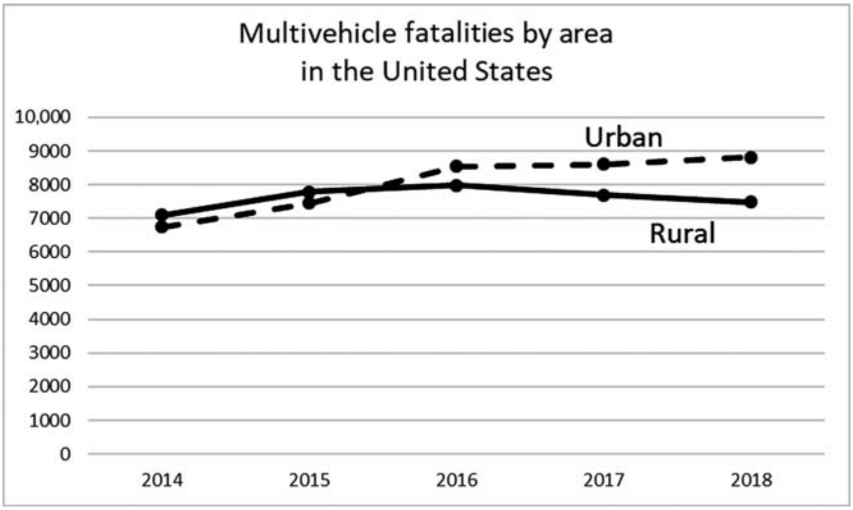


**Figure 2.8** Multivehicle traffic fatalities in rural and urban areas in the United States, 2014–18.

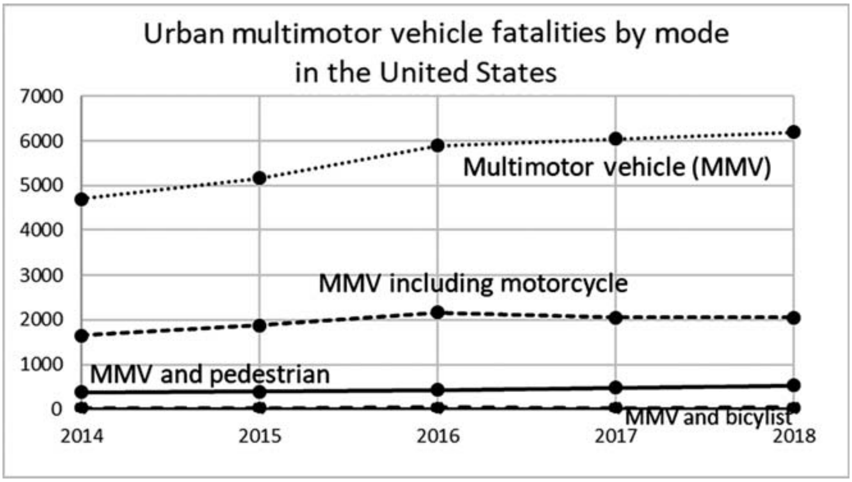


**Figure 2.9** Urban multivehicle fatalities by mode in the United States, 2014–18.

### *Pedestrian and bicycle fatalities*

Fig. 2.10 depicts the trends in pedestrian and bicyclist fatalities stemming from a crash with a motor vehicle. Bicycle fatalities have ranged between 700 and 850, annually from 2014 to 2018, without any dramatic increases or decreases. Using the Federal Highway Administration's Scalable Risk

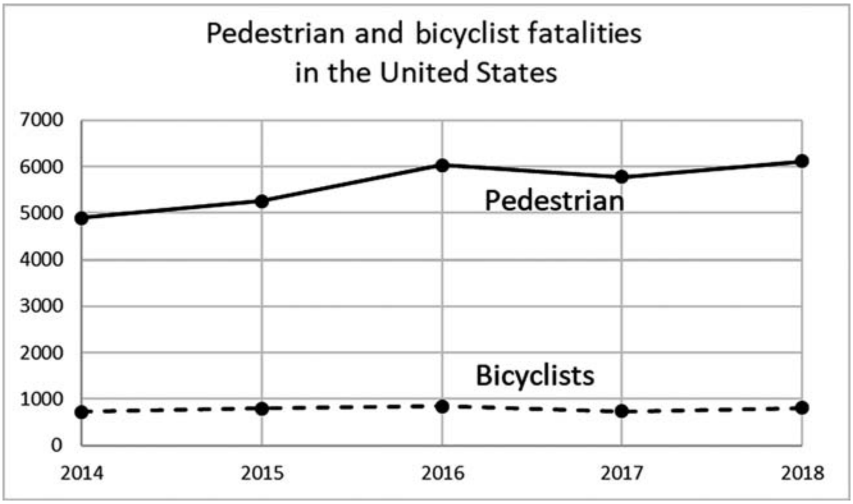


**Figure 2.10** Pedestrian and bicyclist fatalities in the United States, 2014–18.

Assessment tool for pedestrian and bicycles (Federal Highway Administration (FHWA), 2018a) and data from the United States Census Bureau American Community Survey (United States Census Bureau US Census Bureau, 2019), we estimate that bicycle travel in the United States decreased by 3.5% from 2013 to 2017.

In contrast to the numbers for bicyclists, pedestrian fatalities rose 25% to more than 6000 annually with most of the increase occurring between 2014 and 2016. Urban motor vehicle travel increased by far less, about 7% during this period. At the same time, 4.5% increase in walking was estimated between 2013 and 2017. An examination of Fig. 2.11 reveals that the growth in pedestrian fatalities are concentrated in urban areas. Urban pedestrian fatalities make up more than 80% of the pedestrian total. In 2014 pedestrian fatalities comprised 15% of all traffic fatalities. By 2018 that percentage rose to 17%. In addition, the majority of pedestrian fatalities occur during periods of darkness and that percentage is increasing. In 2014 72% of pedestrian fatalities occurred in the dark compared to 76% in 2018 (data not shown).

### *Motorcyclist fatalities*

Motorcyclist fatalities comprise 14% of total traffic fatalities in the United States. Fig. 2.12 depicts the trends in rural, urban and total motorcycle fatalities from 2014 to 2018. Approximately 61% of motorcyclist fatalities

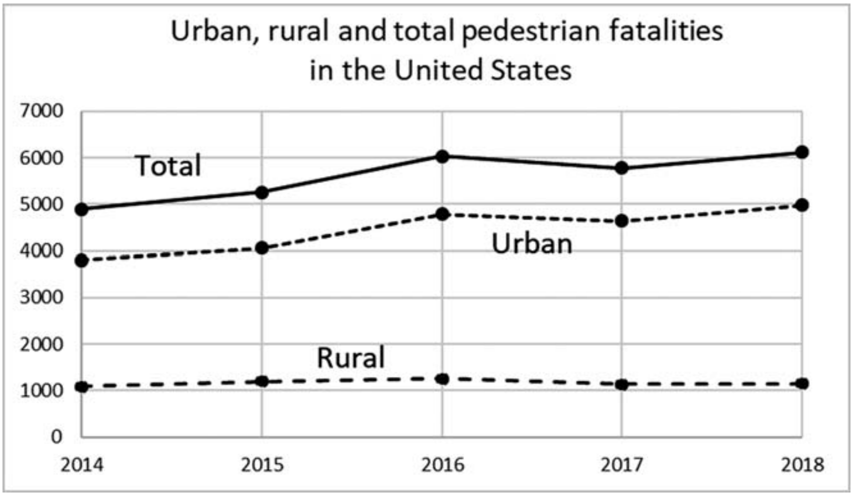


**Figure 2.11** Pedestrian and bicyclist fatalities in urban and rural areas in the United States, 2014–18.

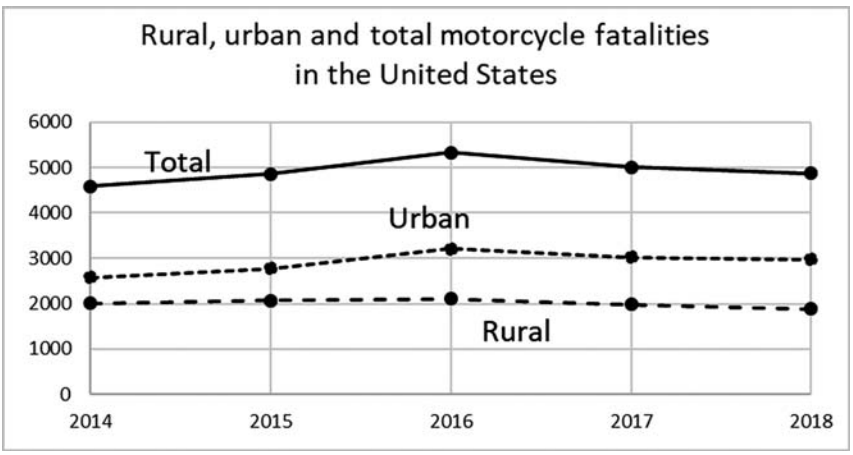


**Figure 2.12** Motorcyclist fatalities in urban and rural areas in the United States, 2014–18.

in 2018 occurred in urban areas, and that percentage has risen steadily from 56% in 2014. Urban motorcyclist fatalities have risen 16% in this period, but rural motorcyclist fatalities have decreased by about 6%. About 40% of motorcyclists die in traffic crashes involving a single motorcycle. These crashes are equally divided between rural and urban settings.

## Summary of key traffic safety trends in the United States

The preceding overview of traffic safety in the United States illustrates the complex and multidimensional nature of the issue. Notwithstanding the complexity of the matter, several trends stand out. The difference between urban and rural crashes is changing. Clearly, fatalities in urban areas are increasing, while rural fatalities are declining. Urban fatalities outnumber rural fatalities and have since 2016. The gap is widening. Equally clear, single motor vehicle crashes in rural areas are declining, while single vehicle crashes in urban areas are now stable after an initial increase. Finally, multiple vehicle crashes in urban areas are rising with numbers now 30% higher than in 2014. Looking beyond motor vehicle only crashes, but retaining the urban versus rural distinction, fatal crashes involving pedestrians increased 25% from 2014 to 2018. This increase has been primarily in urban areas. Regarding trends in motorcyclist fatalities, there has been a 6% increase in fatalities since 2014. Motorcyclist fatalities in rural areas have decreased while the number of urban fatalities grew substantially.

## The impact of risk and exposure on traffic crash frequency

In addition to understanding the magnitude or number of traffic fatalities, it is also important to consider the amount of exposure users have to the roadway. Traffic fatalities occur as a function of risk and exposure. Exposure is a measure of the amount of travel, expressed as a combination of the cumulative number of trips and distance traveled. Examples are vehicle-miles and person-miles. Risk is the probability or likelihood that a crash, injury or fatality occurs per unit of travel. This exposure and risk paradigm is similar to that of a communicable disease, such as the flu, where the likelihood that a person gets the flu is related to the number of people with the flu they are exposed to, and their individual susceptibility to contracting the flu.

Just as this susceptibility to contracting the flu differs by individual, the risk of being involved in a crash, and the likely severity of that crash, also varies among individuals. Generally speaking, males have a higher risk of sustaining a fatal injury due to a crash than females and younger people have greater risk than older ones (Insurance Institute for Highway Safety Highway Loss Data Institute (IIHS HLDI), 2018). Risk also varies by the location of travel. Urban travel on a vehicular mile basis is less risky from an injury standpoint than rural travel. In 2018 the fatality rate per vehicle-mile of travel on rural roads was almost twice that of urban roadways (Federal Highway Administration (FHWA), 2018b). Freeways have the lowest fatality rates (Federal Highway Administration (FHWA), 2018b). Four-lane divided rural roadways present less risky travel than two-lane rural roadways based on the safety performance of each type of roadway in the Highway Safety Manual (AASHTO, 2010).

The role of risk and exposure in traffic fatalities was explored in a recently published study of factors related to the decline in fatalities in the United States from 2006 to 2012 (Blower et al., 2019). Fatalities in the United States fell by 25%. The researchers examined how exposure and risk had varied during this period, which coincided with the "great recession" in the United States. They found that only a small portion of the decrease in fatalities could be explained by the reduction in travel, as measured by vehicle miles. They concluded that the decrease was associated with reductions in risk.

The researchers explored the roles of four major categories of factors—safety regulations, roadway and safety spending, vehicle safety and economic factors and their effect on fatality risk over this period. Because the levels of these factors varied over this time, the researchers constructed three statistical models to determine the degree of association changes in the values of these factors had with the decrease in fatalities. Each of the 50 states was considered separately in these models.

Safety regulations, in the form of belt use rates, motorcycle helmet laws, and impaired driving statutes accounted for about 2%–3% of the change. Because capital spending and safety program and project spending did not vary substantially during this time, no effect could be attributed to them. Vehicle safety improvements, as measured by penetration of model year 1991 or greater in the vehicle fleet, accounted for 12% or 13% of the reduction. Economic factors, such as gross domestic product per capita, fuel price, median income, unemployment of 16–24 years old, and alcohol consumption were associated with 85% of the reduction. The most significant factors were the reductions in median household income and gross domestic product per capita and the increase in young adult unemployment, which accounted for about 60% of the reduction alone (Blower et al., 2019).

The researchers postulate that, "the short-term shock of the recession that drove up unemployment, particularly among teens and young adults, and declining median income that likely reduced driving and risky driving among high-risk populations." (Blower et al., 2019).

Vehicle crashes are related to the number of motor vehicle miles traveled, and pedestrian or bicycle crashes with motor vehicles are related both the number of motor vehicle miles traveled and the person or cyclist miles traveled. Regardless of the combinations, to reduce the number of traffic fatalities, either exposure (travel) must be reduced, or risk must be reduced; either through individual driver risk reductions or changing travel to lower risk modes or locations. Four elements greatly affect risk: infrastructure, weather, behavior, and vehicles. Most efforts to reduce traffic injury and fatalities involve attempts to reduce risk, either by improving infrastructure that is engineered to reduce risk, reducing high-risk behavior, or by improving vehicle design and adding technology that reduces risk.

## Infrastructure risk reduction

Traditionally, decisions about the physical and operational characteristics of roadways were based on the concept of nominal safety, in which a standard, warrant or guideline, establishes a minimum or desirable value for a parameter. As long as that parameter was met, the roadway was deemed "safe." However, it was clear that all roads did not have the same safety performance, even if they met the standard, warrant or guideline. During the past 20 years a new approach to roadway safety has developed, termed substantive safety, where the safety performance of a roadway is based on the number and severity of crashes. As part of this new approach, the relationship between exposure and specific roadway characteristics, called safety performance functions were developed. These safety performance functions also provide a benchmark for determining if a roadway has a higher risk, or greater opportunity for safety improvement, than roadways with similar characteristics. This in turn led to a new way, using the substantive safety approach, to determine locations where the application of safety countermeasures could improve safety. Prior to this approach, candidate locations were often chosen based solely on the highest number of crashes, or perhaps on the highest crash rate per unit of exposure (i.e., risk). However, low exposure locations often have high risk levels and risk does not necessarily have a linear relationship with

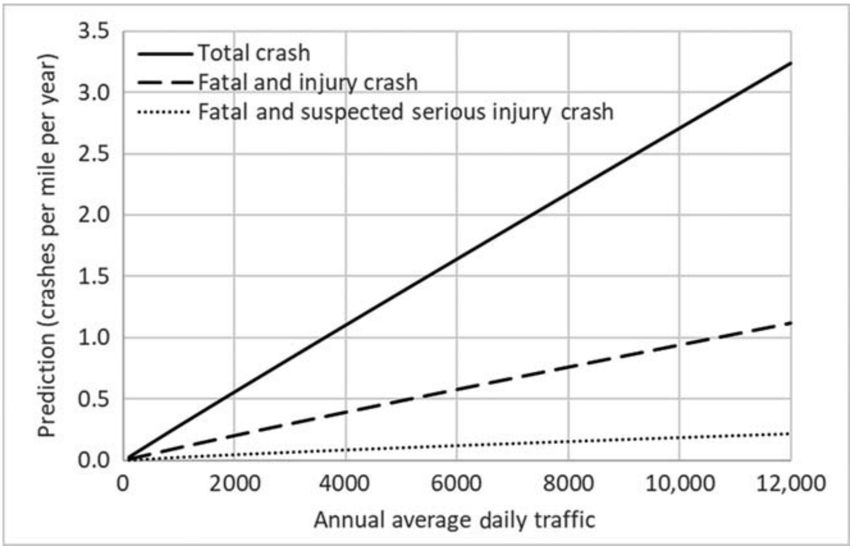


**Figure 2.13** Predicted number of crashes on rural two-lane highways. *Adapted from Wunderlich, R., Dixon, K., Wu, L., Geedipally S., Shipp, E., 2019. Data-driven safety analysis: a user guide. Product 5-9052-01-P1. A Data-Driven Safety Analysis (DDSA) Framework for the Beaumont District. TxDOT Project 5-9052-01. Texas Department of Transportation, Austin, TX.*

exposure. Such analyzes may suffer from regression-to-the-mean effects. The current approach is based on calculating the number of crashes for a segment or intersection based on exposure and definable characteristics. Fig. 2.13 depicts a simple relationship between crashes and exposure by crash severity for rural two-lane roadways in southeastern Texas. These relationships can be used to determine if a segment or intersection has the potential for safety improvement by comparing the observed number of crashes, based on historical data, to the predicted number of crashes for a roadway segment of the same type with the similar characteristics. Statistical techniques are also applied to minimize random variations in crash levels and regression-to-the-mean influences.

This approach works for locations where crashes are concentrated. However, many crashes, although prevalent in the aggregate across a geographic area, are not concentrated on particular roadway segments or intersections. Pedestrian crashes, rural single-vehicle crashes, and crashes involving a vehicle crossing the median on divided highways are examples of crash types that may not be concentrated along a roadway, but are prevalent across a larger area, such as a city, county, region, or state. In this instance a different analysis method is needed. The "systemic approach" provides such a method. Instead of identifying locations with greater than expected crashes, crashes are analyzed to determine what physical or operational characteristics are associated with them. Locations with these characteristics can be identified and addressed systemically. A scoring system can be used to help prioritize these kinds of safety projects (Geedipally et al., 2016; Wunderlich et al., 2019).

A further development in improving infrastructure is the data-driven verification of the effect of roadway characteristics and safety countermeasures on crashes. These relationships are termed "crash modification factors" (CMFs) or "crash reduction factors." CMFs are expressed as a multiplier or factor applied to the number of crashes based on the change in a characteristic. A CMF less than one indicates that a countermeasure results in a reduction of crashes whereas a CMF above one indicates an increase in crashes. Accordingly, a CMF value of 1.00 means no positive or negative affect of a countermeasure. Crash reduction factors are simply the same value or effect expressed as a percentage reduction or increase. There are modification and reduction factors to determine the effect on crashes and their severity. For example, the physical change of adding or widening a shoulder affects the number of roadway departure crashes and the effect of operational changes such as installing left turn signals are similarly documented. The CMF Clearinghouse is an internet-based repository of these factors (Federal Highway Administration (FHWA), 2019a).

These methods can be used to identify and address known safety issues. Another path to improving roadway safety is to apply these techniques during the development of roadway projects, regardless of whether the project's main purpose is adding capacity, rehabilitating or maintaining the pavement, or improving safety. These techniques provide the tools for comparing different design alternatives to determine how safety can be optimized.

These approaches provide data-driven, science-based methods to identify and prioritize locations where changes in the physical or operational characteristics can be determined. The Highway Safety Manual, published by the American Association of State Highway and Transportation Officials, provides a guide to applying these techniques (AASHTO, 2010).

The challenge of making significant reductions in crashes and crash severity through infrastructure changes is the sheer magnitude of the roadway network. A roadway project, notwithstanding how much it improves safety, only affects the users of that roadway while they are using that particular roadway. The project has no effect on other roadways or users on other portions of the network. Roadway crashes are a function of overall exposure and risk, and roadway projects, even when they reduce risk, can only affect a fraction of total exposure. A second issue is the effectiveness of any given countermeasure. Most positive effects range between a few percentage points to a 50% reduction in crashes or severity, although some countermeasures have even greater impacts. However, even after the application of most countermeasures, some amount of risk remains. This is not to say that transport agencies and professionals should not strive to improve roadway safety; rather it is to point out that improving roadway infrastructure cannot solve the road safety issue independently.

## Behavioral risk reduction

Human behavior and capability have an influence on most crashes (National Highway Traffic Safety Administration (NHTSA), 2015). Most, if not all, of the Strategic Highway Safety Plans (SHSPs) developed in each state in the United States include strategies to improve human behavior to reduce crashes, injuries and fatalities (Federal Highway Administration (FHWA), 2019b). Impairment from drugs and alcohol, seat belt usage, distraction, speeding, aggressive driving, inexperience, and helmet usage for motorcyclists are common behaviors addressed in SHSPs. Most states have public education and enforcement campaigns and programs aimed at improving behavior.

Changing ingrained human behavior is complicated and difficult. The National Highway Traffic Safety Administration in the United States has published a guide to these programs, "Countermeasures that Work," that documents, in a qualitative manner, the effectiveness of various behavioral countermeasures (Richard et al., 2018). An examination of the document reveals that the effectiveness of several common approaches is questionable. Generally speaking, even effective programs only marginally impact behavior, and only for the target audience (TxDOT, 2016). In addition, programs often require education to be coupled with incentives or sanctions to be effective.

However, success has been achieved in some areas in the United States. For example, the prevalence of seat belt use has increased dramatically since the mid-1980s when states started enacting seatbelt use laws making seatbelt use mandatory, and now reaches over 90% of front seat occupants in the 35 states that allow for primary enforcement of their seatbelt law (National Highway Traffic Safety Administration (NHTSA), 2019b). Even greater success has been reported for other countries. In 2018 Germany reported seatbelt use rates of 99% overall in the front seat, with a rate of 100% for motorway drivers (OECD/ITF International Transport Forum, 2019a). Rates in Australia for 2018 were 97% for the front seat driver and passenger (OECD/ITF International Transport Forum, 2019b). Australia also reports success in reducing alcohol-impaired crashes that they attribute to their public education combined with an extensive random breath-testing program (OECD/ITF International Transport Forum, 2019b).

In comparison to infrastructure projects, human behavior change has the potential to affect many more users, and improvement in one user affects the safety of other users. But an incremental change in behavior coupled with the relatively modest impact usually realized by such changes, suggests that large reductions in crashes, injuries and fatalities cannot depend solely on efforts to behavioral change.

## Vehicles and technology improvements

Motor vehicle safety has improved significantly since the mid-1950s, when factory-installed lap belts began appearing on cars sold in the United States (Kahane, 2015). Kahane (2015) estimates that vehicle technology improvements have reduced fatality risk by 56% between 1960 and 2012. A similar effect was found by Blower et al. (2019) in their study of the factors influencing the decrease in fatalities in the United States from 2008 to 2012 which indicated that vehicle safety improvements were associated with about 12% of the decline in fatalities over the period. The occupant protection and collision mitigation improvements have had a steady and consistent role in improving safety.

Vehicle safety improvements and advanced driver assistance systems probably have the greatest potential for improving overall safety, because they have the potential to affect each and every vehicle mile of travel. This will depend on the availability of these systems across the vehicle fleet and their acceptance and use by operators, but it is clear that widespread vehicle improvements have a had distinct positive impact on risk reduction.

The future of vehicle improvements holds great promise, particularly in terms of collision-avoidance technology. Forward collision warning, forward and rearward autobraking, lane departure warning, blind spot detection, review cameras, and cross-traffic alert systems have been reported to reduce crashes and in some-cases injuries based on studies of the rate of police-reported crashes and insurance claims. The Insurance Institute for Highway Safety in the United States (Insurance Institute for Highway Safety Highway Loss Data Institute (IIHS HLDI), 2019) reports a 27% decrease in front-to-rear crashes and a 20% reduction in such crashes with injuries for forward collision warning systems. These effects improve even further if autobraking is included, with a 50% reduction in front-to-rear crashes and a 56% reduction in crashes with injuries. Lane departure warnings are associated with a 21% decrease in single-vehicle, sideswipe and head-on crashes with injuries. Blind spot detection reduces lane change crashes about 14%, and rear automatic braking, rearview cameras, and cross-traffic alerts all reduce backing crashes (Insurance Institute for Highway Safety Highway Loss Data Institute (IIHS HLDI), 2019).

However, with the exception of rear cameras, most of these systems are present in less than 10% of the registered vehicles in the United States, and even rear cameras are present in less than 30% of vehicles. Fleet turnover takes a long time, and it is likely to take 15–20 years to reach 90% penetration of these technologies in the vehicle fleet (Insurance Institute for Highway Safety Highway Loss Data Institute (IIHS HLDI), 2017).

The University of Michigan Transportation Institute's Center for the Management of Information for Safe and Sustainable Transportation developed an online tool to assess the effects of nonindependent traffic safety measures (UMTRI, 2016). Using this tool, the authors calculated that 100% adoption of five promising technologies (lane keeping, automatic emergency braking, lane centering, forward collision warning, and electronic stability control) would result in a 26% reduction in all traffic fatalities. The power of combining behavioral changes with technology is demonstrated by the effects of adding ignition interlocks to reduce alcohol-impaired driving and 100% safety belt use with these technologies, wherein a 56% reduction in fatalities can be achieved.

This tool also does illustrate the substantial challenges in reducing fatality risk, and the need to combine many approaches. Nonetheless, because vehicle-based safety systems are becoming available in more vehicle models and adopted by more owners each year, the steady and consistent decrease in risk associated with vehicle technology is likely to continue.

## Designing for safe systems

A great deal of credit for reducing fatality risk in European countries is given to the adoption or acceptance of a safe systems approach to roadway design. The World Resources Institute report lists five guiding principles for a safe system that were developed based on a report that resulted from the International Transport Forum at the Organization for Economic Co-operation and Development (OECD/ITF International Transport Forum, 2015; World Resources Institute, 2018). The guiding principles are

1. People make mistakes that can lead to road crashes.
2. The human body has a limited ability to tolerate crash forces before harm occurs.
3. A shared responsibility exists among the people who design, build, manage, and use roads and vehicles and provide postcrash care to prevent crashes that result in serious injury or death.
4. A proactive approach should be taken to making the mobility system safe, rather than waiting for events to occur and reacting. All parts of the system must be strengthened to multiply their effects, so that if one part fails, road users are still protected.
5. No death or serious injury should be accepted in the mobility system. Lack of safety should not be a trade-off for faster mobility. Rather, the mobility system should be both safe and efficient.

Recently through a collaborative effort with the Institute for Transportation Engineers (ITE) (2019a,b), a task force was established as part of the Road to Zero Coalition to explore and develop a framework for safe systems design applicable for use in the United States. The framework suggests that choosing a safe systems approach in the United States may result in a decrease in throughput and may limit the range of behavioral choices for users. The framework explores how a reliable transportation system might be configured to protect human life. The sections below illustrate specific examples of how a safe systems approach could be implemented in the United States.

### Separating users in time and space

A safe system anticipates human error and can employ strategies that separate transportation users in time and/or space. Separating in space may segregate different users to designated physical space with the roadway environment, particularly if they move at different speeds. Motor vehicles would be separated from bicycles, and both from pedestrians, for example, just as turning motor vehicles are often separated from those traveling through, by using designated turn lanes. In many cases, users with differing speed and resiliency will be required to share the same physical space. But separating them in time and reducing the chances of motor vehicle interactions with pedestrians or bicyclists reduce risk. An example of this approach is to provide a separate traffic signal pedestrian phase to give pedestrians exclusive access to the intersection. This is similar to providing a separate left turn phase for motor vehicle operators to minimize the likelihood of conflict with opposing vehicles.

Limiting opportunities for errors by simplifying decisions fits within a safe system. Intersection designs that limit direct turns can decrease the number of conflicts and the angles at which they occur. Channelizing intersections to provide clear paths for users provides clarity that can reduce mistakes.

## Attentiveness

Strategies that increase attentiveness or awareness could also be used to alert users. Several elements could be deployed as part of this strategy. Visibility could be improved. Higher intensity lighting could be used to provide visibility of all users. Visual clutter and obstructions could be removed from intersections to provide good sight lines for all users. Finally, reflective clothing and lights could be used by all users to increase the chances that other users will see them in limited light conditions. Increasing visibility is clearly an important element of reducing pedestrian fatalities in the United States, especially considering three quarters of fatalities occur during darkness based on data from FARS from 2014 to 2018 (National Highway Traffic Safety Administration (NHTSA), 2019a).

Attentiveness by users can be increased through the use of such measures as rumble-strips, transverse grooves in the pavement that warn that the vehicle has traveled beyond the designated lane, or higher profile pavement markings that achieve a similar effect. Rectangular rapid flashing beacons, which are incorporated into pedestrian crossing warning signs, have a distinctive flash pattern to alert drivers to the presence of people on foot.

## Injury tolerance and reducing speed

A safe systems approach also acknowledges human injury tolerance. Pedestrians are particularly vulnerable when struck by a motor vehicle. In a report published by the AAA Foundation for Traffic Safety, Tefft (2011) indicates that the "risk of severe injury reaches 10% at an impact speed of 16 mph, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph." In addition, Elvik et al. (2009) developed a power model that relates speed to fatal and severe injuries. A 10% reduction in speed results in a 38% reduction in fatalities and a 27% reduction in serious injuries. Consequently, reducing speed has a positive effect on reducing the risk of fatal and severe injury for all users. The challenge is to achieve lower speeds. The use of target speeds is a different approach from the measurement of speeds chosen by drivers, which is the traditional approach in the United States. An alternative is to establish a target speed that explicitly considers other consequences such as risk to other users and quality of environment but the challenge is not just setting a target speed but achieving it.

Strategies to achieve target speeds include changing the width and horizontal alignment of roadways to limit free flow speeds, introducing physical elements such as raised crosswalks, channelization of vehicles, and speed humps that restrict speeds. Traffic signal synchronization might be set to encourage continuous flow at the target speed. Finally, a recent National Transportation Safety Board (2017) report on the effect of speed on safety suggests the use of automated enforcement devices, particularly point-to-point speed enforcement due to its use and effectiveness internationally.

## Reducing impact forces

Safe system approaches seek to reduce impact forces. Alternative intersection designs, such as providing median U-turns downstream of the intersecting roadway and restricting left turns, can reduce the angle and speeds of entering vehicles, both of which will reduce collision forces. The roundabout intersection provides several advantages to conventional intersections. Vehicular conflict points are reduced from 32 to 8, approach vehicle speeds are reduced significantly and impacts occur at low angles but care must be taken to provide for visible and logical pedestrian crossing locations with ample sight lines.

Vehicle design can also help reduce impact forces and their consequences Occupant protection within the vehicle, exterior designs to reduce impacts on pedestrians and cyclists, and the deployment of technology such as automated braking, are part of a safe system.

Roadside treatments to reduce the risk of fatal and serious injuries to occupants of vehicles that have departed the roadway have been deployed and enhanced over many years. Clearing the roadside of obstructions, providing breakaway sign supports, crash cushions and forgiving end-treatments on guardrails are all examples of reducing the injury consequences of roadway departures.

## Other considerations

A safe system could seek to reduce impairment, perhaps through the widespread use of alcohol detection and interlock systems on motor vehicles. Cell phone detection and lockout systems in vehicles to reduce distracted driving or the use of incentive-based apps could be deployed to reduce distraction regardless of mode.

## Chapter summary

Road-related deaths and injuries are a significant public health issue. Much progress has been made in reducing the toll, particularly in Europe and the United Kingdom, but significant issues remain in both developing and developed countries. Continued population growth and expanded economic opportunity is likely to increase travel, and reducing the risk associated with that travel is critical to improving health outcomes.

Fortunately, good analytical techniques now exist to examine the nature and location of road crashes; information on countermeasure effectiveness is available to help prioritize actions; and approaches such as safe systems may change the safety culture of both users and transport officials. Improvements in vehicle technology are promising but it will be many years, if ever, that machines take over the driving task. There is no one approach that appears likely to solve the road crash issue, but increased emphasis on implementing infrastructure improvements, incentivizing safe behavior and sanctioning and discouraging risk behavior, and increasing the rate of availability and acceptance of advanced safety technology can all make a difference in the quality and longevity of life throughout the world.

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CHAPTER THREE

# Traffic, air pollution, and health

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## Contents



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## Abbreviations

**ADHD** attention hyper deficit hyperactivity disorder
**ADMS-Urban** Atmospheric Dispersion Modeling System-Urban
**AVs** autonomous vehicles
**BC** black carbon
**BoD** burden of disease
**CARTEEH** Center for Advancing Research in Transportation Emissions, Energy, and Health
**CO** carbon monoxide
**$CO_2$** carbon dioxide
**COPD** chronic obstructive pulmonary disease
**COPERT** COmputer Programme to calculate Emissions from Road Transport
**DALYs** disability adjusted life years
**EC** European Commission
**EPA** US Environmental Protection Agency
**EVs** electric vehicles
**GHG** greenhouse gases
**GIS** geographic information system
**HC** hydrocarbons
**HIA** health impact assessment
**LCUTP** low carbon urban transport policies
**LUR** land-use regression
**$NO_2$** nitrogen dioxide
**$NO_x$** nitrogen oxides
**$O_3$** ozone
**OECD** Organization for Economic Co-operation and Development
**PAF** population attributable fraction
**PI** prediction interval
**PM** particulate matter
**$PM_{10}$** particulate matter with diameter $<10$ μm
**$PM_{2.5}$** particulate matter with diameter $<2.5$ μm
**ROS** reactive oxygen species
**$SO_2$** sulfur dioxide
**$SO_4$** sulfates
**TRAP** traffic-related air pollution
**UFP** ultra-fine particles
**VMT** vehicle miles traveled
**VOC** volatile organic compounds
**WHO** World Health Organization

## Introduction

### What is traffic-related air pollution and the full-chain linking traffic activity to health impacts?

Traffic-related air pollution (TRAP) is a term that refers to ambient air pollution resulting from traffic activity. Traffic activity includes the use of motorized vehicles such as passenger cars, motorcycles, buses, coaches, light-duty, and heavy-duty vehicles. These vehicles emit air pollutants, including black carbon (BC), elemental carbon, carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides ($NO_x$), nitrogen dioxide ($NO_2$), particulate matter (PM) with a diameter less than 2.5 μm ($PM_{2.5}$), PM with a diameter less than 10 μm ($PM_{10}$), and ultra-fine particles (UFP), to name a few. Pollutants are either emitted directly through the exhaust (known as tailpipe emissions) or through nonexhaust emissions such as resuspended dust, brake and tire wear, and road surface abrasions (known as nontailpipe emissions). While tailpipe emissions for key pollutants such as CO, $NO_x$, $PM_{2.5}$, and $PM_{10}$, and more recently particles number for UFP, are regulated, nontailpipe emissions are not. Vehicle emissions then disperse into the ambient air depending on factors such as meteorology, most importantly wind speed, wind direction and atmospheric stability, local and regional terrain, and background air pollution concentrations originating from other sources, such as industry and coal and wood burning. The result is elevated concentrations of air pollutants, through primary emissions or through the formation of secondary pollutants, which contribute to the degradation of ambient air quality and can also infiltrate indoors. Humans are then exposed to these air pollutants in ambient air (or indoors) and their exposures and inhaled doses which reach target organs or tissues are determined by factors such as their mobility patterns, distance from the source, height, physical activity, and transport mode choice. In its turn, air pollution results in numerous adverse health outcomes for exposed populations ranging from premature mortality to a wide spectrum of global diseases. Certain policies or control strategies and emerging technologies such as the introduction of electric vehicles (EVs) can impact the quantity of emitted air pollutants and, therefore, subsequent air pollution concentrations, human exposures, and health outcomes. A simplified schematic of the full-chain which links traffic activity to its ultimate health impacts is depicted in Fig. 3.1, with an icon


**Figure 3.1** The full-chain: linking TRAP to health impacts. *TRAP*, Traffic-related air pollution.

for technologies and disruptors, such as electric and automated vehicles, placed at the upstream of this chain. The full-chain includes traffic activity, traffic emissions, dispersion and resulting air quality, human exposures and resulting health impacts, as shown in Fig. 3.1.

## Population growth and urbanization and their impacts on traffic-related air pollution and human exposures

The importance and relevance of TRAP continues to increase with the continuing rapid population growth and increasing urbanization. The global population has risen substantially over the past century and is estimated to reach 9.8 billion in 2050, and 11.2 billion in 2100, from just 7.6 billion in 2017 (United Nations Department of Economic and Social Affairs, 2017). With population growth and economic growth comes an increase in the number of vehicles being manufactured, purchased, driven, and emitting more air pollutants. In developed countries, there is already a cultural and economic dependence on motor vehicles as the primary mode of transport which dominates urban transport design and planning. Although mass motorization started much later in developing countries, it is growing rapidly, causing similar problems in many developing cities (Khreis et al., 2016). The increased demand for travel and transport activity continues to overpower emission regulations and advancements in vehicle and fuel technology (Metz et al., 2007), and, therefore, TRAP is expected to rise in some regions. Another worrying trend in this context is the rapid and unprecedented urbanization that the world is currently witnessing. Urban populations are swelling with over 50% of the world's population now living in cities, and this percentage is projected to increase to 68% by the year 2050 (United Nations, 2018). While cities are the world's engines of economic growth, innovation and social change with annual economic activity of about 85% of global gross domestic product (Gouldson et al., 2015), they are also hot spots for human exposure to air pollution, mainly originating from road traffic. In cities, traffic activity is not only (generally) higher but also acts in close proximity to people making their potential for harmful exposures, and associated adverse health effects, higher as well. In 2016 The World Health Organization (WHO) reported that 92% of the world's population lives in cities where air pollution levels exceeds the WHO air-quality guidelines (World Health Organization, 2016), guidelines which are still too high to fully protect public health.

## Traffic's contribution to ambient air pollution levels

Traffic's contribution to ambient air pollution levels varies significantly between and within cities and depends on numerous dynamic factors such as traffic flows, traffic speeds, congestion and start and stop driving, the vehicles' fleet mix including the age and maintenance of vehicles on the roads, fuel used, meteorology, local and regional terrain, and the characteristics of the built and natural environment such as the prevalence of street canyons and green spaces in urban areas which can influence pollutants' dispersion and deposition. The contribution of traffic to ambient air pollution also differs depending on the pollutant(s) being studied. Some pollutants such as BC, $NO_2$, and urban UFPs represent relatively specific signatures of the traffic mixture, while others such as $PM_{2.5}$ and $PM_{10}$ are shared across many other pollution sources and are less-specific markers for TRAP. Overall, TRAP is highly heterogeneous, both in space and in time and concentrations of common vehicular pollutants are spatially misaligned and can significantly fluctuate even over no more than a few tens of meters (Bell, 2014; Briggs et al., 1997; Vardoulakis et al., 2003). Ultimately, all the above factors result in high variability in traffic's contribution to emissions and ambient air pollution in regions across the world and even within cities themselves. For example, in 2013, traffic was responsible for 14% of volatile organic compounds emissions, 38% of $NO_x$ emissions, and 34% of all CO emissions in the United States (U.S. Department of Transportation, 2016). Up to 30% of PM emissions comes from transportation sources in Europe and up to 50% of PM emissions in Organization for Economic Co-operation and Development countries—mostly due to diesel traffic (World Health Organization, 2018), while this percentage drops to less than 10% when observing the United States

(Environmental Protection Agency, 2019). Traffic contribution to urban PM concentrations in Europe ranges from 9%—53% for $PM_{10}$ to 9%—66% for $PM_{2.5}$ with an average of 39% and 43% at traffic sites, respectively, and a higher range for $NO_2$ which can reach to up to 80% (Sundvor et al., 2012). In low-income and developing countries, transportation activity typically accounts for significant overall shares of air pollution [~67% of PM in Sao Paulo, Brazil (Josh Miller and Façanha, 2017), ~33% of all air pollutants throughout India (International Council on Clean Transportation, 2018), and up to 40% of air pollution in Chinese cities (World Resources Institute, 2018)] due to the use of older and less efficient vehicles (World Health Organization, 2018). Exposures to TRAP also remain highly ubiquitous as populations live, work, and play close to traffic activity. A 2015 study revealed that 24% of the population in Toronto (Canada), 41% of the population in New Delhi (India), 66% of the population in Beijing (China), 67% of the population in Paris (France), and 96% of the population in Barcelona (Spain) are potentially exposed to TRAP (Su et al., 2015).

## This chapter

In the following sections, I will broadly overview methods to assess TRAP and human exposure which is the first step toward understanding health effects and population impacts of TRAP and devising mitigation strategies. I will then provide a summary of well-established and emerging health effects and review air quality guidelines which establish limits for key air pollutants that pose health risks, alongside a snapshot of studies which pinpoint adverse health effects below these guidelines. I will briefly discuss the use of burden of disease (BoD) and health impact assessment (HIA) methods to quantify the health burden attributable to TRAP in cities, giving one example of a BoD assessment investigating the health impacts of current air pollution levels. I will then overview quantified and potential impacts of select emerging technologies and outline best transportation practices that were identified in previous work and their overlap with other important agenda, such as increasing physical activity and mitigating climate change. In the final two sections, I will touch on environmental justice issues surrounding TRAP exposures and health and summarize research gaps making recommendations for future studies. This chapter is meant to provide the reader with a high-level overview of key topics, issues and trends under the broader theme of TRAP and human health. For a full account of these topics the reader is invited to read another Elsevier book dedicated to this topic and titled “Traffic-Related Air Pollution: Emissions, Human Exposures and Health” (Khreis et al., 2020b).

## Air pollution and exposure assessment

To study the health effects of air pollution and devise adequate air quality guidelines and mitigation strategies to protect the public's health, air pollution and human exposure must first be assessed. The assessment of air pollution, and subsequently the assignment of human exposure, can be done using a wide variety of methods which may be broadly classified as measurement, modeling or the use of TRAP surrogates. These methods can also be, and are increasingly being, combined.

### Fixed-site monitoring stations and geostatistical interpolation

Measurements of air pollution is often done in cities as a part of regulatory frameworks where air quality must be assessed to determine compliance or breaching of air quality limits enacted in the region, and devise corrective actions, when needed. These frameworks often rely on fixed-site monitoring stations. Fixed-site monitoring stations are located in various locations ranging from background to urban to roadside sites, and continuously measure and record levels of key pollutants at a high temporal resolution, for example, at 1-minute intervals. When these measurements are used to assess human exposures, the air pollution readings from the fixed-site monitoring station is typically assigned to people based on the distance between their locations (e.g., residence, school, kindergarten, and work) and the monitoring station. The aim is to minimize this distance in the hope of minimizing exposure misclassification.

Sometimes, these measurements are interpolated using geostatistical interpolation methods such as inverse distance weighting or kriging. Inverse distance weighting considers closer measurements to contribute more to concentrations through distance-dependent weighted averages, while kriging assigns weights to each location based on spatial correlations among measurements and minimizing error variance. These methods often result in a smoothly varying pollution surface that is not representative of the steep concentration gradients especially close to traffic. These methods are also limited by the number of measurement sites.

The strength of using fixed-site monitoring stations to assess air pollution and human exposures are in their ability to continuously measure multiple pollutants with a high degree of accuracy (assuming adequate ratification and verification of the monitors), and their high temporal resolution. In addition, their readings are recognized by official local, regional or national governments and represent actual measurements rather than estimates or predictions. However, fixed-site monitoring stations are often only present in limited quantities due to their high maintenance levels and cost, and their locations are based on regulatory, rather than scientific, purposes. Air pollution and specifically TRAP concentrations have demonstrated significant spatial variations in intra-urban and urban settings. Fixed-site monitoring stations cannot capture these variations and, therefore, are prone to misclassify human exposures and conceal persons' differences because of a mismatch between data used to estimate exposure and the actual subjects' locations.

## Personal air pollution sensors

Measurements of air pollution and human exposures can also be done using personal air pollution sensors, though this is less commonly practiced in air pollution epidemiological studies. Sensors can be worn around one's neck, placed in pouches or backpacks and mounted onto bicycles. This is believed to provide the best estimates of actual individual exposure to air pollution due to the sensor's constant colocation with the carrier as she or he travels throughout different environments, which inevitably consist of varying types of pollutants and concentration levels. While this method is ideal for capturing the spatial variability of air pollution and TRAP specifically, it is only practical/feasible in small timeframes and populations due to logistic and cost concerns and, therefore, may not be able to provide long-term exposure data for the sample sizes required in epidemiological studies. Air pollution sensors are also still unavailable for all pollutants of concern. Advances in low-cost sensors could help alleviate some of the logistic and cost concerns but their rapid proliferation in the market is still challenged by quality and durability issues.

## Modeling techniques

Where measurements are unavailable, infeasible or insufficient, practitioners, and researchers tend to employ a wide range of modeling techniques to estimate the levels of air pollution, and TRAP, and assign human exposures to populations of interest. In air pollution epidemiology and air pollution BoD and HIA studies, the most commonly employed models are land-use regression (LUR) models, atmospheric dispersion models, and hybrid models which often combine measurements with modeling for enhanced performance and to better capture the variability of exposure estimates. Hybrid models can vary widely and include combinations such as the combination of satellite remote sensing with ground-based measurements and atmospheric dispersion models and/or LUR models, amongst others.

## Land-use regression models

LUR models are increasingly common in air pollution epidemiology and air pollution BoD and HIAs, potentially due to their relatively easy and affordable setup. LUR modeling is an empirical air pollution modeling technique which uses predictor variables such as land-use, geographic, road and traffic characteristics, population density, and other factors to explain spatial variations of measured air pollution concentrations at multiple sites across the study area (Beelen et al., 2014). Traffic variables are often included in the LUR models by describing the road type or traffic density within a fixed distance or buffer of each measurement site, and sometimes splitting the vehicle density by vehicle type. Once the relationship between land-use and the traffic variables is established, the statistical LUR model is used to predict air-pollution exposures in locations where measurements have not been made throughout the study area. LUR models have also been useful in describing the spatial variation of pollutants, where using other methods such as dispersion modeling remains difficult (e.g., UFP), and also for entirely new exposure metrics such as oxidative potential (Beelen et al., 2014). However, LUR models are limited in their ability to provide detailed source apportionment, since model variables, often used in creating the models, such as "traffic density within 100 m," is very difficult to interpret. Furthermore, being based upon regression methods, LUR models are unable to predict future air pollution or test policy scenarios. LUR models can only reflect the predictors used in the model, are subject to varying uncertainties amongst different pollutants, and the quality of the data representing "meaningful" predictors may be an issue which will affect the overall accuracy of the model's outputs. Finally, like geostatistical interpolation methods mentioned above, the models' outputs are sensitive to the locations and density of measurement sites. In practice, LUR models are often used to assign static exposures at fixed locations of people participating in corresponding studies, such as residential or work locations. It is rare that these models are used in combination with mobility patterns, and, therefore, like fixed-site monitoring stations, LUR models can introduce exposure misclassification.

## Atmospheric dispersion models

Another modeling approach that does a better job in source apportionment is atmospheric dispersion modeling. Atmospheric dispersion models utilize mathematical equations and calculations on input data consisting of pollutant emissions, source parameters, land-use, terrain and meteorological conditions to simulate the processes affecting the dispersion and transformation of pollution throughout the environment. Concentrations of select pollutants are then estimated at specified locations, known as receptors, and at high temporal resolution, typically hourly. There are numerous types of dispersion models which operate using different mathematical formulas and assumptions which can be better suited for certain situations or environments. These models do not require dense monitoring networks, which made them suited for use with past and current measurement capabilities. However, their accuracy very much depends on the quality of input data, which can be expensive and time consuming to obtain, and the assumptions or equations used within the models could be unrealistic. Atmospheric dispersion modeling also requires a range of sophistication and expertise from the user and is a data-intensive and time-consuming exercise. Like LUR models, the use of atmospheric dispersion models generally disregards exposure variability due to individual mobility activity and can, therefore, introduce exposure misclassification, when used based on the static location of study subjects.

## Hybrid models

On the other hand, hybrid models often combine measurements with modeling outputs, such as satellite remote sensing with ground-based measurements and atmospheric dispersion models and/or LUR models, amongst others. These models can vary significantly and include numerous combinations which are usually trailed, assessed, and validated before they are adopted. Some of the most common combinations which can be found in the literature include remote sensing, ground monitors, and advanced modeling; the integration of stationary and mobile monitoring methods along with modeling such as LUR; and the use of dense low-cost sensor networks alongside geospatial interpolation techniques. It is worth noting that the integration of these methods seems to improve the methods' capacity to capture air pollution and exposure variation, when compared to the separate individual methods. However, the complexity resulting from such integrations can further hinder the ability of source apportionment and complicate interpretation.

### Traffic-related air pollution surrogates

Finally, some studies use surrogates for TRAP exposures such as proximity to "major roads" or "freeways," vehicles count and composition within a certain buffer from the residence or work locations, and more novel surrogates such as four-way street intersection density and number of transit bus stops (Khreis and Nieuwenhuijsen, 2017). These measures are intuitive, simple and cost effective, and can be developed with relative ease in a geographic information systems (GIS) environment. However, they are likely to result in a higher exposure misclassification when compared to the methods above as they assumes that a road of a certain type or size corresponds to a certain amount of traffic, sometime uses self-reported traffic intensity (collected via questionnaires) which can be subjective, assume all pollutants disperse similarly (limited directional dependence), generally do not consider compounded effects of proximity to multiple roads, and disregard exposure variability due to individual mobility activity.

## Health effects

The health effects of TRAP are generally similar to the health effects of ambient air pollution. However, there are some outcomes, such as the onset of childhood asthma, which have been more strongly associated with intra-urban variations of air pollution, usually dominated by TRAP and not regional air pollution variations, usually dominated by other sources. Further, the toxicity of TRAP is likely different than the toxicity of air pollution originating from other sources due to different chemical composition of the TRAP mixture in addition to different physical characteristics of the pollutants such as the size, surface area, and the number of the smallest particles. These differences, and their relevance to the observed health effects, are generally understudied in air pollution epidemiology. In this section, I will overview the key well-established and emerging health effects which have been associated with urban air pollution and TRAP.

There is now substantial evidence showing an association between air pollution and mortality. This evidence originally stemmed from the seminal Harvard six cities study which demonstrated the association between ambient concentrations of sulfur dioxide ($SO_2$), PM, ozone ($O_3$), and sulfates ($SO_4$) and differences in the probability of survival in a sample of adults (Dockery et al., 1993). The American Cancer Society Cancer Prevention Study also demonstrated these associations (Pope et al., 1995). Both studies have been influential in establishing the association between air pollution and premature mortality which was later accounted for in regulatory decision-making. Both studies were also independently reanalyzed and further extended in numerous following publications. This body of evidence has grown and been strengthened substantially since. There are now documented associations between living near a major road and cardiopulmonary mortality (Hoek et al., 2002), long-term exposures to air pollution and increased risk of cardiovascular mortality (Cao et al., 2011; Brook et al., 2010), natural-cause mortality (Beelen et al., 2014), lung cancer mortality (Yang et al., 2013), and mortality from strokes (Luo et al., 2019).

While the above studies focused on mortality, common traffic-related air pollutants have been linked to a wide spectrum of diseases with substantial public health implications. TRAP has been associated with pulmonary morbidity, such as asthma onset, wheeze and asthma symptoms in children (Nordling et al., 2008; Khreis et al., 2017; Gasana et al., 2012), lung function decrements in school aged children (Chen et al., 2019), pneumonia (MacIntyre et al., 2013), lung cancer incidence (Raaschou-Nielsen et al., 2013), and the development and prevalence of chronic obstructive pulmonary disease in adults (Andersen et al., 2011; Lindgren et al., 2009). Further, studies documented associations between common traffic-related air pollutants and increased blood pressure (Santos et al., 2019), arrhythmia (Link and Dockery, 2010), incidence of acute coronary events (Cesaroni et al., 2014; Mustafić et al., 2012), cerebrovascular events such as stroke (Stafoggia et al., 2014) and hospital admissions for circulatory system diseases, myocardial infarction, lung cancer, kidney cancer, and low respiratory tract infections in adults (Gandini et al., 2018). Other evidence associated air pollution with congenital anomalies (Vrijheid et al., 2010), and a range of adverse pregnancy and birth outcomes such as pregnancy-induced hypertensive disorders and preeclampsia (Pedersen et al., 2014), preterm birth (Sapkota et al., 2012), and low birth weight (Pedersen et al., 2013).

While the evidence on the health outcomes above may be considered as very suggestive to sufficient, there are still numerous health outcomes which have been linked to air pollution and TRAP in emerging research. These include reduced sperm quality (Lafuente et al., 2016), the incidence of diabetes (Eze et al., 2015; Liang et al., 2019), obesity formation in children (Jerrett et al., 2014), and increased number of osteoporosis related fracture hospital visits and decreased bone density (Prada et al., 2017).

More recent studies also show an association between the incidence of neurological disorders, in both children and adults, and common traffic-related air pollutants or living near major roads (Chen et al., 2017b; Chang et al., 2014; Power et al., 2016). For example, children exposed to $NO_2$ and $PM_{10}$ had an increased likelihood of being diagnosed with childhood attention hyper deficit hyperactivity disorder (Min and Min, 2017). Children of mothers exposed to $PM_{2.5}$ during pregnancy had increased odds of developing autism spectrum disorders (Raz et al., 2014). Children exposed to elemental carbon attributable to traffic at birth had higher self-reported depression and anxiety symptoms (Yolton et al., 2019). Emerging research also reveals an association between exposure to PM and faster declines in cognitive function in adults (Weuve et al., 2012; Tonne et al., 2014), lower cognitive function (Tonne et al., 2014; Ailshire and Clarke, 2014), lower verbal learning performances, lower logical memory abilities, and lower executive functioning (Gatto et al., 2014). Dementia incidence, both for Alzheimer's disease and vascular dementia, have also been associated with increased exposures to $NO_x$ (Gatto et al., 2014), $NO_2$ and $PM_{2.5}$ (Chen et al., 2017a), and $PM_{10}$ and $O_3$ (Wu et al., 2015), in addition to living near major roads (Chen et al., 2017b). Associations with new health outcomes continue to emerge at a very rapid pace (Loxham et al., 2019), and the body of evidence has grown and been strengthened substantially to demand urgent action.

It is also useful to consider this body of evidence in parallel to considering toxicological findings. Many credible pathological mechanisms have been elucidated and lend biological plausibility to the epidemiological findings outlined above. Many of the adverse health effects of air pollution, especially cardiovascular and pulmonary effects, occur because of reactive oxygen species (ROS) and oxidative stress. $O_3$, $NO_x$, $PM_{2.5}$, UFP, and transition metals are all potent oxidants and are able to generate ROS (Lodovici and Bigagli, 2011). When an excessive amount of ROS outnumbers antioxidants in the human body, oxidative stress occurs. Excessive oxidative stress can occur due to exposure to the different pollutants. Then, the body's natural antioxidant defense system is not enough, and adverse health effects develop, including morbidity, mortality, decreased lung function, increased airway hyperactivity, pulmonary inflammation, damaged lungs, and cell permeability (Gomes and Florida-James, 2014). Evidence of an oxidative pathway is particularly robust for TRAP (Kelly and Fussell, 2017). Further, with the emerging evidence linking air pollution to neurodegenerative disorders, new biological pathways have also been proposed. Experimental evidence in animals showed how particles (Heusinkveld et al., 2016), and most recently, mineral magnetite (Maher et al., 2016), a toxic mineral associated with memory loss, reach the brain, via inhalation, the circulatory system or directly through the nose and olfactory nerve. These particles, magnetite, and possibly gases such as $NO_2$ cause neuroinflammation, neural oxidative stress, and neurodegeneration (Costa et al., 2017; Block and Calderón-Garcidueñas, 2009), which all are processes on the pathological pathway to neurodegenerative disorders such as cognitive decline and dementia. These mechanisms, in the context of air pollution and TRAP exposures, have been reviewed elsewhere (Kelly and Fussell, 2017; Costa et al., 2017; Block and Calderón-Garcidueñas, 2009; Miller et al., 2012).

## Air quality guidelines

As mounting evidence showed that air pollution has detrimental impacts on human health and the environment, many regulatory bodies; most notably the WHO, the European Commission (EC), and the United States Environmental Protection Agency (EPA), developed a set of health-based standards and objectives for air pollution concentrations for a number of harmful pollutants. These standards and objectives are summarized in Tables 3.1–3.3. These apply over differing periods of time because the observed health impacts associated with various pollutants occur over different exposure times. The aim of these air quality values is to achieve "safe"

**Table 3.1** WHO air quality guideline values—voluntary.

| Pollutant | Concentration ($\mu g/m^3$) | Averaging period |
|---|---|---|
| Fine particles ($PM_{2.5}$) | 25 | 24 h |
| | 10 | 1 year |
| Sulfur dioxide ($SO_2$) | 500 | 10 min |
| | 20 | 24 h |
| Nitrogen dioxide ($NO_2$) | 200 | 1 h |
| | 40 | 1 year |
| Coarse particles ($PM_{10}$) | 50 | 24 h |
| | 20 | 1 year |
| Ozone ($O_3$) | 100 | 8 h |

*Source*: From Krzyzanowski, M., Cohen, A., 2008. Update of WHO air quality guidelines. Air Qual. Atmos. Health 1 (1), 7–13 (Krzyzanowski and Cohen, 2008).

**Table 3.2** European air quality standards—legislative.

| Pollutant | Concentration | Averaging period | Permitted exceedances/year |
|---|---|---|---|
| Fine particles ($PM_{2.5}$) | 25 $\mu g/m^3$ | 1 year | n/a |
| Sulfur dioxide ($SO_2$) | 350 $\mu g/m^3$ | 1 h | 24 |
| | 125 $\mu g/m^3$ | 24 h | 3 |
| Nitrogen dioxide ($NO_2$) | 200 $\mu g/m^3$ | 1 h | 18 |
| | 40 $\mu g/m^3$ | 1 year | n/a |
| $PM_{10}$ | 50 $\mu g/m^3$ | 24 h | 35 |
| | 40 $\mu g/m^3$ | 1 year | n/a |
| Lead (Pb) | 0.5 $\mu g/m^3$ | 1 year | n/a |
| Carbon monoxide (CO) | 10 $mg/m^3$ | Maximum daily 8 h mean | n/a |
| Benzene | 5 $\mu g/m^3$ | 1 year | n/a |
| Ozone | 120 $\mu g/m^3$ | Maximum daily 8 h mean | 25 days averaged over 3 years |
| Arsenic (As) | 6 $ng/m^3$ | 1 year | n/a |
| Cadmium (Cd) | 5 $ng/m^3$ | 1 year | n/a |
| Nickel (Ni) | 20 $ng/m^3$ | 1 year | n/a |
| Polycyclic Aromatic Hydrocarbons (PAH) | 1 $ng/m^3$: expressed as concentration/ Benzo(a)pyrene | 1 year | n/a |

*Source*: From European Commission, 2014. E.C. Air Quality Standards. January 14–18, 2014. Available from: <http://ec.europa.eu/environment/air/quality/standards.htm> (European Commission, 2014).

air quality levels, which will not result in unacceptable impacts on, and risks to, human health. The WHO air quality guidelines are voluntary while the EC and EPA's values are legislative, despite not being met in many regions. Other regions of the world also have their own air quality standards and

**Table 3.3** U.S. EPA Air Quality Standards known as US National Ambient Air Quality Standards (NAAQS)—legislative.

| Pollutant (links to historical tables of NAAQS reviews) | | Primary/ secondary | Averaging time | Level | Form |
|---|---|---|---|---|---|
| Carbon monoxide (CO) | | Primary | 8 h | 9 ppm | Not to be exceeded more than once per year |
| | | | 1 h | 35 ppm | |
| Lead (Pb) | | Primary and secondary | Rolling 3 month average | 0.15 μg/m$^3$ | Not to be exceeded |
| Nitrogen dioxide ($NO_2$) | | Primary | 1 h | 100 ppb | 98th percentile of 1-h daily maximum concentrations, averaged over 3 years |
| | | Primary and secondary | 1 year | 53 ppb | Annual mean |
| Ozone ($O_3$) | | Primary and secondary | 8 h | 0.070 ppm | Annual fourth-highest daily maximum 8-h concentration, averaged over 3 years |
| Particle pollution (PM) | $PM_{2.5}$ | Primary | 1 year | 12.0 μg/m$^3$ | Annual mean, averaged over 3 years |
| | | Secondary | 1 year | 15.0 μg/m$^3$ | Annual mean, averaged over 3 years |
| | | Primary and secondary | 24 h | 35 μg/m$^3$ | 98th percentile, averaged over 3 years |
| | $PM_{10}$ | Primary and secondary | 24 h | 150 μg/m$^3$ | Not to be exceeded more than once per year on average over 3 years |
| Sulfur dioxide ($SO_2$) | | Primary | 1 h | 75 ppb | 99th percentile of 1-h daily maximum concentrations, averaged over 3 years |
| | | Secondary | 3 h | 0.5 ppm | Not to be exceeded more than once per year |

*Source*: From United States Environmental Protection Agency, 2016. U.S.E. Criteria Air Pollutants: NAAQS Table. 20 December 2016 [cited November 19, 2019]. Available from: <https://www.epa.gov/criteria-air-pollutants/naaqs-table> (United States Environmental Protection Agency, 2016).

guideline values, but the three sources overviewed below are the most prominent and perhaps the most stringent.

In recent years, however, adverse health effects were detected at relatively low pollutants' concentrations, which, in many cases, were well below the European, the EPA's, and the more stringent WHO air quality standards (Beelen et al., 2014; Pedersen et al., 2013; Loxham et al., 2019; MacIntyre et al., 2014; World Health Organization, 2013; Nishimura et al., 2013; Scoggins et al., 2004; Belanger et al., 2006; Castro et al., 2009; Chen and Omaye, 2001; Wei et al., 2019). Similarly, the beneficial effects of relatively small reductions in ambient air pollution levels were previously documented in other trials, also suggesting that no air pollution threshold for the adverse health effects can be established (Bayer-Oglesby et al., 2005; Currie et al., 2011). These results confirmed the conclusion of others who suggest that there is no known "safe" lower limit for exposure to air pollution. It, therefore, seems that current guideline values and standards, which many countries and regions are already failing to meet, do not reflect the latest evidence put forward by several epidemiological studies, and that *"the science is outpacing legislation"* (Hitchcock et al., 2014). It is notable here that while the WHO is currently in the process of revising its guidelines, these have, until now, been without legal enforcement. On the other hand, additional research findings show that not only is the science outpacing the legislation, but also that some scientific evidence has yet no place in current guidelines. For example, several studies have identified negative health effects of pollutants such as ammonia and UFPs. In recent years, both pollutants have been suggested to be abundant on the local scale due to traffic emissions (Cape et al., 2004; Durbin et al., 2001; Perrino et al., 2003; Perrino et al., 2002; Skjøth and Hertel, 2013; Onat and Stakeeva, 2013; Dennekamp et al., 2002; Tomlin et al., 2010). The levels of both pollutants are yet unregulated in ambient air and are rarely measured. Similarly, there is evidence that links BC, a relatively good marker for TRAP, to a wide range of adverse health effects (Khreis et al., 2017; Luben et al., 2017). Yet, this pollutant is also unregulated.

## Burden of disease and health impact assessments

The public health impacts of TRAP at the population level can be quantified using numerous approaches which employ standard BoD assessment frameworks. Quantitative BoD or HIAs commonly follow a comparative risk assessment approach as described in detail in Chapter 14, Health impact assessment of transport planning and policy. The key aim of these frameworks is to provide a quantitative estimate of the expected health impacts (e.g., number of cases of disease, premature deaths, and disability adjusted life years) and the distribution thereof for the exposed population that is attributable to the exposure to TRAP and/or the changes in the exposure to TRAP due to an intervention, policy or program outside the health sphere. The subtle difference between a BoD assessment and a HIA is in whether the health impacts of an intervention, policy, or program are being quantified where a HIA includes the assessment of an intervention, policy, or program while a BoD assessment does not. The following focuses on giving one example of a BoD assessment investigating the burden of childhood asthma attributable to TRAP in Bradford, in the North of England.

## Burden of disease assessment of traffic-related air pollution and childhood asthma

One form of quantitative BoD assessment can be conducted using the full-chain approach, previously introduced in Fig. 3.1. In a full-chain BoD model the modeling considers the full-chain from exposure source, through pathways to health outcomes. As such, the modeling can trace back the health impacts being quantified to the particular source of exposure. In practice, a full-chain BoD assessment is done by integrating existing models of traffic activity, traffic emissions, and air pollution dispersion to estimate and map ambient air quality. The produced ambient air quality maps are then overlaid with people's residential locations, and people's exposure to select air pollutants are estimated. Subsequently, the health impacts attributable to these exposures are estimated (Fig. 3.2). Data on the physical traffic network, traffic counts, origins and destinations and vehicle fleet composition can be used to construct traffic models for cities. Often, such models are readily, available in cities for other applications such as strategic transport planning. The outputs from traffic models, most importantly the traffic flows and average traffic speeds on a link by link basis, are then linked to vehicle emission models such as the European leading emission model known as COPERT (COmputer Programme to calculate Emissions from Road Transport). From this data, vehicle emission inventories are calculated for the entire traffic fleet on the road network. Vehicle emission inventories are then entered into air pollution

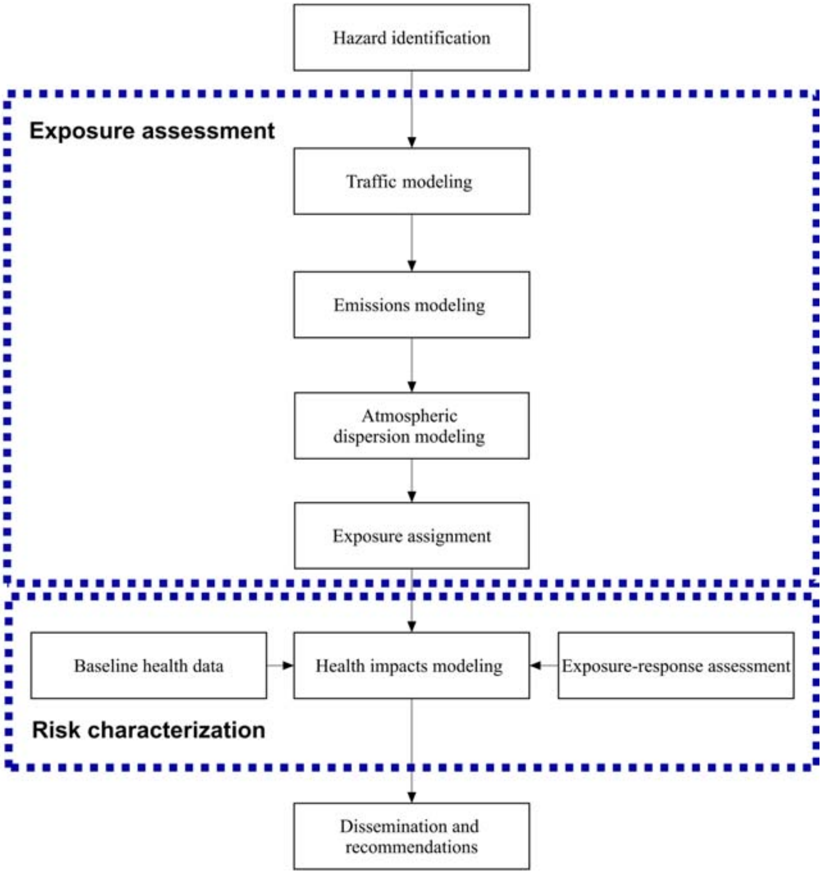


**Figure 3.2** Full-chain BoD assessment of TRAP. *BoD*, Burden of disease; *TRAP*, traffic-related air pollution.

dispersion models such as the widely used European model ADMS-Urban (Atmospheric Dispersion Modeling System-Urban). In dispersion models, traffic and emissions data alongside terrain, meteorological, and boundary layer data are used to estimate seasonal and/or annual air pollution concentrations and produce ambient air quality maps in a GIS environment. Exposures can then be assigned at the residential or census tract level, or even at the exposure microenvironments or routes (although this is less common in the literature), and the health impacts attributable to the exposure then estimated using standard BoD assessment methods.

Using the framework presented above, we previously conducted a full-chain BoD assessment of TRAP and childhood asthma onset for

Bradford, in the United Kingdom. The aim of the analysis was to estimate how many new cases of asthma, per year, may be attributable to children's exposure to TRAP, assigned at the smallest census tract level. The age group considered in this analysis was from birth to 18 years old, in line with the WHO definition of childhood and other biological evidence about that age group's susceptibility to air pollution. Besides modeling traffic, emissions, air-pollution dispersion and assigning children's exposure to the modeled air pollutants, exposure−response functions that quantify the strength of association between the exposure and the health outcome of interest were needed. Exposure−response functions for the association between exposure to TRAP and the subsequent development of childhood asthma from birth to 18 years old were extracted from metaanalyses reported in (Khreis et al., 2017). The exposure−response functions expressed the percentage change in the risk of developing childhood asthma in association with the selected unit of exposure for two different pollutants: $NO_2$ and $NO_x$. The $NO_2$ exposure−response function was based on the synthesis of 20 international studies and equaled 1.05 (95% confidence interval (CI): 1.02−1.07), per the exposure to 4 $\mu g/m^3$ $NO_2$. The $NO_x$ exposure−response function was based on the synthesis of seven international studies and equaled 1.48 (95% CI: 0.89−2.45), per the exposure to 30 $\mu g/m^3$ $NO_x$. Using these exposure−response functions, the risk estimates for asthma development were scaled to the difference in exposure level between the counterfactual (no exposure) and reference (current exposure as estimated from the air pollution dispersion model) scenarios to be able to estimate the risk that is due to that difference in exposure. To scale a risk estimate to the exposure difference between the counterfactual and reference scenarios, standard methods were used and are described elsewhere (Khreis et al., 2018). The result was a new risk estimate at each census tract which corresponded to the difference in exposure level between the counterfactual (no exposure) and reference (current exposure) scenarios.

The population attributable fraction (PAF) was then calculated. PAF is a standard metric used in quantitative BoD and also HIA. PAF defines the proportional reduction in morbidity that would occur if the air pollution exposure was reduced to the counterfactual scenario (no exposure scenario in this case). PAF is calculated using standard methods which use the proportion of the exposed population (100% in this case as all kids are exposed to some level of air pollution) and the previously scaled risk estimate at each census tract which corresponded to the difference in exposure level between the counterfactual (no exposure) and reference (current exposure) scenarios. Finally, the number of childhood asthma cases attributable to the excess exposure compared to the counterfactual (no exposure) scenario was calculated by multiplying the PAF by the overall number of new asthma cases in Bradford observed in the analysis year (i.e., number of new childhood asthma cases due to all causes). The overall number of new childhood asthma cases in Bradford that year was equal to the childhood population multiplied by the childhood asthma incidence rate observed in Bradford that year as was extracted from the literature. A full description of the methods and results from this analysis can be found in Khreis et al. (2018).

The key results of this exercise are shown in Table 3.4 and indicate that up to 638, or 35% of all, annual childhood asthma cases in Bradford may be attributable to air pollution, specifically children's residential exposure to $NO_x$. A total of 219 cases (12%) of those 638 were specifically attributed with the traffic component of $NO_x$ pollution, that is, TRAP. As shown in Table 3.4, the choice of the pollutant in the analysis ($NO_2$ vs $NO_x$) also made a measurable impact on the final estimates. $NO_x$ had a larger attributable burden, but a wider/less precise confidence interval, which was also statistically insignificant. These results are in line with other reports that show that the selection of the pollutant in the BoD assessment makes a measurable impact on the final estimates where, for example, traffic-related $PM_{2.5}$ was estimated to result in 7% of all annual childhood asthma cases in Bradford, while traffic-related BC was estimated to result in 12% of all cases (Khreis et al., 2019a). The numbers of asthma cases attributable to each pollutant should not be added up, but instead viewed as independent estimates of the potential impact of traffic-related air pollutants on childhood asthma burden. Which is the putative agent remains an open question and it is also unclear which pollutant is the most suitable to be used in future BoD assessments. A better integration with toxicological findings may shed light on the putative agent(s).

While the example above was concerned with the burden of childhood asthma, full-chain BoD assessments of TRAP can be used for any health outcome such as premature mortality, cardiovascular diseases, and metabolic diseases, if the baseline health data and exposure—response functions for that outcome are available for the study area and time.

**Table 3.4** Estimated annual attributable asthma cases in Bradford using the full-chain model (baseline asthma incidence = 137 per 10,000 person-year).

| Model | Pollutant | Attributable cases | Attributable cases lower confidence interval | Attributable cases upper confidence interval | Percentage of all cases | Attributable cases due to traffic |
|---|---|---|---|---|---|---|
| Full-chain | $NO_2$ | 394 | 173 | 520 | 22 | 128 (7%) |
| Full-chain | $NO_x$ | 638 | −256 | 1125 | 35 | 219 (12%) |

## Impact of emerging technologies

In this section, I will focus on the potential impacts of EVs and autonomous vehicles (AVs) on air quality and health. These two technologies are considered major disruptors in the transportation sector and are receiving increasing public and policy attention as potential solutions to the air quality and health crisis in many regions. However, their potential remains critiqued in a less balanced manner. EVs and AVs may enable "smart," more fuel, and energy-efficient transportation options and, therefore, have the potential to make cities healthier places through improved vehicle efficiency and reduced emissions. However, there remains a risk that adverse air quality and other outcomes such as reduced physical activity could be the result of their integration into the market. This is known as the "rebound effect" which refers to increased consumption or vehicle use [i.e., vehicle miles traveled (VMT)] following improved efficiency through the introduction of low-emission vehicles, EVs, and the convenience of autonomous and connected vehicles, including lowered travel costs (Litman, 2010). These effects, alongside select examples of quantification, are described in the following.

### Electric vehicles

EVs are often presented as a technology option with potential to result in significant reductions in greenhouse gas (GHG) emissions and exhaust TRAP, and therefore potentially resulting in many health benefits. However, a very small number of studies actually attempted to quantify the reduction in TRAP and improvements in public health for different EV scenarios, and these were reviewed elsewhere (Gouldson et al., 2018). It is also clear that overall air quality benefits cannot be achieved unless electricity used for charging these vehicles is generated by clean energy methods, such as solar, wind, and hydro. In many regions, there is a lack of progress with electricity decarbonization which significantly limits the potential emission and air quality benefits of EVs. The use of coal, for example, still constitutes 40% of global electricity generation (Smith et al., 2013). On the other hand, some good examples of practice emerge. Norway is a global leader in the production of clean energy (Global Citizen, 2018) and in the EV fleet size per capita (World Economic Forum, 2018). Norway also has the fifth lowest average concentration of fine particles in urban areas and the fourth lowest air pollution-related mortality rate, when compared to the rest of Europe (Bertrand, 2017). While Norway is a sterling example of how vehicle technologies may contribute to clean air through reduced exhaust pollution, EVs still pose air pollution and health risks through non-exhaust pollution (dust, brake, tire, and road surface abrasions, and electricity generation emissions) (Timmers and Achten, 2016; Thorpe and Harrison, 2008), which remain unregulated. Nonexhaust pollution can account for 90% and 85% of $PM_{10}$ and $PM_{2.5}$ produced by vehicle traffic, respectively, and the difference in nonexhaust pollution between internal combustion motor vehicles and EVs is negligible (Timmers and Achten, 2016). A state-of-the-art review by Timmers and Achten in 2016 discussed the potential effects of fleet electrification on nonexhaust PM emissions and found that total $PM_{10}$ emissions from EVs—originating from power plant emissions—are likely to be higher than their nonelectric counterparts, while a reduction in $PM_{2.5}$ emissions from EVs is estimated to be negligible (1%–3%) (Timmers and Achten, 2016). Soret et al. (2014) on the other hand estimated that fleet electrification can reduce total $NO_x$ emissions by 11% and 17%, in Barcelona and Madrid, respectively, but only if 40% of all vehicles were substituted by EVs (including two-wheelers, heavy duty vehicles, buses, and light-duty vehicles). Like Timmers and Achten's conclusion, the fleet electrification was found to have a limited impact on $PM_{10}$ emissions (3%–4% emissions reductions). In a large-scale and a rare HIA, Ji et al. modeled the health impacts of the use of conventional vehicles and EVs in 34 major Chinese cities. $PM_{2.5}$ emissions from EVs were estimated to be higher than conventional gasoline vehicles, resulting in more preventable deaths, even after accounting for proximity to the emission sources. Of the total excess deaths per year in Shanghai, nine were attributable to gasoline cars and 26 to EVs. When compared with diesel cars, EVs were shown to provide health benefits, yet the main reason behind these was not the reduction of total exhaust $PM_{2.5}$ emissions from EVs, but the fact that most of these emissions occur at power plants, away from major population centers. There was evidence, however, that the urban use of EVs will move exposures and adverse health impacts to rural, nonelectric-car-users, who are lower socioeconomic populations (Ji et al., 2012).

## Autonomous vehicles

Twenty-two states in the United States (Brookings Institute, 2018), as well as the United Kingdom, Germany, South Korea, and Singapore

(Bloomberg, 2018), have passed legislation permitting the use of fully autonomous (Level 4 according to the US Department of Transportation) (National Highway Traffic Safety Administration, 2013) vehicles on their roads. This trend necessitates research to understand how AVs will impact air quality and public health.

Two opposing schools of thought have emerged regarding the potential impacts of AVs: one espouses the benefits of reduced road congestion (Alessandrini et al., 2015), and the redevelopment and densification of urban spaces (Papa and Ferreira, 2018), while the other warns against the potential risks of increased comfort and convenience of automobile travel which is likely to increase VMTs and encourage further sprawl of urban areas (Papa and Ferreira, 2018; Stead and Vaddadi, 2019). Accordingly, the impact of AVs on air pollution and human exposure will depend on whether the use of AVs increases VMT. It will also depend on the fuel technology AVs will adopt and the extent to which AVs pollute (with gasoline and diesel engines polluting more than electric AVs). The extent of integration between AVs and active and public transport is another important aspect to consider when assessing the air quality and health impacts of AVs. In brief, there has been suggestion that AVs' implementation could increase air pollution exposure if it increases overall VMT, which is a valid possibility, especially if AVs continue to rely on internal combustion engines, and/or if AVs use does not facilitate active and public transport use. Also, as TRAP is not limited to exhaust emissions, even the electrification of the AVs fleet might not be enough to mitigate adverse impacts. EVs have been suggested to emit more nonexhaust emissions due to their higher weight compared to non-EVs (Timmers and Achten, 2016). If AVs use increases VMT, even with a shift to electrification, nonexhaust emissions will be an issue. Potential strategies to reduce these emissions include source minimization by improving the wear properties of materials, and reducing the wear potential of traffic (e.g., studded tires), and minimizing dust suspension to air by removing dust from road surfaces (road cleaning), immobilizing dust (binding dust to road surfaces), and adjusting traffic (less traffic, lower speeds, lighter weight vehicles). Another function of AVs that could contribute to reduced emissions is car sharing (Faisal et al., 2019). Shared AVs could remove more than twice as many vehicles compared to conventional car sharing systems, which would reduce congestion, travel time, pollution sources, and emissions (Fagnant and Kockelman, 2015; Paradatheth, 2015). Liu et al. (2017) estimated vehicle emission reductions due to shared AVs replacing conventional motor vehicles. While substantial vehicle emission reductions were estimated (−16.8% GHG, −24.3% PM, −30.7% $NO_x$, −24.3% $SO_2$, −42.7% CO), VMT was assumed to increase, offsetting some reductions (Liu et al., 2017). Similarly, a 2017 simulation of AVs integration (37.5% vehicle mode share) in Boston estimated that the number of vehicles on the road would decrease by 15%, but VMT would increase by 16% as a result of additional trips to pick up or drop off passengers in mobility-on-demand offerings and from empty miles driven by mobility-on-demand vehicles between passenger rides (World Economic Forum, W. and B. The Boston Consulting Group, 2018). These findings echo the sentiment of the rebound effect that (shared) AVs may reduce the temporal (Wadud et al., 2016) and monetary costs (Paradatheth, 2015; Wadud et al., 2016) of motor vehicle travel and contribute to an increase in total automobile travel (number of trips and VMT) (Wadud et al., 2016), degrading air quality and having other adverse health effects through, for example, reducing active and public transport. A more detailed discussion of the potential health impacts of AVs through changes in TRAP and other exposures can be found in Sohrabi et al. (2020) and Rojas-Rueda et al. (2020).

## Best practices and overlap with other agenda

While this chapter focused on TRAP and associated adverse health impacts, it is important that the health issues of urban traffic are considered holistically, and not just from an air quality perspective. Urban traffic is responsible for many adverse environmental exposures and associated adverse health effects that extend well beyond the effects of poor air quality (Khreis et al., 2016), as outlined in this book, and the relative importance of these different exposures varies significantly based on the local context and baseline environmental and health conditions. In the most comprehensive framework to date, we identified as many as 14 pathways linking transportation and health (Khreis et al., 2019b), namely, green space provision and aesthetics; active travel; access to health care and health promoting opportunities; mobility independence; contamination; social exclusion; transportation noise; urban heat islands due to transportation infrastructures; motor vehicle crashes; transportation air pollution; community severance; electromagnetic fields from connected and automated vehicles; and commuting stress and climate change due to transportation GHGs. It is clearly simpler to address any of these issues in isolation, but there is emerging research that shows how a narrow focus on any one of these issues can result in unintended consequences (Khreis et al., 2020b, 2016; Cames and Helmers, 2013), and also, how integrated policy packages which aim to address more than one of these issues can be particularly effective in achieving a multitude of goals such as increasing physical activity to promote public health and mitigating climate change (Gouldson et al., 2015; Glazener and Khreis, 2019; May et al., 2018). This section briefly overviews the best urban transportation practices which can not only improve air quality and public health outcomes but also address the lack of physical activity in many cities and the dangers of climate change. The section draws on two large-scale reviews which we conducted in previous work and which the reader can refer to for full details (Gouldson et al., 2018; Glazener and Khreis, 2019).

## Best practices for climate change mitigation and reduced traffic-related air pollution

Three core categories of low-carbon urban transport policies (LCUTP): land-use changes toward more dense, diverse and connected designs, modal shift to active transport and public transport improvements, and fleet improvement and transport electrification were identified in previous work as the most promising policies to mitigate transportation-related GHG in cities (Gouldson et al., 2018). These three categories also have great potential to reduce TRAP in cities and improve associated health outcomes. It, however, is more plausible that the first two categories (land-use and modal shifts) would yield the most benefits as these LCUTP tackle the issue of TRAP at its root, by reducing dependence on private motor vehicles and VMT. For example, Ewing et al. (2008) found that increasing density in the United States by shifting to a type of urban development with a 50-unit increase per hectare could reduce vehicle kilometers per capita by up to 40%. Comparisons of urban centers have found that dense, highly connected urban centers such as Hong Kong produce only one-third of the carbon emissions per capita of European cities, while European cities produce only one-fifth of the carbon emissions of sprawling and poorly connected cities such as Houston (Rode et al., 2014). Conversely, urban sprawl, and the resulting homogenous land-use and low-density development patterns, commonly found in the United States, reinforce the need and convenience for extensive road networks and private car travel, leading to higher emissions and higher TRAP (Frumkin, 2016). Land-use changes are also tightly linked to modal shifts and the feasibility of public transport investments. Higher density, for example, is often a prerequisite for large scale public transport investments. At the same time, choices made around land-use in urban areas heavily influence transport choices and can "lock" a region to a particular travel pattern. Low density suburbs around the periphery of many cities in North America are laced with roads and highways that are expensive to remove (infrastructural lock-in). These patterns eventually make nonmotorized transport practically impossible for many trips (behavioral lock-in) leading to dependency on private vehicles that policymakers are cautious to challenge (institutional lock-in).

Overall, there is plenty of evidence to show that model shifts toward active and public transport options can reduce GHG emissions, improve air quality and associated health outcomes, in addition to increasing population levels of physical activity. For example, Nieuwenhuijsen and Khreis (2016) evaluated the emerging concept of car-free cities, primarily driven by the need to reduce GHG emissions, and their potential impacts on public health. The authors highlighted potential benefits due to the reduction in not only air pollution (up to a 40% reduction in $NO_2$ on car-free days) but also noise and heat island effects, and potential increases in green space and physical activity, suggesting that more systemic approaches are needed to realize the full benefits beyond a narrow focus on one exposure. A previous HIA estimated that 76 annual deaths, 16 minor injuries, 0.14 major injuries, 127 cases of diabetes, 44 of cardiovascular diseases, 30 of dementia, 11 of breast cancer, 3 of colon cancer, 7 of low birth weight, and 6 of preterm birth can be prevented each year, if 40% of long-duration car trips were substituted by public transport and cycling in Barcelona. The carbon dioxide reduction for shifting from car to other modes of transport (bike and public transport) in Barcelona metropolitan area was estimated to be 203,251 t/$CO_2$ emissions per year (Rojas-Rueda et al., 2012). Similarly, another HIA explored the potential health impacts of expanding cycling networks in 167 European cities. The study concluded that a cycling network of 315 km/100,000 persons maximizes the mode share of bicycles, which was estimated to be 24.6% of all trips taken (Mueller et al., 2018a). The health impacts of extending cycling network infrastructure are greatest in cities that have relatively limited cycling networks, while positive health impacts are lower in cities with well-established cycling networks (Mueller et al., 2018a). This study further examined the health impacts in seven European cities if a bicycle mode share of 24.6% was achieved and estimated that premature mortality would decrease by over 10,000 deaths annually (Mueller et al., 2018a).

Finally, the last category of LCUTP: fleet improvement and transport electrification is perhaps the least effective in producing TRAP reductions and health improvements through other pathways, although it has potential in reducing GHG. Electrification was already discussed in the previous section with the key take home message that if electricity generation is not clean, and adaptation rates are not high, air quality benefits will be limited. Further, the issue of nonexhaust TRAP has been understudied and warrants further attention. There is also little assessment of total life cycle, but some evidence that even the GHG impacts of EVs are heavily dependent on use phase energy consumption and the electricity mix used for charging (Hawkins et al., 2012). On the other hand, less evidence is available on the impacts of fleet improvement strategies on air pollution and health, despite it being a promising GHG reduction strategy. The available evidence suggests some improvements with potential for unintended consequences. For example, Lee et al. (2012) assessed the air quality and health impacts attributed to a clean truck program in the Alameda corridor in the United States, which progressively banned the older and most polluting trucks. The truck replacement was estimated to have reduced $NO_x$ and PM emissions by 48% and 55%, respectively, within a 7-year period. The health benefits from the reduction of $PM_{2.5}$ only was equivalent to US$428.2 million, but these estimates only incorporated two age groups (age 30−65, > 65), and two health endpoints (mortality and chronic bronchitis) (Lee et al., 2012). Sathaye et al. explored the air quality effects of a conventional freight logistics policy: shifting the logistic operations to night-time hours. Due to the more stable/restrictive atmospheric boundary layer conditions during the night, the authors showed that such a policy can increase the 24-hour air pollution concentrations in most locations in California and, therefore, worsen the daily human intake or, at best, leave it unimproved (Sathaye et al., 2010). There is clearly a need for more research regarding the effects of freight policies on air quality and public health, but there is also current evidence that freight vehicles are a major contributor to local and regional air quality problems, and that these can be mitigated by upgrading freight fleets and increasing their efficiency (Lee et al., 2012; Bickford et al., 2013).

## Best practices for increased physical activity and reduced traffic-related air pollution

Best transportation practices for increased physical activity and improving air quality have been reviewed in more depth in Glazener and Khreis (2019). This section will only briefly review the results from Glazener and Khreis (2019) and update some of them, as shown in Table 3.5. The best practices to encourage active transportation and improve air quality we identified have been separated into six categories: car-free policies, vehicle technologies, urban design interventions, active transportation investments, green spaces, and integrated policy strategies. Most of these strategies were addressed to a certain extent earlier. Under each of these categories lies a range of potential specific policy measures which vary in their capacity to reduce TRAP and increase physical activity via active transportation. More details on these strategies can be found in Table 3.5.

## Environmental justice

Environmental justice is a key issue which needs careful consideration when assessing the health impacts of TRAP and planning or making policies to mitigate them. In the author's opinion, there is no shortage of literature showing that exposures to TRAP, and, therefore, its associated adverse health effects, tend to be higher and more concentrated in lower socioeconomic locales and ethnic minority communities, and the reader can refer to the chapter by Fuller and Brugge in Khreis et al. (2020b) and the chapter by Khreis and Nieuwenhuijsen in Lucas et al. (2019) for a more detailed overview of the literature. There is, however, some noteworthy heterogeneity in the literature which can especially be observed in large metropolitan areas and some European cities. All these trends will be briefly described next.

Morello-Frosch et al. (2001) employed recent advances in air emissions inventories and air pollution modeling to consider a range of outdoor air toxics in Southern California and calculate lifetime cancer risks associated with pollutants. The authors found that such risks are attributable mostly to transportation and small-area sources and not the usually targeted large-facility pollution emissions. Their analysis also suggested that race played an explanatory role in the risk distribution, even after controlling for other

| Policy/practice | Targeted outcome | Benefits air quality? | Benefits active transportation? | Overall impact |
|---|---|---|---|---|
| *Car-free policies* | | | | |
| Car-free cities/days (Nieuwenhuijsen and Khreis, 2016) | Reduce motor vehicle use and emissions | Yes | Yes | Reducing motor vehicle use will improve air quality and result in more physically active populations through shifts to active transportation |
| Low-emission zones (O'Sullivan, 2018) | Restrict motor vehicle access to high polluting cars | Yes | No | Restricting access to certain parts of the city to high polluting vehicles can improve air quality |
| CicLAvia (Shu et al., 2016) | Encourage cycling | Yes | Yes | Restricting car access in certain areas or specific streets in Los Angeles to promote cycling and also reduce TRAP |
| Congestion charging (Eliasson, 2014) | Disincentivize motor vehicle use through increased cost | Yes | Potentially | Reduce motor vehicle use by requiring a fee to drive on designated roads and potentially induce a mode shift |
| Distance-based road pricing (Cavallaro et al., 2018) | Disincentivize motor vehicle use through increased cost | Yes | Potentially | Charging a fee based on distance driven can discourage total VMT and related emissions |
| Parking pricing (Pierce and Shoup, 2013) | Disincentivize motor vehicle use through increased cost | Yes | Potentially | San Francisco has introduced a fluctuating pay-to-park systems that limits the amount of time spent cruising for parking |

Table 3.5 Best practices to reduce traffic-related air pollution (TRAP) and increase physical activity.

(*Continued*)

**Table 3.5** (Continued)

| Policy/practice | Targeted outcome | Benefits air quality? | Benefits active transportation? | Overall impact |
|---|---|---|---|---|
| *Vehicle technologies* | | | | |
| Autonomous vehicles | Improve vehicle operation efficiency | Potentially | No | Improved efficiency of driving patterns can increase fuel efficiency and reduce the total number of vehicles on the road |
| Electric vehicles | Reduce vehicle exhaust pollution | Potentially | No | By removing tailpipe emissions from TRAP air quality can be improved |
| *Urban design interventions* | | | | |
| Active transportation infrastructure (Smith et al., 2017) | Increase active transportation | Yes | Yes | Constructing sidewalks and cycling lanes to increase safety and accessibility for traveling by active modes |
| Built environment design (Sallis et al., 2016) | Create a built environment more conducive for walking and cycling | Potentially | Yes | Walkability, density, land-use mix, and active transportation infrastructure can reduce vehicle use |
| Traffic calming measures (Speck, 2012) | Slow motor vehicle traffic | Potentially | Potentially | Shrinking lane width, adding medians, and lowering speed limits can reduce vehicle traffic speed and make active transportation safer |
| Segregated bike lanes (Hull and O'Holleran, 2014) | Increase safety for cyclist | Potentially | Yes | Constructing bike lanes that are separated from the street can improve safety and increase cycling rates and potentially induce a modal shift |

| | | | | |
|---|---|---|---|---|
| Mode shift (Rojas-Rueda et al., 2016) | Encourage the use of alternative transportation modes to motor vehicles | Yes | Yes | Increased active transportation can derive health benefits and reduce motor vehicle use and TRAP |
| Superblocks (Klause, 2018) | Restrict motor vehicle access and provide space for active transportation | Yes | Yes | Superblocks aim to restrict motor vehicle access and provide more space for active transportation |
| Extended cycle networks (Mueller et al., 2018a) | Increase cycling connectivity | Potentially | Yes | Further developing cycling networks can increase cycling mode share in cities |
| Complete streets (Zhu et al., 2016) | Improve safety and connectivity for pedestrians and cyclists | Yes | Yes | Adding infrastructure on streetscapes to slow vehicle traffic and allow active transportation can produce healthier outcomes |
| Parking standards (Kodransky and Hermann, 2011) | Limit the amount of parking provided | Potentially | Potentially | Enforcing parking maximums, or banning the development of parking spaces, forces people to travel by active and alternative transportation |
| *Green spaces* | | | | |
| Tree planting (Nowak et al., 2006) | Increase pollution uptake by trees | Yes | No | Trees can uptake air pollution and have a positive impact on air quality |
| | Provide green spaces in urban areas | Yes | Yes | |

(*Continued*)

**Table 3.5** (Continued)

| Policy/practice | Targeted outcome | Benefits air quality? | Benefits active transportation? | Overall impact |
|---|---|---|---|---|
| Green space provision (Wolch et al., 2014) | | | | Green spaces can improve local air quality and invite people to be more active if green spaces are perceived to be safe and aesthetically pleasing |
| SGIS (National Parks Board) | Vegetation that can uptake air pollution | Yes | No | Substituting the loss of green ground cover by installing green roofs, green walls, and gardens |
| *Public transportation investment* | | | | |
| Developing public transportation systems (Anderson, 2014; Saelens et al., 2014) | Improving/introducing public transportation connectivity and access | Yes | Yes | Public transportation users generally exhibit higher physical activity rates than motor vehicle commuters and public transportation can replace motor vehicle trips and congestion, reducing emissions and TRAP |

*SGIS*, Skyrise greenery incentive scheme; *VMT*, vehicle miles traveled.

economic, land-use, and population factors. Similarly, a recent study estimating annual average $NO_2$ concentrations across the contiguous United States and over a 10-years period (2000–10) demonstrated that disparities in air pollution exposure were related to income and race-ethnicity. These disparities were, however, larger by race-ethnicity, than by income (Clark et al., 2017). On average, estimated $NO_2$ concentrations remained 37% higher for nonwhites than whites in 2010, which showed no progress compared to the year 2000 (Clark et al., 2017). Another pioneer United States national-level study paired information about the geographic locations and demographics of 84,969 public schools with air neurotoxicant exposure estimates pertaining to 24 known neurotoxicants included in the US EPA's National Air Toxics Assessment. The study found that students attending "high risk" public schools nationwide (in the top 10% most burdened by air neurotoxicant exposures) were significantly more likely to be eligible for free/reduced price meals, and to be Hispanic, black, or Asian/Pacific Islander than white or another race. The study also showed that schools serving the youngest students (e.g., prekindergarten) have greater presence of air neurotoxicants than schools serving older students (Grineski and Collins, 2018). Another HIA focusing on adults' premature mortality related to $PM_{2.5}$ exposure in Bradford, in the United Kingdom, found that residents of lower socioeconomic position, as defined by deprivation status and ethnicity, had the highest risks for adverse exposure and attributable premature death (Mueller et al., 2018b). The above observations are in line with a wealth of older and newer studies from around the world. These trends showing that exposure levels are often socially patterned with more socioeconomically deprived or ethnically diverse communities being more adversely exposed are not limited to air pollution. In fact, they extend to other traffic-related exposures such as noise, heat, green space and access to physical activity opportunities (Khreis et al., 2016; Mueller et al., 2018b).

However, some perhaps less intuitive trends emerge in the literature as well. For example, we recently showed that the distribution of childhood asthma cases attributable to $NO_2$ and stratified by median household income group broadly followed a U-shaped distribution: the lowest and the highest median household income groups had the highest burden (Khreis et al., 2020a), corresponding to the highest $NO_2$ exposures in those strata (Clark et al., 2017; Khreis et al., 2020a). While we cannot exclude the potential for exposure and median household income misclassification, this trend may reflect two things. First, low-income populations reside in the most polluted census blocks due to financial costs of housing in less polluted areas, a finding that is well established in the environmental justice literature (Hajat et al., 2015). Second, it is possible that the highest income populations also live in highly polluted census blocks as they prefer to live near the amenities of busy downtowns and central business districts, where TRAP is higher. If this were the case, it does not apply to all states and may even differ by rural, urban, and urbanized area status (Khreis et al., 2020a). Indeed, previous work suggested that metropolitan areas in particular exhibit considerable heterogeneity when it comes to socioeconomic status and exposure to air pollution. For example, in cities such as New York, wealthy neighborhoods have been associated with higher concentrations of pollution (Hajat et al., 2013). Finally, it is worth noting that lower socioeconomic status populations and ethnic minorities do not only often bear the highest exposure burden but also exhibit a variety of intrinsic and extrinsic factors which makes them even more susceptible to their exposures (Khreis et al., 2016, 2019a). These factors include malnutrition and the lack of antioxidant intakes, exposure to stress, exposure to violence, and genetics. These factors can modify and often amplify the adverse health effects of TRAP exposures.

## Research gaps

The research on TRAP and human health has greatly evolved in the past few decades. Many subareas were significantly advanced, including advancing methods to assess TRAP and human exposures, establishing numerous and studying emerging health effects, devising air quality guidelines and yet showing health risks occur below these thresholds, using BoD and HIA methods to quantify the health burden attributable to TRAP and demonstrating the distribution of that burden, quantifying the potential impacts of a wide range of policies and an enhanced understanding of the potential health impacts of emerging technologies and best practices to achieve a multitude of goals, beyond air quality. We have come a long way, but there are as yet important knowledge gaps which need to be filled and which offer exciting research opportunities and a pathway to push and track progress toward the goal of universal clean air. In this section, I will outline key open questions and research gaps in the broader area of TRAP and health research.

We need a better understanding of mortality and morbidity effects at low and high air pollution concentrations, which are two air pollution ends that are becoming increasingly relevant, as the air of developed nations becomes progressively cleaner, while air pollution in developing nations is unprecedentedly peaking. We also lack information on the health effects of the multitude of traffic-related air pollutants. For example, several studies have identified negative health effects of pollutants such as BC, nonexhaust PM components, UFPs and ammonia (a by-product of selective catalytic reduction technology and an important contributor to the formation of secondary fine particles and UFPs). These pollutants are not routinely measured or commonly researched and are yet unregulated. However, studies have shown that these pollutants are abundant on the local scale due to traffic emissions and that their toxicity might be higher due to factors such as the size of particles, very high local concentrations (and numbers in the case of UFPs), high surface areas, oxidative potential, and toxic chemistry. Recent research has focused on $NO_2$ as a relatively easy to measure marker of traffic, especially in urban areas, and on $PM_{2.5}$, yet the putative agents in the TRAP mixtures remain largely unknown and speculated. Specifically, there is unresolved debate about whether $NO_2$ is a causal agent for numerous associated health outcomes or simply an indicator of other traffic-related air pollutants and/or the effect of the mixture. Researching the wider range of air pollutants' effects, beyond $NO_2$ and $PM_{2.5}$, and specifically studying subsets of PM, their chemistry and their toxicity, might further advance the science. A better integration between epidemiological and toxicological research is also needed to ground epidemiological observations and identify underlying mechanisms driving the observed effects (Khreis et al., 2019a). Another contemporary issue which also warrants further attention is the relative importance of nonregulated, nontailpipe emissions in health effects and the BoD of TRAP. These emissions can increase, both in the developed and developing world, with the expected widespread introduction of EVs and are currently unregulated. Despite this, very few studies addressed the health effects of nontailpipe emissions, which again relates to the need for better PM speciation and analysis, and not treating all PM as one pollutant with homogenous health effects.

There are also emerging health effects of air pollution which can substantially contribute to BoD assessments. The inclusion of these outcomes can provide a more complete picture of the true burden of TRAP across a spectrum of outcomes beyond mortality. These health effects include, but are not limited to, pregnancy complications and adverse birth outcomes, effects on fetal growth and birth defects, human reproduction and neurotoxicity outcomes such as dementia and cognitive decline. These impacts are yet to be included in routine BoD assessments such as the Global Burden of Disease Study or even in academic exercises of BoD and HIA. For example, no BoD or HIA currently exists for (traffic-related) air pollution and cognitive decline or dementia, and the overall BoD and associated health costs attributed to air pollution exposure may have, therefore, been grossly underestimated.

The health effects of air pollution are also not the same in different populations, despite the tendency in research, partly due to data availability and statistical power concerns, to estimate overall risk estimates in the total population rather than analyzing susceptible subpopulations. Extrinsic and intrinsic effect modifiers that have been identified in air pollution epidemiology, but which have not been systematically studied, include socioeconomic status, nutrition, stress, exposure to violence, coexposures (e.g., noise, heat, and contamination), ethnicity, age, sex and genetics. A better understanding of these factors, and a more specific exposure—response function estimation in subpopulations, can help advance HIA and BoD assessment methods and better steer limited mitigation resources within cities. While there is a consensus that the benefits of regulations and pollution abatement strategies outweigh the costs of implementation, especially when considering cobenefits beyond human health such as climate change mitigation, the benefits of solutions are very policy and context specific and should be treated as so. Additional analysis, especially tracking the full-chain between air pollution sources and their ultimate health impacts, can shed light on the impacts of specific measures in specific locations and populations and may strengthen the case for action. Full-chain HIA and BoD assessments will be particularly useful in studying the potential impacts of emerging technologies.

New advancements in the practice of air pollution monitoring also open new questions for research. Historically, air pollution surveillance has relied on costly and resource-intensive fixed-site monitoring stations. However, in recent years, the rapid development of low-cost sensor technologies is playing increasingly important roles in measuring air pollution concentrations and assigning human exposures. The proliferation of low-cost sensors is still challenged by quality and durability issues, and before these technologies can be increasingly used in citizen science and serve a role in air quality surveillance, health studies and public awareness, more research on their accuracy and precision is needed.

Finally, it is imperative that future research considers the multitude of exposures that occur in the real world and studies the interactions and effect modifications of air pollution effects with other exposures such as green space, heat, noise, and physical activity. Such research can further advance the estimation of exposure−response functions and, therefore, HIA and BoD assessments. It is also important that when quantifying the health impacts of select policies or emerging technologies, research not only considers TRAP, but also cobenefits for climate change and changes in health outcomes due to other pathways such as green space, heat, noise, and physical activity (Khreis et al., 2019b). We are in desperate need for systemic and holistic approaches to tackle the increasingly multifaceted issues in our contemporary societies. The one exposure-one outcome approach is no longer valid and will only lead to a narrow focus and negative, "unintended," consequences.

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CHAPTER FOUR

# Transport, noise, and health

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## Contents



## Introduction

### Mette Sørensen

Urbanization and traffic growth have led to a rise in noise pollution, particularly in transportation noise pollution (from road, railway, and aircraft traffic). The dominant source is road traffic noise, and mapping of EU shows that >25% of the population are exposed to road traffic noise exceeding the EU guideline limit of 55 dB ($L_{DEN}$: average over whole

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day) (European Environment Agency, 2014). In a recent report, WHO strongly recommends to lower this limit to 53 dB for road, 54 dB for railway, and 45 dB for aircraft noise to prevent adverse health effects (World Health Organization, 2018).

Transportation noise is classified as the second worst environmental risk factor in Europe, only exceeded by air pollution (Hanninen et al., 2014; World Health Organization, 2011). According to WHO, environmental noise (dominated by transportation) accounts for >1 million healthy years of life lost annually in Europe, with a disability-adjusted life-year (DALY) loss of 61,000, 654,000, 903,000, and 45,000 for ischemic heart disease, annoyance, sleep disturbance, and cognitive impairment in children, respectively (World Health Organization, 2011). Moreover, transportation noise may increase risk for other major diseases, which would add substantially to the DALY estimate, including stroke (Sorensen et al., 2011), diabetes (Zare Sakhvidi et al., 2018b), cancer (Sorensen et al., 2014), and major risk factors, such as obesity (An et al., 2018).

In this chapter, we summarize mechanistic and epidemiological research on effects of transportation noise on health.

## What are the mechanisms by which noise can lead to disease?

### Thomas Münzel

According to the noise-effect reaction scheme introduced by Babisch, noise can act through a direct and an indirect pathway (Babisch, 2002). The direct pathway dictates that high noise levels (>85 dB) can lead to hearing loss, whereas lower levels of noise will initiate the indirect pathway, with a cognitive perception of the sound followed by a physiological reaction resulting in cortical activation and disturbances of sleep, activities, and communication (Babisch, 2002; Munzel et al., 2014). The activation of the indirect pathway by noise is characterized by an increase in sympathetic responses and release of corticoids (Munzel et al., 2014), which may increase a number of biological risk factors, including higher blood viscosity, blood coagulation, and rise in blood pressure (Lundberg, 1999).

In recent years, clinical and mechanistic studies investigating potential roles of noise in disease development have been conducted. A field study with controlled exposure to nighttime noise at home, found simulated aircraft noise (30 and 60 flights/night, peak noise 60 dB) to be associated with worsening of vascular (endothelial) function, increased stress hormone levels, and decreased sleep quality in both healthy subjects (Schmidt et al., 2013) and in patients with prevalent coronary heart disease (Schmidt et al., 2015). Interestingly, the impairment of vascular function in healthy subjects was significantly improved by the single administration of vitamin C, suggesting that increased oxidative stress was at least in part responsible for aircraft noise-induced impairment of endothelial function (Schmidt et al., 2013). This was confirmed in two recent animal studies, which found that simulated aircraft noise exposure for 4 days led to a significant increase in stress hormone levels, increased blood pressure, changes in vascular wall gene expression and impaired vascular function, mainly due to increased free radical formation and oxidative stress (Kroller-Schon et al., 2018; Munzel et al., 2017). These two studies furthermore identified the involvement of two enzymes in the initiation of noise-induced vascular dysfunction: the nicotinamide adenine dinucleotide phosphate oxidase (NOX-2) and the nitric oxide synthase (NOS). The noise-induced dysregulation of these enzymes enhanced the formation of reactive oxygen species, which directly led to decreased vascular bioavailability of nitric oxide (NO), an important radical with powerful vasodilator and antiatherosclerotic properties and thus resulted in the impairment of endothelial function. Aircraft noise applied during the sleeping phase of the animals furthermore reduced the expression of genes responsible for the regulation of the circadian clock, reduced the expression of neuronal NOS (an enzyme being responsible for memory and learning) and uncoupled the enzyme along with an increase in cerebral NOX-2 expression (Kroller-Schon et al., 2018). In NOX-2 knockout mice, aircraft noise did not increase blood pressure or caused damage to the vasculature and the brain (Kroller-Schon et al., 2018). Fig. 4.1 summarizes the proposed biological mechanisms behind an effect of noise on cardiometabolic disease.

## Noise-induced annoyance and sleep disturbances

### Mark Brink

The implication from the plethora of noise effect studies conducted during the last decades is that noise impacts on a wide array of parameters of health

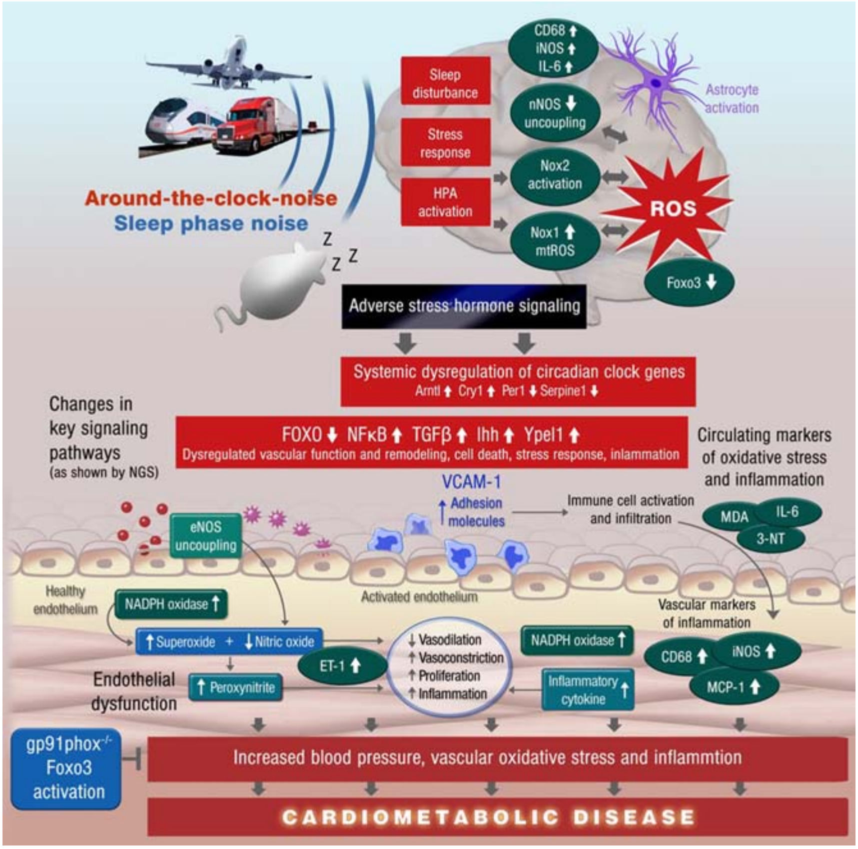


**Figure 4.1** Mechanistic scheme showing potential effects of noise on the cardiovascular system. Around-the-clock and sleep phase noise triggers cerebral oxidative stress and a neuroinflammatory phenotype that translates the adverse effects of noise to the vascular and systemic level (e.g., by adverse stress hormone signaling and dysregulation of circadian clock inducing changes in key signaling pathways). Noise via neuronal pathways triggers vascular oxidative stress and inflammation with subsequent endothelial dysfunction, increases in blood pressure, all of which contributes to the development and progression of cardiometabolic disease.

and well-being. Of those, noise annoyance and sleep disturbances are probably the most prevalent effects of noise. The WHO reported in terms of DALYs that in Western Europe, 587,000 healthy years are lost due to annoyance, which puts this effect in the second place after noise-induced sleep disturbances (903,000 years), and ahead of ischemic heart diseases (61,000 years) (World Health Organization, 2011). Due to its omnipresence, road traffic is responsible for the largest fraction of this burden.

In the population the probability to be annoyed by noise is many times larger than noise-induced somatic disease risks. As noise annoyance usually develops in short time, it can be seen as an early warning signal for other long-term health risks. The rather general expression of annoyance is, therefore, assumed to provide the most straightforward (and simplest to measure) estimate of the overall effect environmental noise exerts on populations.

The noise annoyance response of an individual comprises several elements: an often repeated disturbance of certain activities (e.g. sleeping or doing homework), an effective response such as anger about the disturbance or the source of the noise, and a cognitive response, that is, the distressful insight that one cannot do much about it (Guski and Felscher-Suhr, 1999).

Research into noise annoyance is largely empirically driven and usually aims at describing the relationship between exposure to noise from a specific source and the degree of annoyance that this source generates. Annoyance is usually assessed by self-report using verbal or numeric (thermometer) scales (Fields et al., 2001). The annoyance response of a particular individual can be predicted from noise exposure only with considerable uncertainty. It is therefore more practical to use the percentage of highly annoyed persons (%HA) within a noise exposure category as the descriptor of interest, at least when it comes to informing regulatory purposes, for example, the setting of exposure limits. A recent metaanalysis (Guski et al., 2017) provides a practical yardstick for the assessment of annoyance from road, rail, and air traffic noise.

Evidence has increased that annoyance reactions to noise from transportation sources have changed over the last few decades and recent studies indicate that people react more strongly to a given noise exposure level today than in the past, especially in the case of aircraft noise (Janssen et al., 2011; Schreckenberg et al., 2015). Fig. 4.2 shows recently derived confounder-adjusted exposure response-curves reflecting the percentage of highly annoyed persons for road traffic, railway, and aircraft noise in Switzerland (Brink et al., 2019a).

When William Shakespeare once called sleep the “chief nourisher of life’s feast," he was doubtlessly ahead of his time. Nowadays, it is undisputed that undisturbed sleep of sufficient length is an essential prerequisite for daytime alertness and performance, quality of life, and ultimately, health (Luyster et al., 2012). While visual stimuli can be largely suppressed during sleep, hearing is not reduced and retains its ability to alert us from

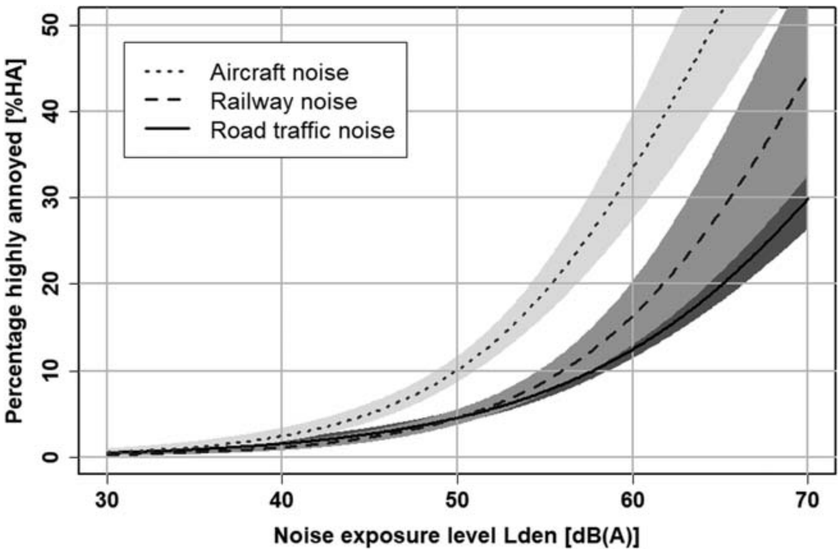


**Figure 4.2** Exposure–response curves that describe the relationship between noise level, here, expressed as Day-Evening-Night Level ($L_{DEN}$), and the percentage of the exposed population that reports to be highly annoyed (%HA) by aircraft, railway, or road traffic noise, including 95% confidence limits as shaded areas.

sources of danger also during sleep. As it lies in the human nature to constantly perceive, evaluate, and react to environmental sounds, being exposed to noise while asleep impacts on sleep both quantitatively and qualitatively. Sleep disturbance is considered one of the most deleterious nonauditory effects of environmental noise (Muzet, 2007). From a public health perspective, sleep disturbance in and of itself can be regarded a relevant health outcome. But noise-induced sleep disturbances are also suspected to be in the causal pathway to cardiovascular disease (CVD) as nonhabituating autonomic reactions to noise events during sleep may be important precursors of long-term cardiovascular outcomes (Brink, 2012; Schmidt et al., 2013). There is evidence that nocturnal noise exposure also disturbs metabolic processes, for example, glucose regulation (Thiesse et al., 2018). Too much noise at night may also lead to chronic partial sleep loss, which plays a role in the current epidemics of obesity and diabetes (Van Cauter et al., 2007).

Noise-induced sleep disturbances can be objectified by a number of indicators [for overview see (Basner et al., 2012)]. Unlike the measurement of noise annoyance, where a well-established standard is commonly applied in surveys (Fields et al., 2001), consensus on a measurement technique for the assessment of environmental noise effects on sleep is still missing. In laboratory and field studies, researchers typically investigate not only the effect of noise on outcome measures such as actigraphy (with wrist-worn devices that infer sleep and wake patterns from body movements), alterations of the electroencephalogram (EEG) (i.e., awakening reactions), and cardiovascular arousals (short-living heart rate increases), derived from polysomnography or electrocardiography respectively, but also on changes in the so-called global sleep quality parameters such as total sleep time or sleep efficiency. Last but not least, self-reported sleep disturbances due to noise can relatively easily be measured with questionnaires, a method typically used in large observational field studies.

The probabilities of acute physiological reactions to noise during the night are clearly correlated with acoustic characteristics of individual noise events, not only with the maximum sound pressure level ($L_{max}$) (Elmenhorst et al., 2012) but also with rise time (Brink et al., 2008) and spectral composition (Basner et al., 2011). Transportation noise events with $L_{max}$ as low as about 35 dB at the ear of the sleeper have been shown to induce EEG awakening reactions in ecological settings (Basner et al., 2006). Railway-induced vibrations also affect heart rate responses during sleep in a dose-effect manner (Schmidt et al., 2013). It is noteworthy that the mere existence of such acute responses does not necessarily qualify them as health outcomes, but they are probably a prerequisite thereof. Regarding self-reports of noise-disturbed sleep, a large survey derived statistically significant exposure—sleep disturbance relationships and found the most sleep disturbing noise source to be aircraft noise, followed by railway, and then road traffic noise (Brink et al., 2019b), reproducing the same order as found in a recent metaanalysis (Basner and McGuire, 2018).

While many field and laboratory studies clearly demonstrated associations between noise exposure and objective or subjective markers of disturbed sleep, the scientific community seems to be discordant about what exactly constitutes a relevant "noise-induced sleep disturbance" (and by which means it should be objectified) in persons who, besides being disturbed by noise, have normal sleep (Basner et al., 2010; Fidell et al., 2010). Lack of sufficiently confounder-controlled longitudinal information from amply powered cohorts is still the most serious drawback to infer causality between acute responses to noise and long-term health outcomes. However, it can also be argued that undisturbed sleep per se constitutes an asset worthy of protection, simply because people *enjoy* sleep, irrespective of its functional aspects. Thus it currently seems that the assessment of noise-induced sleep disturbance from self-reports is the outcome of choice for informing nighttime noise protection policy, evidenced also by its adoption in recent noise-related WHO publications (World Health Organization, 2011, 2018).

## Transportation noise and lifestyle factors

### Nina Roswall

Over the last few years, studies investigating the association between traffic noise and lifestyle-factors have emerged, suggesting that a noise-induced change in health behavior may be an important element on the causal pathway between noise and disease.

Transportation noise has been suggested to directly affect physical activity by rendering the outdoor environment unappealing as a venue for physical activity. But it may also exert indirect effects through sleep disturbance, which may negatively affect the capacity for physical activity, impair recovery, and increase the risk of injuries (Chennaoui et al., 2015) and stress, which, albeit with some heterogeneity, has been found to predict less physical activity and more sedentary behavior (Stults-Kolehmainen and Sinha, 2014).

Two studies have investigated the association between road traffic noise and physical activity: one examined subjectively assessed road traffic noise annoyance (Foraster et al., 2016) and the other modeled road traffic noise exposure (Roswall et al., 2017a). Both found road traffic noise negatively associated with physical activity in cross-sectional and longitudinal analyses, with the effect seen mainly on participation in leisure time sport (yes/no), rather than intensity, suggesting that noise affects whether people exercise at all, rather than the amount of time spent exercising.

Several cross-sectional studies have found a positive association between disrupted sleep and smoking and alcohol consumption (Chaput et al., 2012; Phillips and Danner, 1995; Stein and Friedmann, 2005; Wetter and Young, 1994), and a longitudinal study found onset of impaired sleep associated with subsequent lower odds for quitting smoking and initiating high-risk alcohol consumption (Clark et al., 2015). Both smoking and alcohol consumption have also been associated with stress:

people consume more alcohol during and after stressful life events (Jose et al., 2000) and use alcohol to cope with stress (Pohorecky, 1991). Stress has been positively associated with smoking initiation (Byrne et al., 1995; Torres and O'Dell, 2016), difficulty quitting smoking, and relapsing (Cohen and Lichtenstein, 1990; Torres and O'Dell, 2016).

One study has investigated transportation noise in relation to alcohol and tobacco use (Roswall et al., 2018b). They found road noise positively associated with alcohol consumption (adjusted difference per 10 dB: 1.38 g/day, 95% confidence interval (CI): 1.10−1.65), smoking intensity (adjusted difference per 10 dB: 0.40 g/day, 95% CI: 0.19−0.61), and odds for being a current versus never/former smoker at baseline (odds ratio: 1.14; 95% CI: 1.10−1.17) in cross-sectional analyses. In longitudinal analyses, there was no association with changes in smoking and alcohol habits. No associations were observed for railway noise. More studies on effects of noise on health behavior are needed, preferably of longitudinal design.

## Transportation noise and risk for cardiovascular and metabolic disease

### Mette Sørensen and Maria Foraster

A growing number of epidemiological papers are investigating effects of transportation noise on risk for cardiovascular and metabolic diseases, especially in recent years. Furthermore, technological advancements have enabled estimation of residential transportation noise in larger and larger study populations. This has resulted in a consolidation of the evidence for ischemic heart disease (Babisch, 2014; Kempen et al., 2018; Vienneau et al., 2015) and suggested that transportation noise may increase risk for other CVDs not investigated previously in a noise context (Heritier et al., 2017; Monrad et al., 2016).

### Noise and cardiovascular disease

Animal studies and field studies in humans have found transportation noise exposure in controlled settings to increase a number of cardiovascular risk markers, including vascular oxidative stress, endothelial dysfunction, inflammation, and arterial hypertension (Kroller-Schon et al., 2018;

Munzel et al., 2017; Schmidt et al., 2015; Schmidt et al., 2013), proposing that transportation noise is a cardiovascular risk factor.

Since the first epidemiological study in 1988 (Babisch et al., 1988), the association between transportation noise and ischemic heart disease has been extensively studied. In 2018 the WHO published a systematic review of the epidemiological evidence on transportation noise and risk of cardiovascular and metabolic diseases (Kempen et al., 2018; World Health Organization, 2018). For incident ischemic heart disease, road traffic noise was found associated with an 8% increase in risk for every 10 dB increase in noise, starting from 53 dB. The WHO expert group ranked the quality of evidence for an effect of road traffic noise on ischemic heart disease as high and concluded "further research were very unlikely to change their confidence in the risk estimate." The systematic review also found rail and aircraft noise to increase the risk of incident ischemic heart disease, but the quality of evidence was ranked lower than for road traffic noise due to fewer high-quality studies. Transportation noise has also been associated with a higher risk for mortality due to ischemic heart disease, although the increase in risk is generally found to be lower than for incident disease, suggesting that the influence of noise is not the same for incident and fatal ischemic heart disease (Heritier et al., 2017; Kempen et al., 2018).

Another CVD extensively investigated in relation to transportation noise is hypertension. The systematic WHO review from 2018 identified 37 studies on transportation noise and hypertension for their metaanalyses, which showed a risk estimate for prevalent hypertension per 10 dB higher noise of 1.05 (95% CI: 1.02−1.08) for road traffic, 1.05 (95% CI: 0.97−1.17) for aircraft, and 1.05 (95% CI: 0.88−1.26) for railway noise (Kempen et al., 2018). However, the quality of the evidence was ranked as "very low," as almost all studies were of cross-sectional design, preventing interpretations regarding causality. Subsequently, a few studies on transportation noise and risk for incident hypertension have been published (Dimakopoulou et al., 2017; Fuks et al., 2017; Pyko et al., 2018; Zeeb et al., 2017). Some of these studies find significant associations between transportation noise and incident hypertension, whereas others fail to see any associations, and more high-quality studies are needed. Interestingly, one study found significant associations for both road, rail, and aircraft noise only after restricting to cases later diagnosed with a hypertensive heart disease, which may suggest that noise primarily affect risk of more severe hypertension (Zeeb et al., 2017).

Recent studies have investigated whether transportation noise increases the risk of other major CVD, including stroke, heart failure, and atrial fibrillation (Hahad et al., 2018; Halonen et al., 2015; Heritier et al., 2017; Monrad et al., 2016; Pyko et al., 2019; Seidler et al., 2016, 2018; Sorensen et al., 2011, 2017) and cardiovascular markers, such as arterial stiffness (Foraster et al., 2017). Of these, only stroke was evaluated in the WHO report (Kempen et al., 2018). However, in 2015 when data collection for the WHO report ended, only five prospective studies were included: one study on incidence, which found road traffic noise to increase the risk (Sorensen et al., 2011), and four studies on cerebrovascular mortality, reporting no increase on association (Beelen et al., 2009; Huss et al., 2010; Kempen et al., 2018). However, cohort studies published after 2015 have led some further support to an association between transportation noise and increased risk of stroke incidence and mortality, especially ischemic stroke (Halonen et al., 2015; Heritier et al., 2017; Pyko et al., 2019; Seidler et al., 2018).

The few existing studies on noise and heart failure have rather consistently reported an association with both heart failure incidence and mortality ranging from 2% to 8% increase in risk per 10 dB (Heritier et al., 2017; Seidler et al., 2016; Sorensen et al., 2017). Interestingly, these studies suggest that road traffic, railway, and aircraft noise, may increase risk, although for railway noise only one of the two studies addressing this found an association. Similarly, two studies have indicated that transportation noise may increase risk for atrial fibrillation (Dimakopoulou et al., 2017; Monrad et al., 2016), though more research are clearly needed for this outcome.

It is unclear whether exposure to transportation noise affects cardiovascular health earlier in life, such as with subclinical increases in blood pressure levels, which progress into CVD during adulthood. According to two recent systematic reviews and metaanalysis, few studies have investigated the association between exposure to road traffic noise and blood pressure in children, and the results have been inconsistent (Dzhambov and Dimitrova, 2017; Kempen et al., 2018). The WHO systematic review ranked the quality of the evidence as “very low," because of the cross-sectional design and methodological differences between studies. Kempen et al. 2018 further identified one study on exposure to aircraft noise, which found a positive but nonsignificant association with blood pressure in children. There is no evidence for railway noise.

## Noise and metabolic disease

Stress and disturbance of sleep, the two key pathways through which noise is thought to trigger its harmful effects, have both been associated with metabolic abnormalities, including impaired glucose tolerance, reduced insulin sensitivity, and dysregulation of appetite-regulating hormones (Eze et al., 2017; McHill and Wright, 2017; Munzel et al., 2017; Schmidt et al., 2015; Thiesse et al., 2018). Also, reduced sleep quality and quantity have consistently been shown to increase risk for obesity and diabetes (Cappuccio et al., 2010; Irwin et al., 2015; McHill and Wright, 2017).

Cross-sectional studies have found road traffic noise to be positively associated both waist circumference and BMI among adults in four out of five studies, either among the whole study population (Christensen et al., 2016b; Foraster et al., 2018; Pyko et al., 2015) or in subsamples of highly noise-sensitive women (Oftedal et al., 2015) or job-strained nurses (Cramer et al., 2019). Pyko et al. (2015) only found associations with waist circumference and not with BMI (Pyko et al., 2015), and two studies furthermore found associations with higher percent body fat (Christensen et al., 2016b; Foraster et al., 2018). In addition, two recent studies indicated that road traffic noise may affect adiposity in children (Christensen et al., 2016a; Weyde et al., 2018). There are three longitudinal studies on road traffic noise and adiposity in adults: A Swedish study found road traffic noise to be associated with a wider waist circumference and risk of central obesity (Pyko et al., 2017). However, they found no association with changes in weight, which is in line with a Swiss study showing no associations between road traffic noise and changes in BMI (Foraster et al., 2018). As suggested by the authors, the stress hormone, cortisol, is expected to result primarily in central obesity. However, the Swiss study reported an association with higher risk for obesity, which is also supported by a Danish study showing road traffic noise to be associated with changes in both weight and waist circumference (Christensen et al., 2015). Therefore although the overall picture suggests that road traffic noise affects development of adiposity, more research into the biological mechanisms to disentangle whether noise primarily is associated with central obesity, general obesity, or both is important. More research is also required into the association between railway and aircraft noise and obesity, as findings for these noise sources have been mixed and based on fewer populations, for both aircraft (Eriksson et al., 2014; Foraster et al., 2018; Pyko et al., 2015, 2017) and railway noise (Christensen et al., 2015, 2016b; Foraster et al., 2018; Pyko et al., 2015, 2017).

During the last decades the number of people with diabetes has increased dramatically, from 108 million in 1980 to 422 million in 2014. Environmental factors are suspected to contribute to this rise. A systematic review published in 2018, evaluated whether transportation noise was associated with a higher risk for diabetes (Zare Sakhvidi et al., 2018b). They included five prospective studies, two cross-sectional studies, and two case-control studies in their metaanalysis and found odds ratios per 5 dB increase in exposure of 1.17 (95% CI: 1.06−1.29) for aircraft noise exposure and of 1.07 (95% CI: 1.02−1.12) for road traffic noise. The findings of an increase in diabetes risk, for two noise sources only weakly correlated, supports that transportation noise is indeed a risk factor for diabetes.

## Adjustment for air pollution in studies of transportation noise

Exposure to transportation noise and air pollution correlates, as traffic is a main source of both exposures. This is most pronounced for road traffic noise, and especially in urban settings (Fig. 4.3). As both exposures are thought to be risk factors for many of the same diseases, including CVD and diabetes, disentangling the effects of road traffic noise and air pollution are challenging. The few studies including both exposures are inconsistent, as some studies find independent effects of the two exposures on risk for CVD, whereas others find that the association between air pollution and CVD disappears after adjustment for road traffic noise or *vice versa* (Cai et al., 2018; Foraster, 2013; Heritier et al., 2018; Roswall et al., 2017c; Tetreault et al., 2013). A potential explanation for this inconsistency is that disentangling of the two exposures requires high-quality assessment of both exposures to avoid that one exposure is estimated more precisely than the other, leading to a more robust association for the most precise exposure (Foraster, 2013; Sorensen and Pershagen, 2019). Sufficient information about the quality of the exposure assessment (method specification, input specifications, etc.) and the treatment of the variables (exposure range, lower limit of detection, etc.) should be provided to contextualize the quality of the adjustment and results for the most and less precisely assessed exposure (Foraster, 2013). Furthermore, confounding may be higher in some study areas than others, depending on the urban characteristics, sample size, outcome, etc., which calls for a systematic assessment of confounding in individual studies. In areas where collinearity may arise between exposure to outdoor air pollution and road traffic noise, additional refinement of the exposure assessment toward more

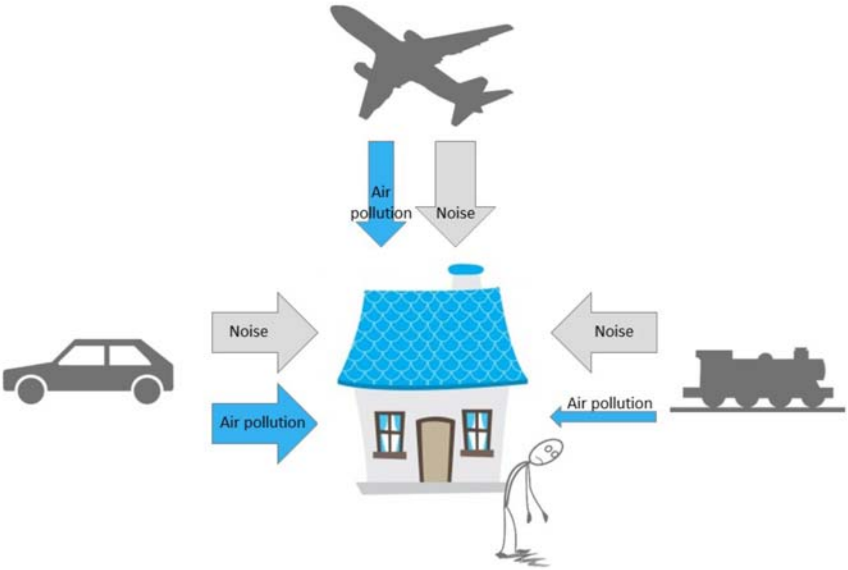


**Figure 4.3** Relative contributions from noise compared with air pollution at the residence for three modes of transportation: road, rail, and aircraft. The size of the arrows illustrate how closely the two exposures correlates at the residence for each of the three transportation sources.

personal exposure, for example, estimating road traffic noise levels at the bedroom facade or indoors may be useful (Foraster et al., 2014).

Studies on railway and aircraft noise are important contributions in unraveling this, as these correlate less with air pollution at the residence compared to road traffic noise, especially for railway noise as many trains operating in, for example, Europe are electric (Fig. 4.3). The rather consistent finding of an association between noise and, for example, ischemic heart disease across all three modes of transport therefore clearly supports an effect of transportation noise that is independent from air pollution (Heritier et al., 2017; Kempen et al., 2018).

## Transportation noise and cancer

### Nina Roswall

Transportation noise may affect carcinogenesis through sleep disruption, which has been found positively associated with cancer incidence and progression (Phipps et al., 2016), and through stress. Sleep and stress may both affect the circadian rhythm (Sephton and Spiegel, 2003), suppressing melatonin, which possesses anticarcinogenic properties, including antioxidant defense, immune response, and DNA repair (Reiter et al., 2009), and reduced growth of already established tumors, blocking cell invasion and metastasis (Cos et al., 1998). Noise-induced stress-responses have also been shown to increase the levels of cortisol (Babisch et al., 2001) and oxidative stress (Yildirim et al., 2007), which is involved in carcinogenesis (Valko et al., 2007). Furthermore, transportation noise has been positively related to several established cancer risk factors: smoking, alcohol, physical inactivity, obesity, and diabetes, suggesting an effect on carcinogenesis also through these.

Three studies have investigated transportation noise and breast cancer: One cohort study found a positive association between road traffic noise and estrogen receptor (ER) negative tumors only (HR, 95% CI: 1.20, 0.97−1.48, per 10 dB), with suggestions of a similar association for railway noise (Sorensen et al., 2014). Another cohort study found a positive association with overall breast cancer (HR, 95% CI 1.10, 1.00−1.20, per 10 dB), which was confined to estrogen- or progesterone receptor-positive tumors (Andersen et al., 2018). A German case-control study found a positive association with aircraft noise, which was confined to ER negative tumors upon stratification. There were suggestions of similar tendencies for road and railway noise (Hegewald et al., 2017). Studies on road traffic noise and mammographic breast density, one of the strongest risk factors for breast cancer, and breast cancer survival have found no association (Roswall et al., 2016, 2018a).

A cohort study on colorectal cancer found road traffic noise to increase risk for distal colon cancer with 18% (95% CI: 1.00−1.40, per 10 dB), but not railway noise (Roswall et al., 2017d). In the same cohort the authors found no association with colorectal cancer survival (Roswall et al., 2017b).

Three studies have examined road traffic noise exposure and other cancers, showing no association with vestibular schwannoma and prostate cancer (Roswall et al., 2017e), but an 18% higher risk of non-Hodgkin lymphoma among those exposed to >65 dB compared to <55 dB (95% CI: 1%−37%). In subanalyses the association was strongest for B-cell lymphomas and unspecified lymphomas (Sorensen et al., 2015).

Taken together, biological mechanisms explaining pathways through which transportation noise could affect carcinogenesis, combined with findings of epidemiological studies, suggest that there might be a harmful effect of traffic noise in relation to some cancers. However, given the limited number of studies, further research is required.

## Transportation noise, cognition, and mental health

### Maria Foraster

Research about the effects of transportation noise on cognition has mainly focused on noise exposure at school in children. Childhood is a critical period of brain maturation. External environmental stressors such as noise could pose a thread on such processes during this time window and contribute to impaired cognitive development and learning. A smaller number of studies have investigated the role of transportation noise as a stressor on mental health, both in children and adults.

Several pathways have been proposed on how noise may affect cognition in children, such as frustration, learned helplessness, impaired attention, interference between processes, physiological or psychological noise-related stress reactions or even sleep disturbance, which decreases task performance (Basner et al., 2014; Stansfeld and Clark, 2015). In turn, noise-induced stress would lead to psychological and physiological reactions, trigger the endocrine and autonomous nervous systems, and could contribute to mental health disorders under long-term exposure to noise (Basner et al., 2014; Clark and Paunovic, 2018a).

To date, there is substantial evidence indicating an association of exposure to aircraft noise with impaired reading comprehension and long-term memory in children. In specific the WHO systematic review on noise and cognition classified the quality of the evidence for these associations as moderate, as supported by longitudinal and intervention studies (Clark and Paunovic, 2018b). In contrast the review suggested that more and better studies were needed to reach conclusions for any associations with other transportation noise sources (i.e., road traffic and railway noise) as well as for the association of noise with other cognitive domains and abilities (Clark and Paunovic, 2018b).

Regarding mental health, the corresponding WHO systematic review evaluated the evidence for aircraft, road traffic, and railway noise in relation to quality of life, depression and anxiety (and medication use), psychological symptoms, emotional conduct disorders, and hyperactivity in children. The review found moderate quality evidence in children for an association between (1) exposure to road and railway noise and emotional conduct disorders and (2) road traffic noise and hyperactivity. For the rest of the evaluated relationships, both in children and adults, the quality of the evidence was rated as low, very low or inexistent by the WHO review, due to one or more of the following: only studies of cross-sectional design, very few studies, only small studies, or inconsistencies in methods and results (Clark and Paunovic, 2018a).

A more recent systematic review on environmental noise and neurodevelopment and mental health in children, reached similar conclusions to those of the WHO reviews: while the evidence supports some of the associations stated above, they observed inconsistencies for several outcomes and a need for more and better studies (Zare Sakhvidi et al., 2018a). Regarding adults, further evidence suggests a potential link of transportation noise with depression and cognitive decline, though there are still few studies, for example, Seidler et al. (2017). Finally, the associations between road traffic noise and cognitive and mental health reported above were generally found independent of traffic-related air pollution, in those studies accounting for it, for example, Stansfeld (2015).

## Transportation noise and pregnancy outcomes

### Maria Foraster

The investigation on the effects of transportation noise on pregnancy outcomes has only gained attention in recent years. The main mechanism by which noise may affect fetal development and birth outcomes relates to the general stress model. Noise may lead to perceived and nonperceived stress reactions on the endocrine and autonomic nervous system, with a subsequent release of hormones and cathecolamines involved in the correct functioning of the placenta and fetal development. Noise-induced sleep disturbance may also contribute to the adverse birth effects (Dzhambov et al., 2014; Nieuwenhuijsen et al., 2017).

A systematic review for the WHO noise guidelines identified six studies on aircraft noise, five studies on road traffic noise and three on railway noise, exposure of mothers during pregnancy and adverse birth outcomes

(Nieuwenhuijsen et al., 2017). Due to the few studies, together with study limitations and inconsistencies in results, the quality of evidence was rated as very low to low for the different associations. A recent update of the evidence specific for road traffic noise and pregnancy outcomes found five additional studies between 2017 and May 12, 2019 (Dzhambov and Lercher, 2019) and performed metaanalyses for different birth outcomes, including between three and seven studies at a time. This systematic review concluded that the quality of the evidence for the association between road traffic noise and the continuous lower birth weight was moderate, whereas for other pregnancy outcomes (i.e., binary outcomes of low birth weight, small for gestational age, and preterm birth) it was very low and did not indicate associations (Dzhambov and Lercher, 2019). The review also observed that findings were similar in air pollution−adjusted metaanalysis. Further studies are needed that assess the different transportation noise sources using high-quality noise estimation.

## Noise sources and mitigation measures

### Jean Marc Wunderli

Sources of transportation noise, such as cars, trains, or airplanes, cover a wide range of sound exposure level, as indicated in Fig. 4.4. Train and aircraft noise are characterized by prominent single pass-by events, whereas road vehicles produce substantially lower event levels. Because of the much higher number of vehicles, the acoustic dose, typically expressed as long-term average sound pressure level, $L_{eq}$, is nevertheless highest for road traffic noise.

For road traffic, rolling noise, which is the sound generated by the interaction of tires and pavement, is typically the dominating noise source (Heutschi et al., 2018). Only at very low speed regimes, for passenger cars below 30 km/h, and with strong acceleration, engine noise become dominant. Consequently, the most promising strategies for noise reduction at the source are installation of quiet road surfaces (3−6 dB), promotion of low-noise tires (at least 2 dB), and the introduction of general or temporal speed reductions in densely populated areas (3 dB).

For railway traffic, rolling noise also dominates the sound generation for typical traveling speeds. The sound generation of rolling noise is

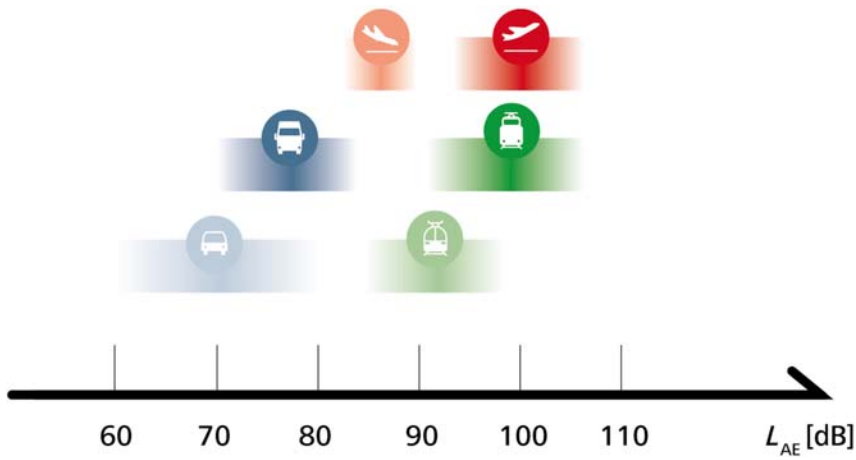


**Figure 4.4** Sound exposure level of traffic noise sources: (1) passenger car (30–120 km/h, 25 m), (2) truck (30–80 km/h, 25 m), (3) passenger train (1 locomotive, 10 wagons, 80–200 km/h, 25 m, average rail roughness), (4) freight train (2 locomotives, 30 wagons, 80 km/h, 25 m, varying rail and wheel roughness), (5) civil aircraft take-off (A320 / B777, 305 m), (6) civil aircraft landing (A320 / B777, 305 m) (Heutschi et al., 2018; Thron and Hecht, 2010; Zellmann et al., 2017).

primarily a consequence of the combined roughness of wheel and rail. The wheel roughness depends on the breaking system. Therefore a highly effective and cost-efficient mitigation measure is the replacement of cast-iron block breaks, which causes a high wheel roughness, with composite block breaks—or even better—with disc brakes, resulting in reductions of 8–12 dB. On the rail side, many infrastructure operators established network-wide monitoring programs combined with targeted acoustic rail grinding (Kalivoda et al., 2003; Kuijpers, 2008).

Noise from aircraft is primarily caused by the engines. During landing, where engines are often in idle, also airframe noise can become relevant. Noise emissions of commercial aircrafts were substantially reduced over the last decades, primarily as a side-effect of initiatives to reduce fuel consumption (IATA, 2011). In addition to these measures at the source, noise abatement operational flight procedures, which optimize the vertical flight profiles and points in time of aircraft configuration changes, have a certain potential for noise reduction at the ground (ICAO, 2007; Khardi and Lina, 2012).

If mitigation measures at the source are not sufficient, measures along the propagation path have to be evaluated, which however are only effective for ground-borne noise sources. The most common approach is the installation of noise barriers, with an effect of up to 20 dB directly behind the barrier. Barriers, however, are useless for residents in upper floors, need space and among others have negative impacts on accessibility and landscape scenery. They are, therefore, not ideal in urban situations, where alternative approaches, for example, with vegetation should be fostered in the future, despite their lower sound reduction potential (van Renterghem et al., 2015).

Finally, mitigation measures can be taken at the resident's home. Apart from general measures to improve sound insulation, typically by installing soundproof windows, the focus should be on orienting noise-sensitive rooms such as sleeping or living rooms toward the quiet side of the building (Brink et al., 2019b; Van Renterghem and Botteldooren, 2012).

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CHAPTER FIVE

# Active transportation, physical activity, and health

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## Contents



## A body built to move

The human body is designed to stride long distances. Here are some of the tell-tale signs: a long elastic Achilles tendon, a flexible lower spine, upright stance, muscular buttocks, sweat glands everywhere, and short toes of mostly even length (Rolian et al., 2009). Combined, these features of our anatomy are unique and their purpose seems plain: to enable humans to walk and run, sometimes at speed, in short bursts if needed, but more commonly at a steady pace over long distances.

It is roughly 2 million years since large-brained human ancestors moved out of forests onto open grass-lands (Plummer et al., 2009), and until agriculture and fixed settlement 10–20,000 years ago, our ancestors were wide-ranging hunters and foragers. For millennia, reproductive success depended on mobility. The physiological machinery of humans and the genetic script that commands it were selected on the capacity for long-distance aerobic travel.

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Nearly every body system is involved (Pontzer, 2019). For example, there are chemical rewards for prolonged physical activity. Substances such as serotonin that are released in the brain during exercise boost feelings of well-being and suppress the perception of pain. Exercise also promotes the development of new cells in the brain and other organs. The way energy is handled in the body has evolved to accommodate long periods of walking and running—the human $VO_2$ max, a measure of maximum sustained power output, is more than four times greater than that of chimpanzees. We differ from other apes especially in the size and makeup of our leg muscles, which are 50% bigger and have a much greater proportion of "slow-twitch" fatigue-resistant fibers. The human body also has proportionately more red blood cells to carry oxygen to working muscles (Pontzer, 2019).

Bicycles do not feature in the evolutionary story—they were not common on the African savannah 2 million years ago. But the physical movements involved in riding a bike differ little from those of walking. The earliest version of the bicycle was known as the "pedestrian accelerator" for good reason. It was a device that stretched each step and reduced resistance, more than tripling the speed of travel (Gustafsson and Archer, 2013). Even with the addition of pedals and chain drives, the same big muscle groups are involved as those that are used for walking: the distinctive human buttock is the engine for both pedestrian and cyclist.

As with walking, cycling involves big lower limb muscles contracting at high frequency against moderate loads. As with walking, the rhythm or cadence is determined by the traveler depending on fitness and comfort. There are differences between walking and cycling (for instance, there are fewer lateral forces acting through the lower limb when on the bike than walking, and the weight of the body is supported by the saddle and handlebars). But the similarities are substantial, and they enable the cyclist and pedestrian to turn physiological potential into health-protecting energy expenditure. The bicycle packs more work into the same block of time, since speeds are higher and the rider travels further than the walker: in the city, pedestrians move at about 5 km/h; cycling speeds are commonly 15−20 km/h.

Table 5.1 shows typical levels of physical activity for a 70 kg person at rest, walking on flat ground, and riding a bike (Jetté et al., 1990). The power required for each activity is described in watts, and the energy expended in the body is reported using the unit of metabolic equivalents or METS, where 1 is the metabolic rate at rest. According to the table, the typical pedestrian would burn about 3 METS per hour; roughly, half

**Table 5.1** Approximate metabolic costs of walking and cycling.

| Activity | Watts[a] | METS |
|---|---|---|
| At rest | | 1 |
| Walking (km/h) | | |
| 3 | 32 | 1.8 |
| 5 | 56 | 3.2 |
| 7 | 93 | 5.3 |
| Cycling (km/h) | | |
| 10 | 84 | 4.8 |
| 20 | 124 | 7.1 |
| 30 | 172 | 9.8 |

[a]Assumes 70 kg body weight.
*Source*: Based on Jetté, M., Sidney, K., Blümchen, G., 1990. Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. Clin. Cardiol. 13 (8), 555–565.

the expenditure of the cyclist. Since on the whole the health gains from physical activity are related to the energy expended, one would expect cycling to be more beneficial, per minute or hour, than walking, and this is in fact what is observed.

Members of modern societies seldom hunt and forage in the old-fashioned sense. But the critically important point is our bodies are still tuned for physical activity. As a result, inactivity has a high cost in health terms, as demonstrated in one scientific study after another. Here is an example: more than 6000 men who attended a US clinic in the 1990s were tested on a treadmill to assess their exercise capacity (Myers et al., 2002). This was measured by finding out how quickly a person could walk comfortably on an incline. The researchers found that low exercise capacity was a stronger predictor of death in the next 6 years than blood pressure, cholesterol, smoking behavior, or any other classic risk factors for heart disease and stroke. This was not a trivial finding: the difference in risk of dying early between the least fit quintile and the fittest 20% was fivefold.

## The rise of physical inactivity

Modern societies have become healthier in almost every other respect, but there is a significant exception—humans move less than ever before. Although we are conditioned to be mobile and active, immobility and inactivity are now so common that a sedentary lifestyle is regarded as normal.

Studies of hunter forager societies estimate habitual levels of physical activity equivalent to walking 10–20 km a day (Cordain et al., 1998). The World Health Organization (WHO) definition of a minimal healthy level of physical activity is 600 MET minutes a week. This would be achieved by walking 1–2 km a day, about one-tenth the activity of hunter forager groups. The WHO standard is a modest target, but even so, about a third of adults worldwide fall short (Hallal et al., 2012). And there are few signs, in any country, that rates of physical activity are improving.

In China, for example, inactivity has risen as the country races through the social changes that have taken much longer elsewhere. Between 1991 and 2006, average weekly physical activity (measured in MET hours) reduced by a third among Chinese adults, and the proportion who walked or cycled for more than 30 min/day fell from 46% to 28% (walking) and 51% to 33% (cycling). In 1986, 63% of trips in Beijing were made by bicycle; in 2014 the proportion was 11% (Jiang et al., 2017).

The decline in physical activity applies to children as well as adults. Recent generations tend to be less active and less fit than young people of the same age in the past. For instance, a review of 50 studies of running fitness around the world found children aged 9–17 took 90 seconds longer to run a mile, on average, than their peers 30 years before (Tomkinson and Olds, 2014). Walking and cycling to school are much less common than they used to be, while sedentary activities dominate, from an early age. In the late 1980s, 1 in 12 school children in New Zealand rode a bike to school; in 2014 that figure was 1 in 50 (Ministry of Transport, 2015).

## Studies of physical activity and health

Throughout the history of medicine, exercise, especially the vigorous form, has been regarded with suspicion. Galen, the Greek physician whose views dominated medical thinking for more than a thousand years, thought moderate physical activity was important but warned that "athletes live a life quite contrary to the precepts of hygiene" (Hartley and Llewellyn, 1939). Robert Burton in his 17th century text "The Anatomy of Melancholy" wrote "Some prescribe frequent and violent labour and exercises... the most forbid, and by no means will have it go farther than a beginning sweat, as being perilous if it exceed" (The New York Times, 2015).

In the 19th century, many doctors warned that sports would strain the heart and other organs, sometimes with fatal consequences. One of those who took part in the early Cambridge Oxford boat races said, "We used to be told that no man in a racing boat could expect to live to the age of 30" (Hartley and Llewellyn, 1939). It was thought that women were especially susceptible, and harmful effects of physical exertion on reproductive health were a particular concern—an article published in Harper's Bazaar in 1912 asked "Are athletics a menace to motherhood?" (Verbrugge, 2002). While the more florid fears of exercise have abated, there is an abiding suspicion of "strain" and "overuse." In the 1980s, magazines still ran stories with headlines such as "Babies or barbells: make your choice" (Verbrugge, 2002). Until the end of the 20th century, prolonged bed rest was recommended for many men and women who were recovering from surgery or serious medical events, a regime that has now been accepted as very likely to do more harm than good (Lee et al., 2012).

One of the first to seriously examine that possibility that the big problem was not too much physical activity, but rather, not enough, was a British epidemiologist, Jerry Morris. His career covered almost 70 years, from early work on malaria in British troops in India to studies in the Tony Blair era of the minimum income required to sustain good health (Blair et al., 2010). But physical activity was where he made his biggest contribution. He lived what he researched. When one of us (AW) met him for the last time, he was in his early 90s, animated, full of energy and as always, great company. But he was angry—he said that he had been forced to give up his regular swim at the local pool, as every time he started on his laps, one of the lifeguards would jump in to save him.

Motivated by the steep increase in deaths due to coronary heart disease after World War II, Morris investigated factors in the workplace that might be important. He began with a study of men working for London Transport and found that drivers of buses, trams, and trolleybuses suffered more from heart disease than conductors on the same vehicles (Morris et al., 1953a,b). (He also compared trouser sizes—those issued to conductors were several sizes smaller than the trousers worn by drivers of the same age.) Morris speculated that being physically active on the job might be important. (All the London Transport vehicles were double-deckers; the conductors' job was to constantly patrol both floors collecting fares.) His hunch was supported by a second study of postal workers and civil servants. Death from heart disease among postmen, whose work was largely taken up with delivery of the mail, was half as common as it was among telephonists and clerks of the same age (Morris et al., 1953a,b).

There have been many more sophisticated studies since the work on British bus drivers and postmen, but the findings fit well with those reported 60 years ago by Jerry Morris. Physical activity leads to better health. Unlike the engine of a car, the human motor improves the more it is used and deteriorates if not switched on.

There are large effects in public health terms. More than 3 million deaths a year, worldwide, are attributed to inactivity (Hallal et al., 2012). People who meet the WHO guideline (equivalent to 30 minutes a day of moderately intense physical activity for at least 5 days a week) cut their risk of dying in the medium term by about 20% compared with those who are inactive (Woodcock et al., 2011). Benefits have been reported for heart disease, stroke, diabetes, and some cancers and it is thought that people who become more active experience both a reduction in the incidence of these diseases (i.e., the occurrence of new cases) and an increase in survival (Mytton et al., 2017).

Lack of physical activity is associated with higher blood pressure, more unhealthy fats in the circulation, sluggishness in the hormonal systems that regulate blood sugar, and thicker waistlines. In those who seldom move, the untrained heart beats more quickly, even at rest. Inactivity appears to be associated with metabolic and physiological brittleness—the body does not cope so well with disruption. For instance, calcium deposits are found in the lining of coronary arteries (a sign of inflammation and scarring of the vessel wall) as commonly in highly active men as those who are less active, according to one study, but those who are relatively inactive are more likely to have heart attacks (DeFina et al., 2019). One explanation may be that physical activity promotes the growth of new vessels to secure the flow of blood to heart muscle; another is that the calcium deposits in active individuals are different in kind, and less likely to rupture and cause obstruction.

## Physical activity and the brain

If being active is a good thing for your heart and lungs, then it would not be surprising if physical activity promotes brain health too, and it appears that this is indeed the case. People who undertake regular aerobic exercise (activity sufficient to puff but not so vigorous that the body cannot get enough oxygen to the muscles to keep going) have better brain function than those who do not exercise, all else being equal. This applies especially to cognitive functions, but exercise is linked also with improvements in motor capacity. It is seen at all ages, in both men and women, among those without evident impairments and among people suffering from disorders such as dementia (Hillman et al., 2008).

Recently, light has been shed on biological mechanisms that might explain the association between activity and brain function. There are physical changes that occur in the brain in responses to physical activity—exercise gives you a bigger brain, it is true! (Halloway et al., 2019). Better perfusion as a result of a healthier, stronger, free-flowing cardiovascular system is part of the story. But there is more—physical activity prompts the production of new brain cells. And interestingly, the effects are localized. Mostly, the action takes place in the hippocampus and close by (Inoue et al., 2015) a part of the brain that is closely associated with memory, motivation, emotions, and spatial awareness (Li et al., 2013). The growth in cells and pathways may increase neurological reserve, echoing what happens in the heart. Studies report even with similar levels of pathology (such as the presence of dementia-related proteins), those with a history of physical activity are less affected, in terms of cognitive performance (Buchman et al., 2012).

What kind of physical activity results in the biggest gains? This question cannot be answered fully yet, but there are some hints. The biggest effects appear to result from moderate, regular activity: brain gain does not require extreme exercise (Paolucci et al., 2018). And it seems clear that the combination of physical activity and cognitive challenge has a bigger effect than either exposure on their own. The quality of the environment in which someone is active is important, in other words.

"Cognitive challenge" might be doing a crossword puzzle while striding on the treadmill in the gym, but it is exercise in complex and engaging environments (natural or built) that appears to have the largest impact. The human brain seems to be evolutionarily primed for the types of physical activity provided by the foraging imperative: moderate-intensity exercise that activates the sensory, attentional, navigation, and decision-making and planning parts of the brain (Raichlen and Alexander, 2017). Exercising in the gym (even if you are doing a crossword) does not boost mental well-being or brain renewal as much as similar levels of activity outdoors (Coon et al., 2011).

## Active transport and health

Attempting to insert activity into people's daily schedules, as a discretionary item, is difficult. Due to time pressures, working-aged people, and particularly female workers and those working in low-status jobs, tend to report high "opportunity costs" associated with exercising in nonwork hours (Martin et al., 2014). Particularly for women, time to exercise competes with care responsibilities and is often perceived as a "luxury" (Miller and Brown, 2007). Not unsurprisingly then education and behavior change campaigns to promote the use of gyms, participation in sports and regular exercise in other settings have had limited success (Cradock et al., 2017). Finding ways to make existing everyday routines like travel more active is an important way to work within rather than competing for already overstretched time-budgets.

Importantly, active transport is also a useful tool for increasing physical activity because it provides both a form and intensity of exercise that taps into a number of primal pleasure pathways. Active commuters, those that walk or cycle, have the highest commute satisfaction (Wild and Woodward, 2019), and exercise intensity is an important part of the picture. Moderate-intensity exercise, provided by cycling or brisk walking, is experienced as the most "pleasurable" exercise intensity by the majority of people and appears to promote stronger exercise motivation and increase the amount of time spent exercising (Ekkekakis, 2010). Moderate exercise is also the most effective intensity for improving mental alertness (Lambourne and Tomporowski, 2010) and elevating mood (Paolucci et al., 2018). As well as providing the optimal exercise intensity, research suggests that there are a range of additional cobenefits of active transport that work to further enhance and sustain exercise motivation, including the mood-enhancing effects of nature exposure (Rogerson et al., 2016) and increased social connection (van den Berg et al., 2017), and the ways that active transport modes heighten feelings of "self-efficacy" and "control" over travel conditions, important components of psychological well-being and life satisfaction (LaJeunesse and Rodriguez, 2012).

Active transport therefore generates a number of important additional social and psychological "reward" feedback loops that help to sustain physical activity motivation. And there is indeed evidence that those who use active transport regularly as a means of transport obtain the physical activity required to meet health guidelines, and their well-being is improved as a result (Shaw et al., 2017).

Follow-up of the participants in the UK Biobank study found that those who used relatively active means of travel to work (cycling was combined with walking and public transport, due to small numbers) were 30% less likely to suffer from a fatal heart attack or stroke than those who commuted by car (Panter et al., 2018). A metaanalysis that pooled all the research available up to 2014 found the risk of dying from any cause was reduced by 10% for a "dose" of 11.25 MET hours of cycling per week (this corresponds roughly to 30 minutes per working day riding at the average cycling speed in the city of Copenhagen) (Kelly et al., 2014).

Among those who cycle regularly, there is a clear relation between amount cycled and health improvements. The more the better, in brief. More hours on the bike is associated with fewer diagnoses of high blood pressure or raised blood cholesterol, and less overweight. The more frequent the cycle commutes, the greater the decline in heart disease risk factors, and none of this is explained by differences in behaviors such as smoking or alcohol consumption or other physical activities than cycling (Hollingworth et al., 2014).

Those who cycle tend to be lighter (have lower body weights) than people who habitually travel by other means. Moreover, those who change their mode of commuting gain weight (if they shift from cycling or walking to car travel) but lose weight on shifting from cars to active transport (Flint et al., 2016). A study in Chinese households conducted during the years when mechanized transport (petrol-driven scooters in particular) were becoming popular found that acquisition of a motorized vehicle was associated with weight gain in men between 1989 and 1997; in the same period, men and women in households that acquired a non-motorized vehicle (mostly a bicycle) lost weight (Bell et al., 2002).

It is known that workers who frequently take part in vigorous physical activity, such as competitive sports, are less likely to be away from work due to poor health than other employees. Those who commute by bicycle also take less sick leave (than workers who travel by other means), and this effect is particularly marked among people who cycle relatively long distances (more than 5 km) more than 3 days a week (Hendriksen et al., 2010).

If cycling and walking were increased by modest amounts in the United Kingdom (on average, an extra 3 and 1 km per day, respectively), it was estimated that the National Health Service would save roughly £17 billion within 20 years, mostly through reduction in the number of people with type 2 diabetes (Jarrett et al., 2012).

The scientific literature on active transport and the brain is slim, but the findings fit with the much larger body of knowledge on the effects of physical activity. An 8-week trial of outdoor cycling, including older adults (age 50−83 years), found that those in the cycling group improved both cognitive function and mental well-being compared with noncycling controls. Similar results were obtained with regular push bikes and electric bikes (Leyland et al., 2019). There are strong associations, consistently reported, on the differences between commuting behavior and mood, satisfaction, and happiness. Those who travel to work by walking or cycling tend to be happier than those whose trip is made by motor car or public transport (St-Louis et al., 2014). We know the bicycle delivers self-modulated levels of physical activity, more vigorous than activity associated with other transport modes, and when cycling is embedded in daily routine, the exposure is reliably frequent. As mentioned already, the combination of arousal, sensory reward, and exercise is a powerful brain tonic and this mix of challenge, sensation, and exertion is familiar to most city cyclists (and pedestrians). Finding a way through the traffic, alert to threat and opportunity, being prepared to slow or speed up as required, this is travel that blends both mental stimulation and physical effort. And where there are chances to ride in natural environments, cyclists and pedestrians enjoy a more intimate experience of green and blue spaces than do travelers in cars and other motor vehicles: these environmental exposures are known to be health-promoting in their own right (Rogerson et al., 2016).

## Is the association cause and effect?

Most studies in this field compare the health of people who elect to walk or ride bikes with those who choose not to. Perhaps, good health leads to more active transport, rather than the other way round? Perhaps, the happy are more likely to walk or bike? Or perhaps electing to ride a bike and walk is associated with other aspects of a person's life such as a higher education, social advantage, and fewer health-damaging behaviors such as smoking, and these other factors are the real explanation for physical and mental health differences? What is more, physical activity is mostly self-reported and we know that often these reports are inaccurate (Prince et al., 2008). The work done while cycling depends on many factors, such as the terrain, wind, speed of riding, and the qualities of the bike itself such as weight and gearing. Yet such information is seldom collected in health studies. Might all these deficiencies in the research undermine the conclusions that have been drawn?

We say no, despite the shortcomings, the different kinds of research generally point in the same direction. Consistency is important given the limitations of research into long-term health outcomes in free-living populations of willful and independent human beings. Studies that have employed direct measures of activity (e.g., accelerometers) have reported even stronger associations of physical activity with positive health outcomes than studies that rely on self-reported activity (Ekelund and Tarp, 2019). There have been many experiments with laboratory animals, which show plainly that physical activity reduces health risks in a manner similar to what is observed in humans (Li et al., 2013).

The long-term outcomes in humans (such as the reduction in rates of heart disease) are consistent with acute changes (such as blood pressure lowering) observed in controlled laboratory studies, in which participants undertake prescribed, observed activities (e.g., treadmill training). Also, detraining studies follow individuals who reduce levels of physical activity and report corresponding declines in health measures (such as mental performance). And for some outcomes (such as mood improvement among those with clinical depression), it is possible to conduct randomized trials with human participants, and by and large these confirm the findings of the observational studies (Schuch et al., 2016).

There are epidemiological studies that attempt to mimic randomized trials. For example, the relation between physical activity and depression has been studied using genetic variants that are known to be associated with being more active. These variants may be considered to be randomly allocated through the population. Consequently, an association between the genotype and the outcome (depression in this case) can be explained neither by reverse causation, nor by confounding. Using this approach, known as "Mendelian randomization," objectively assessed physical activity was found to be strongly protective against major depressive disorders (Choi et al., 2019).

Longitudinal studies of transport behavior and psychological well-being also challenge the idea that perhaps the happy are just more likely to walk or bike. One British study based on 17,985 adult commuters in 18 waves of the British Household Panel Survey found that even accounting for potentially confounding variables such as job satisfaction, residence, workplace, and health, there is a strong positive association between active transport and psychological well-being as well as a distinct mental health boost associated with switching from car to active transport for your commute (Martin et al., 2014).

To sum up, there are many ways in which a city that was oriented to walking and cycling would improve the health of citizens. The effects on mood and commuter satisfaction are largely explained by the increase in physical activity associated with active transport. But there are almost certainly other mediating factors. A city built for slow speed active travel would increase opportunities for social interactions, since motorists tend to be isolated from the populations they move through. Traveling at high speed, inside a steel box, is traveling alone. It is difficult to even make eye contact with others along the way. Experimental studies have shown that the view from the car tends to magnify suspicion of unfamiliar places and people (Gatersleben et al., 2013), which is likely to reduce social engagement and a sense of belonging, both important components of mental well-being. A walking- and cycling-oriented city would reduce the stress related to travel uncertainty, and where bikes replaced cars there would be less noise and local air pollution. Worldwide, one in eight new cases of childhood asthma has been attributed to traffic pollution (Achakulwisut et al., 2019). And finally, the reductions in greenhouse gas emissions released from motor vehicles powered by fossil fuels would also bring a health dividend.

## Conclusion

About 5 years ago, one of us (AW) visited Troels Andersen. Troels was the cycling engineer in chief in Odense, the man responsible for pushing ahead with the Danish city's ambitious plan to promote the use of the bicycle by better design of streets and facilities. What was going on? Odense had always been a conspicuous leader in this area—in fact the first bicycle path in Denmark was built there (in 1895). The city was already rated as one of the most bike-friendly in Europe. Why did the authorities want to attract even more two-wheeled person-powered traffic? This was Troels' answer—"Denmark is a small country with few resources apart from its people." What he meant, but saw no need to spell out in full because it was (in his mind) so obvious, was that a city built for active travel promoted the health and well-being of its population, and there was no more important cause in transport planning.

Physical activity is the front-page story here because the health costs of inactivity are so large (this is one of the most common preventable causes of early death and preventable ill-health), and because there are few downsides. Physical activity has been called the best buy for public health because it is effective, cheap, and by and large is risk-free. If city streets are designed for walking and cycling, and this means more people are more active more often, then this is an opportunity that should not be missed.

In the final instance, it is perhaps in the narratives of pedestrians and cyclists themselves that we encounter the most compelling case. Anthropologist Elizabeth Whitaker interviewed older Italian male cyclists and writes the following:

> *Through the combination of … physical effort, speed, and contact with the open air and the sights and sounds of the road, the cyclist experiences feelings of happiness and well-being, a balancing of emotions, an improvement of focus, and an increase in vital energy. As [one participant] puts it,* la bici fa sorridere gli occhi *(the bicycle makes the eyes smile).*
>
> **Whitaker (2005)**

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CHAPTER SIX

# Public transport and health

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## Contents



## Introduction

The transport sector contributes 25% of total energy-related $CO_2$ emissions globally and has increased at a faster rate than other energy end-use sectors (IEA, 2018). Road vehicles constituted 80% of the transport emissions, especially from the Asian cities of emerging economies such as China and India (Intergovernmental Panel on Climate Change, 2014). The increasing scales of the urban metropolitan areas due to rising population have necessitated the use of automobile to drive daily from the urban periphery into cities, mainly for employment. This is reinforced by the high housing price within cities, and lack of sustainable transport system infrastructures and connections across cities. Increasing incomes have also made individual vehicle ownership more affordable, resulting in mostly single-occupancy vehicles on the roads, and the gradual phaseout of the traditional active transport modes in the developing countries. For the less privileged, motorized two-wheel vehicles become the second option as can be seen from the high number of motorcycle ownership in the Asian developing countries such as Thailand and Indonesia (Senbil et al., 2007).

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Such situation has caused a wide range of problems on the socioeconomy, environment, and people's health and well-being.

One of the approaches in the sustainable mobility paradigm is the "avoid, shift, improve" (ASI) strategy that was first developed in Germany to reduce environmental impacts (Bongardt et al., 2014). "Avoid" is addressed through the initial spatial planning by reducing the distances between destinations; "shift" involves shifting commuters to more efficient transports such as public and active transport; and "improve" is implemented through advancing technologies that reduce emissions. Public transport falls under both the "shift" and "improve" strategies from increased fuel efficiencies and behavioral change of commuters to reduce motor vehicle travels, while "avoid" supports the role of public transport services in sustainable development. Compared to private vehicles, public transport moves people more efficiently in a collective manner and therefore contributes lesser emissions in terms of person trips. In large metropolitan areas, public transport is a sustainable alternative for people to move between cities. Therefore early planning of public transport infrastructures could avoid the long-term negative impacts caused by physical lock-in especially in the developing countries.

Given the increasing problems caused by motor vehicles, addressing transport issues presents opportunities to alleviate these problems simultaneously. This approach is also called the cobenefits approach, which was first brought into public attention from the IPCC report (2001), that climate change mitigations would bring equally important ancillary benefits to multisectors (Miyatsuka and Zusman, 2009). Health cobenefits of climate mitigation have been mentioned in many transport studies and models in the past decades in order to provide added justifications for governments to mainstream climate actions into national policies (Gao et al., 2018). Public transport strategies such as bus rapid transit (BRT) and metros that often require intensive resource investments usually have to proceed with careful planning and impact assessments before decisions are made based on the benefits and trade-offs. This is where cobenefits need to come in to leverage the investments in these infrastructures, including from health and well-being. With each sector typically working in silos, health has conventionally not been considered in transport planning until recent decades where health impact assessment was integrated into transport policies (Woodcock et al., 2009). In developing countries where economic advancement is prioritized, along with multiple environmental and social targets to be met within national financial capacity, cobenefits plays an important role for leveraging these investments and reducing duplicated efforts in reaching the common goals between sectors. Besides, these health cobenefits are tangible and near-term compared to the uncertainty of climate change impacts and thus create good opportunistic justifications to catalyze more ambitious carbon reduction targets in transport (Puppim De Oliveira et al., 2013).

Public transport is one of the urban transport strategies to reduce emissions. This chapter discusses how public transport can promote health cobenefits among population sustainably in their daily rhythmic commute. The three sections of this chapter look at the most assessed health-related cobenefits of public transport: air pollution, traffic injuries, and physical activity (Fig. 6.1). Both empirical studies and scenario modeling on the three health determinants are reviewed and discussed. The last section briefly discusses about modal shift and accessibility that are the major determinants of the success of public transport services in mitigating carbon emissions and bringing these health cobenefits into place.

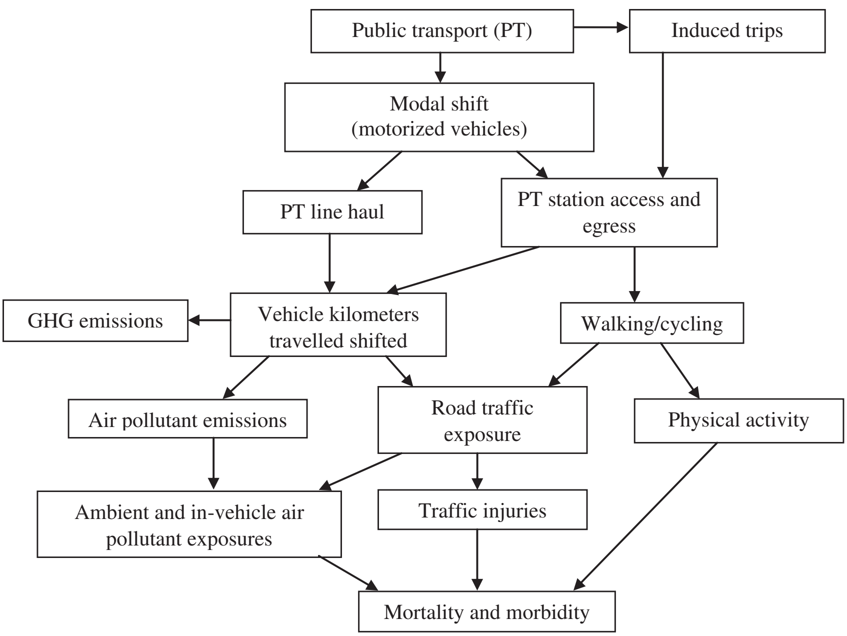


**Figure 6.1** Health impacts of public transport. *Adapted from Kwan, S.C., Tainio, M., Woodcock, J., Sutan, R., Hashim, J.H., 2017. The carbon savings and health co-benefits from the introduction of mass rapid transit system in Greater Kuala Lumpur, Malaysia. J. Transp. Heal. 6, 187–200. Available from: https://doi.org/10.1016/j.jth.2017.06.006.*

## Air pollution

The positive health impacts from air pollution reduction have been used widely to push for climate policies given that greenhouse gases (GHGs) are often emitted together with copollutants such as particulate matter and gases that are detrimental to health. A study indicated that the health cobenefits from achieving the targets of carbon reduction in the Paris agreement could completely outweigh the costs of implementations in all scenarios, and these health cobenefits were significantly larger in more polluted countries (Markandya et al., 2018). PM10 and PM2.5 are the most commonly used surrogates to measure ambient air pollution level for comparisons with international guidelines and standards. The WHO air pollution guideline stipulated that the annual air pollutant level should not exceed 10 $\mu g/m^3$ for PM2.5 and 20 $\mu g/m^3$ for PM10 (WHO, 2006). However, out of 45 megacities in the world, 91% did not meet the standards (Cheng et al., 2016). Globally, exposure to PM2.5 caused 7.6% of global deaths and 4.2% disability-adjusted life years (DALYs) in 2015, of which 59% of them were in China and India (Cohen et al., 2017). Abundant evidence has been established on the acute and chronic health effects of ambient air pollution, with the most significant impacts being from ischemic heart disease (33% deaths), followed by chronic obstructive pulmonary disease (22% deaths), and lower respiratory infection (15%) (GBD 2017 Risk Factor Collaborators, 2018). More studies are emerging on other health impacts such as low birth weight, preterm labor, and neurodegenerative diseases (Costa et al., 2017; Malley et al., 2017).

Motor vehicle traffic is a major source of air pollution in cities, and public transport could play a fundamental role in reducing air pollution by shifting motor vehicles from the roads. The importance of public transport in air pollution mitigation was reflected during the public transport strikes, which increased 4.1%–7.7% of NOx and black carbon in Barcelona (Basagaña et al., 2018), and brought about 14% increase in PM10 concentration in Germany, accompanied with increased hospital admissions of 11% for respiratory illnesses and 13% for abnormalities in breathing especially among young children (Bauernschuster et al., 2017). Few empirical studies have looked into the role of public transport in air quality improvement (Beaudoin et al., 2015). A study showed that the opening of a new metro line in Taipei reduced carbon monoxide (CO) concentration by 5%−15% but had little effects on the ground-level ozone (Chen and Whalley, 2012). A comparison analysis in Houston, Texas with exposure and control sites before and after the opening of a light rail transit (LRT) found that the level of acetylene (a proxy for motor vehicle exhaust emission) reduced by 13% in the exposure sites, and daily stroke mortality reduced by 30% within 10-mi buffer from the LRT (Park and Sener, 2017). Besides the conventional public transport, there have been increasing studies on BRT that has been an emerging form of public transport built-in segregated lanes, with a similar concept to metro system but on lower costs. In Mexico City, the BRT Metrobus reduced the air pollutant concentrations by 5.5%−7.2% for CO, 4.7%−6.5% for nitrogen oxide (NOx), and 7.3%−9.2% for PM10 within 2 years of its implementation (Bel and Holst, 2018); while a case study on TransMilenio BRT in Bogota also reported a reduction of 43% sulfur dioxide ($SO_2$), 18% NOx, and 12% particulate matter after its implementation (Turner et al., 2012).

Other studies involved quantifying air quality and health impacts from transport scenario modeling using comparative health impact assessment with the baseline data and projections. Public transport scenarios are often based on percentage modal shift from motor vehicles to existing or new infrastructures, and fuel improvement. Therefore, vehicle tailpipe emission is the most direct way to quantify transport air pollution associated with public transport. Vehicle tailpipe emissions can be calculated bottom up using the ASIF components (Schipper, 1999). The ASIF structure represents vehicle activity (A), modal share (S), fuel intensity (I), and fuel carbon content (F). Fuel intensity and carbon content are usually determined by national fuel policies with standard emission factors that are affected by other factors such as vehicle age, cold/hot starts, and driving behaviors (Nouri and Morency, 2015). For example, a speeding vehicle will have different emission amount from an idling vehicle trapped in traffic congestion. Besides, motor vehicle also contributes to resuspended dusts from brake wear, tire wear and road frictions. Vehicle activity in terms of distance traveled and modal share from which motor vehicle (passenger car, motorcycle) are shifted to public transport are more likely to be subjected to social intervention scenarios. Review of scenario modeling studies showed that the impact of public transport on emissions and air quality varied between cities projected with different scenarios (Kwan and Hashim, 2016). All public transport scenarios had shown certain amount of emission and air pollution reductions, although it might not be the largest amount compared to alternative or combined intervention scenarios. For instance, the number of avoidable deaths from air pollution for 40% car trips replaced by public transport was four times less than the number of avoidable deaths for 40% car trips replaced by public transport and biking (Rojas-Rueda et al., 2012). Public transport can generate more benefits in large cities with population above a million (Creutzig et al., 2012). In the developing countries, increasing ridership and modal shift to public transport such as Delhi metro and Trans Jogja buses were emphasized to bring down transport emissions and air pollution (Dirgahayani, 2013; Doll and Balaban, 2013). Most of the modeling studies did not explicitly quantify the contributions of emissions during the access and egress of public transport mode, but the use of other transport modes (e.g., motor vehicle, walking, cycling) in these access trips could be important to accrue benefits and account for the impact of the entire public transport trip (Kwan et al., 2017). Another consideration is the potential that a public transport trip may have been induced by a new public transport service without which the trip would not have occurred. The emissions calculated from these scenarios were then subjected to air dispersion and source apportionment model to quantify the spatial concentrations of air pollutants attributable to modal shift to public transport.

Although using public transport can reduce motor vehicle emissions and general air pollution, the exposures of commuters in each public transport modes vary. The level of air pollutant exposures differs by the type of air pollutant and the transport mode. Systematic reviews showed that the levels of exposure for all types of air pollutant [including PM2.5, carbon monoxide, ultrafine particles (UFP)] were the highest for car, followed by bus, motorcycle, car with air conditioner on, rail, and the lowest was found in walking and cycling in the European cities (Cepeda et al., 2017; de Nazelle et al., 2017). In a review on specific exposure to UFP concentration, commuters were found to be increasingly exposed in the order of cycling, bus, car, rail, walking, and ferry (Knibbs et al., 2011). On the other hand, some studies have found high levels of air pollutants both in-vehicle and at public transport stations. In California, train commutes had the largest exposure to most air pollutants compared to others (car, bus, light rail, cycling), while UFP concentrations were 1.6–5.3 times greater in train and bus, and 30% lower in light rail than in private vehicles (Ham et al., 2017). Subway platforms in Europe were found to contain higher PM2.5 concentrations than in the trains due to abrasion and wear of rail tracks, train frequency, and ventilation systems in the trains (Martins et al., 2015, 2016). Bus stops and enclosed terminals near busy roadsides tend to be high-risk areas with high particle levels due to the potential of self-pollution as indicated in a study in Hong Kong where black carbon and UFP were higher in diesel-fueled bus, and CO higher in bus fueled by liquefied petroleum gas (Tan et al., 2017; Yang et al., 2015). The open traffic exposures rendered driving with window closed with the lowest PM2.5 exposure compared to bus and light rail train in the Salt Lake City of Utah (Chaney et al., 2017). In Jakarta, PM2.5 measurements in bus and minibus were also both higher than in cars especially with air conditioning on; however, due to the longer commuting hours in cars, the net exposure was concluded to be higher for car passengers than for public transport commuters (Both et al., 2013). From the conflicting results in different cities, the commuters' exposure level apparently depends on the local environmental contexts. In particular, there are limited studies done in the developing countries for comparisons. Generally, Asian countries had higher exposure levels for all transport modes (cycling, car, bus, motorcycle, and walking), with walking exposures to PM2.5 in Asian cities being 1.6 and 1.2 times higher than in Europe and the United States (Kumar et al., 2018).

In the attempt to mitigate climate change, alternative energy such as electric, hydrogen, compressed natural gas (CNG), and methanol has been adopted in the public transport sector especially diesel buses in many cities (Tzeng et al., 2005). As GHG emissions are often accompanied by other air pollutants, improvement of fuel technology in public transport vehicles can reduce both urban air pollution and in-vehicle commuters' exposures especially children (Adar et al., 2015). For example, the replacement of diesel buses with hydrogen fuel in Trapani, Italy could reduce 1500 t $CO_2$, 1.12 t PM10, and other pollutants (CO, nonmethane volatile organic compounds, NOx) (Franzitta et al., 2017). Comparisons of commuters' exposures between diesel and electric buses found that particle counts in diesel buses were 32% higher than electric buses with self-pollution from exhaust of up to 30% for diesel buses (Zuurbier et al., 2010). On the flip side, alternative energy while reducing the emissions of some air pollutants may also increase the emissions of other air pollutants. A scenario comparison of emissions between buses using different fuel types showed that a battery electric bus could remove all tailpipe emissions, while diesel hybrid electric buses increased NOx emissions by 50%, and liquefied natural gas and CNG-fueled buses increased methane emission by 64 times (Tong et al., 2017). In Delhi, the total phaseout of diesel public transport to CNG-powered buses in 2002 reduced 51%–74% PM10 concentration and 58%–68% PAH concentration (Khillare et al., 2008). However, the uptake of CNG public transport in Delhi also saw an increased NOx level by 10%–20% (Chelani and Devotta, 2007; Ravindra et al., 2006). As NOx is one of the GHGs and also the precursor for forming secondary pollutant ozone that impacts health, the trade-offs for using alternative energy need to be considered carefully. Besides, although electricity-based energy could reduce direct human exposures to combustion emissions from tailpipes due to off-site power plant generation, the GHG emissions from the electricity consumption for public transport also need to be considered for climate mitigation (Ji et al., 2012).

## Road traffic injuries

Road traffic injury (RTI) is the eighth leading cause of premature death globally, with 90% contributed by the low- and middle-income countries (WHO, 2018). Although global rate per population has stabilized over the recent years, the health burden of RTIs has significantly increased in the LMIC due to rapid motorization from the rising economies (GBD 2016 DALYs and HALE Collaborators, 2017). The impact of RTIs is most significant for the working-age groups as it is the major cause of disability among those aged 15–29. This has caused huge economic burden to both high-income countries and the LMIC (Alam and Mahal, 2016; Dalal et al., 2013). Without any significant remedies the number of DALYs from RTIs was projected to rise from the ninth ranking in 2015 to the fourth by 2030 (GBD 2015 DALYs and HALE Collaborators, 2016). A 50% reduction in road traffic injuries aligned with UN Sustainable Development Goals target 3.6 could generate 7%–22% income growth over a 24-year period among the LMIC (World Bank, 2017).

Empirical evidence on the role of public transport in alleviating traffic injuries is scarce as it is often overlooked in road safety interventions. Comparisons of macrolevel data in the United States showed that transit-oriented cities with high public transport trips recorded one-fifth less traffic fatality rate per capita compared to automobile-dependent cities, and using public transport was 10 times safer per mile compared to automobile (APTA, 2016). Empirical studies on BRT such as the Bogota's TransMilenio and Guadalajara's Macrobus suggested that these services had caused significant improvement in road safety by reductions of 25%–60% for injuries and 38%–100% for fatalities (Carrigan et al., 2013). Using public transport instead of driving could reduce high-risk behaviors such as speeding and drunk driving among the young age groups. For example, the introduction of late-night buses in Israel reduced 24% of road traffic injuries among the younger travelers in its metropolitan area (Lichtman-Sadot, 2019). However, a review indicated that the net effect of BRT on road safety is still ambiguous and could not apply to all cities (Vecino-Ortiz and Hyder, 2015). It pointed out that although overall crash rates reduced, pedestrian crashes increased in some spots in the BRT corridor such as in the case of TransMilenio (Bocarejo et al., 2012), and traffic deaths more than double in Delhi. Therefore the role of BRT in mitigating RTI still requires further investigations especially in the management of its pedestrian environment in order to maximize its road safety benefits.

Modeling studies on the health impacts of increased modal shift to public transport generated varying extents of reductions in RTIs in different cities. In Barcelona of 3.2 million people a 20%–40% shift to public transport was expected to reduce only 1–2 road traffic fatality and 30–60 DALYs (Rojas-Rueda et al., 2013, 2012). In Adelaide city of 1.1 million people a 20%–40% shift to public transport was expected to reduce 12–18 deaths and 460–750 DALYs (Xia et al., 2015). An increase in transit mode share from 3.8% to 24.1% in California was expected to reduce 200 deaths and 12,000 DALYs from RTIs (Maizlish et al., 2017). Public transport fare increase of 35% and service cuts affecting 53–64 million trips in Massachusetts could bring 1.15 new crash fatalities per year (James et al., 2014). In some cases the benefits of RTI from public transport could exceed those of physical activity and air pollution depending on the local environment (Dhondt et al., 2013; Maizlish et al., 2017). Multimodal interventions combining effects of modal shift to public transport, car-sharing, walking, and cycling generally reduced RTIs (Dhondt et al., 2013; Sá et al., 2017; Woodcock et al., 2013) but could also produce negative impacts due to increased volume and exposures of pedestrians and cyclists to traffic based on higher percentages of walking and cycling applied (Jarrett et al., 2012; Maizlish et al., 2017). Mixed traffic with other motorized vehicles without dedicated lanes increase the likelihood of collision with other transport modes. However, the nonlinear relationship of mode-specific commuters and RTI rates (safety in numbers), which have been consistently found across studies (Elvik and Bjørnskau, 2017), suggested that high number of pedestrians and cyclists would have lower rates of traffic injuries (Jacobsen et al., 2015). As public transport facilitates active transport (walking and cycling) to the access of stations, appropriate pedestrian and cyclist infrastructures could strengthen the overall safety of using public transport.

Most of the modeling studies apply measurement of fatality or burden per distance traveled while there were sources that pointed out the inaccuracies of the measure due to environmental biases and confounders, and suggested that per capita measure can reflect the benefits of reduced vehicle distance traveled more effectively (APTA, 2016; Schepers et al., 2019). Besides, using the existing baseline traffic injury reports as modeling inputs could subject the results to underestimation of the benefits as RTIs were often underreported especially in LMIC with insufficient reporting system and dense cities with large traffic volume where minor injuries were often overlooked (Ma et al., 2012; Yamamoto et al., 2008).

To maximize the potential of public transport in alleviating traffic fatalities and health burden, public transport such as rail and bus needs to exercise the highest safety standards to both its infrastructures and operations. Public transport accidents usually involve large number of victims from commuters in the public transport itself, and sometimes from the other transport modes (Santos-Reyes et al., 2005). The subsequent media reporting diminish people's confidence on the safety of the public transport mode and thus discourage their usage among the population (APTA, 2016). Nonetheless, the rates of rail accidents per train kilometer have declined by 6.3% per year from 1990 to 2009 in Europe, with 1.35 accidents per billion train kilometers in 2009 (Evans, 2011). Other small scale accidents include falls and slips at, and in the access or egress of transit stations (Kim et al., 2016). In the LMIC where passenger rail network is limited in coverage, bus is the most common public transport. However, due to lack of systematic management (overcrowding, driver's lack of training, and speeding), traffic injuries involving buses have been higher in LMIC with most victims being the low-income groups (Nantulya, 2002; Stewart et al., 2016; Suraji et al., 2017). Nonetheless, the injury risk of taking public transport is still way lower than motorists especially two and three wheelers which made up the majority of RTI deaths in LMIC (WHO, 2018).

## Physical activity

Active transport has been widely promoted in cities as an intervention to the global pandemic of physical inactivity, by incorporating opportunistic walking and cycling in the daily travel rhythm of urbanites. The WHO recommends 150 minutes of moderate-intensity physical activity per week for adult's health (WHO, 2010). Using public transport can facilitate this achievement as people accrue physical activity by walking or cycling to the stations (Besser and Dannenberg, 2005). A non-exhaustive review showed that there have been increasing studies focusing specifically on using public transport and physical activity (Table 6.1). All studies have shown significant positive effects on physical activity among public transport users compared to non-public transport users (i.e., automobile users).

From the collection of studies reviewed, it is apparent that the mean magnitude of physical activity generated from using public transport (existing or new) differed between studies. Many studies have shown varying levels of transit physical activity moderated by factors such as age, gender, income, and car ownerships. For example, the effects of using public transport on overweight and obesity only occurred in men for both studies in Australia (Wen and Rissel, 2008) and Sweden (Lindström, 2008). This is probably attributable to less walking minutes among females compared to male in transits (Morency et al., 2011; Wasfi et al., 2013). The amount of transit physical activity also decreased with age (Knell et al., 2018; Morency et al., 2011), and lower income groups were more likely to walk more to transits than higher income groups (Jiang et al., 2012; Knell et al., 2018; Lachapelle and Frank, 2009). Car ownership and access to car have been proven to be an impediment to modal shift and walking for transits (Collins and Agarwal, 2015; Harada et al., 2018; Knell et al., 2018).

Among the urban environment correlates, residential density, junction density, public transport density, and parks have been significantly related to increased physical activity in 14 cities (Sallis et al., 2016). Train users generally produced more physical activity than bus users (Miller et al., 2015; Morency et al., 2011) following the conventional acceptability of access distance or service area of bus stops (400 m) and train stations (800 m). Durand et al. (2016) reported that there was a decrease of 12% probability of active travel to transit stations with every mile increase in distance in California; nonetheless, there was still a 50% chance of people

**Table 6.1** A review of studies on public transport and physical activity.

| Authors (year), city | Measurement methods/interventions | Key findings |
|---|---|---|
| Chaix et al. (2014) Paris, France | Method: GPS, accelerometer, mobility survey for 7 days | • PT trips were associated with 1211 more steps taken, 10.2 min longer MVPA, and 60.8 kcal larger energy expenditure than using a personal motorized vehicle<br>• PT trips were associated with 11.7 min longer sedentary time than personal motorized vehicle trips |
| Chang et al. (2017) Mexico City | Method: pre- (2011) and post- (2014) intervention questionnaire (long International Physical Activity Questionnaire- IPAQ), propensity score matching<br>Intervention: New bus rapid transit network and Complete Street scheme | • Post-intervention analysis reported 24 min more walking for transport per week, and 32 min more walking for transport and recreation per week |
| Knell et al. (2018) Houston, United States | Method: Houston TRAIN study—self-administered questionnaire, accelerometer | • Primary transit use was associated with 134.2, more mean min per week of transport MVPA, and had 7.3 times relative odds of achieving recommended PA compared to non-transit use<br>• Car ownership was associated with 70 min less transport MVPA<br>• Transit PA was not associated with leisure time PA |
| Lachapelle et al. (2011)<br>Seattle and Baltimore, United States | Method: NQLS—survey (long IPAQ) | • Frequent and infrequent transit commuters accrued 8 and 4 min more MVPA per day than nontransit commuters<br>• Frequent transit commuters had higher odds of meeting recommended PA in high walkability (3.1 times) and low walkability (3.8 times) neighborhoods<br>• Transit commuters walked more frequently to destinations especially near to their workplace |

| | | |
|---|---|---|
| Lachapelle and Noland (2012)<br>Atlanta, Georgia | Method: SMARTRAQ travel survey—telephone interview | • Transit users had 2.23 odds of meeting recommended PA compared to car users<br>• Making use of employer-sponsored transit pass had five times odds of meeting recommended PA |
| Lachapelle and Pinto (2016)<br>Canada | Method: Canada's General Social Survey | • Bus and train transit users had 1.66 and 2.78 higher odds of reaching recommended PA, including walking to transit stations and to other destinations |
| Langlois et al. (2016)<br>United States and Canada | Method: Online travel behavior survey | • People with access to reduced transit fares had 44% higher PA level than those without<br>• PA reduced by 0.57 METs per week during bad weather |
| Laverty et al. (2018)<br>England | Method: ELSA | • Elderly who initiated and increased public transport use (from free bus pass) were associated with increased PA and lower adiposity. Women who increased public transport use had a mean BMI 0.40 $kg/m^2$ lower at follow-up than those who did not |
| Wasfi et al. (2013)<br>Montreal, Quebec | Method: OD survey—phone survey | • Commuter train trip contributed the highest walking distance at 14.47 min followed by buses at peripheral areas (9.86 min), subway (6.9 min), suburban bus (6.95 min), and city bus (2.99 min). 11% commuters achieve recommended PA solely by walking to or from transit stations |
| Voss et al. (2016)<br>Vancouver | Method: GPS, accelerometer for 7 days | • Public transit trips accrue similar amount of MVPA with walking trips (5.5 ; 4.8 min) among elderly |
| Wen and Rissel (2008)<br>New South Wales, Australia | Method: 2003 New South Wales Adult Health Survey | • Men who used public transit to work were 35% less likely to be overweight and obese |

(*Continued*)

**Table 6.1** (Continued)

| Authors (year), city | Measurement methods/interventions | Key findings |
|---|---|---|
| Smart (2018)<br>United States | Method: Panel Study of Income Dynamics. 1999–2013; University of Minnesota's Accessibility Observatory 2015 | • Moving to transit-oriented development area was associated with reduction of 2.2 kg body mass |
| Lindström (2008)<br>Skåne, Sweden | Method: 2004 public health survey in Skåne- postal questionnaire | • Men using public transport to work were 28% less likely to be overweight and obese |
| Morency et al. (2011)<br>Montreal | Method: 2003 Montreal telephone household surveys | • A round transit trip generated 2500 steps, representing a quarter of recommended PA per day |
| Saelens et al. (2014)<br>King County, Washington | Method: GPS, accelerometer, 7-day travelog | • Transit users had higher total physical activity by 1.6–14 min/day and lower BMI (26 vs 27) than nontransit users<br>• Taking transit day recorded 12.4 min more walking than a nontransit day<br>• There were no significant differences in nontransit PA between transit and nontransit users |
| Freeland et al. (2013)<br>United States | Method: National Household Travel Survey—telephone survey | • Living in a large urban area with bus and rail systems was 72% more likely to transit walk more than 30 min/day than with only bus system |
| Collins and Agarwal (2015)<br>Kingston, Ontario, Canada | Method: Online survey (2013, 2014)<br>Intervention: Introduction of Kingston's transit express service | • Transit commuters accrued an average of 80 min/week of commute-related PA and 50 min/week more total PA than those that commuted entirely by cars |
| Hong et al. (2016)<br>California, United States | Method: Survey and accelerometer before-and-after intervention with treatment and control group<br>Intervention: New light rail transit line | • New transits significantly increased walking trips and PA especially among those with low baseline PA and living within half mile from the transit stations |

| | | |
|---|---|---|
| Huang et al. (2017)<br>Seattle | Method: Survey and travelog, accelerometer, GPS pre- (2008) and post (2010)<br>Intervention: new LRT line | • There was an increase in station area walking by 126% within <0.25 mi, 44% within 0.25–5.0 mi, and 26% within 0.5–0.75 mi, compared to those living >0.75 mi |
| MacDonald et al. (2010)<br>Charlotte, North Carolina, United States | Method: Phone interview<br>Intervention: South Corridor Light Rail (LRT) line | • LRT users reduced 1.18 $kg/m^2$ BMI and were 81% less likely to become obese over time |
| Miller et al. (2015)<br>Salt Lake City, Utah, United States | Method: GPS, accelerometer before (2012) and after (2013) intervention<br>Intervention: Light rail transit | • New transit riders had an increase of 5.27 min of total PA and 3.46 min of transit PA per day<br>• Former transit riders had a reduction of 5.54 min of total PA and 2.34 min of transit PA as they shifted to nearer transit stations<br>• Transit riders' increase in physical activity was not associated with a decrease in nontransit-related PA |
| Panter et al. (2016)<br>Cambridge, United Kingdom | Method: 7-day recall instrument, recent physical activity questionnaire 2009–12<br>Intervention: Cambridgeshire Guided Busway | • Cycle commuting increased by 86.6 min/week for those exposed to the busway especially within 4 km<br>• However, there was no effect on total physical activity |

*BMI*, Body mass index; *ELSA*, English Longitudinal Study of Ageing; *GPS*, Global Positioning System; *MVPA*, moderate-to-vigorous physical activity; *NQLS*, Neighborhood Quality of Life Study; *OD*, Origin-destination; *PA*, physical activity; *PT*, public transport; *TRAIN*, travel-related activity in neighborhoods.

walking to transit stations within 2-mi distance. A study on BRT stations in Jinan, China found that walking distance to BRT terminal (1392 m) more than double those of transfer stations (586 m) and typical stations (549 m), and walking distance was influenced by corridor type where integrated boulevard stations had a walk access distance of 649 m compared to 475 m on arterial-edge and 580 m below-expressway (Jiang et al., 2012). The larger spacing between train stations and streetscapes are determinant to the walking amounts (Chang et al., 2017).

Finally, whether transit physical activity influenced activity from other domains remains ambiguous. Several studies in this review found no associations between transit physical activity and other physical activities (Knell et al., 2018; Miller et al., 2015; Saelens et al., 2014); while a review of five studies by Hirsch et al. (2018) showed a decrease in total physical activity after transit intervention. Besides, although it has been widely accepted that the amount of health benefits from physical activity outweighs the impacts of increased exposures to air pollution in active travel, the potential of solely using transit physical activity to reach the recommended level, and whether the intensity of walking to transit stations is sufficient to impact on health still need further investigations (Shaw et al., 2017; Tainio et al., 2016). As active travelers remain the most vulnerable commuters to traffic injuries, it is important to provide infrastructures that ensure their safety and net health benefits.

## Modal shift

Given the large social environmental and health benefits that can be brought by public transport, various strategies have been implemented in cities to encourage public transit as a feasible and attractive alternative to motor vehicles, including the offer of free transit pass included in the earlier review. There are many factors that determine the modal choice of commuters including travel time, costs, purpose, and ease of use. The introduction of new transit infrastructures such as BRT, LRT, and metro that significantly reduced travel time could bring large modal shift up to 50% among the passengers (Ingvardson and Nielsen, 2017). Besides, it has been shown that the service qualities such as waiting time, cleanliness, and comfort were most valued by existing public transport users in order to retain them, while waiting time, travel time, and occupancy level could attract new users from motorized vehicles (Dell'Olio et al., 2011). However, Redman et al. (2013) suggested that the commuters' demand on public transport service quality varies depending on the context and perceptions of individuals, stating personal motivations as the more important factor to induce modal shifts. On the strategies to reduce car use and encourage public transits, experiences in successful countries showed that a mix of transport and land use policies are needed to make car use less convenient and more costly, and public transport more attractive, such as providing network expansions, fare discounts, and improved service quality (Buehler et al., 2016). Parking management has been recognized as the most important in car restriction policies for reinforcing reduced car use. Besides, the ease of travel in the first and last mile of public transport stations is important to boost ridership (Tilahun et al., 2016). Although providing the park and ride service could increase ridership (Walton and Sunseri, 2010), using motor vehicles to access or egress stations could partly forfeit the intended health benefits of public transport through active travel and may generate additional emissions, air pollution, and risk of traffic injuries to the commuters especially from induced trips.

## Conclusion

This chapter summarizes and discusses the results of empirical studies and scenario modeling on the emission, air quality, traffic injury, and physical activity impacts from public transport. Although public transport can generally bring health benefits to population, the amount of benefits depends largely on local contexts. Careful planning is needed to ensure net positive health impacts from the entire public transport system. Improvements on certain aspects such as safe built environment surrounding transit areas may accrue more beneficial health impacts to the local population.

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CHAPTER SEVEN

# Transport and community severance

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## Contents



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## What is community severance?

Transport-related community severance is the "barrier effect" of transport infrastructure, or vehicles using that infrastructure, on the movement of pedestrians and cyclists, impeding access to the goods, services, and social networks necessary for a healthy and fulfilling life. Barriers from infrastructure include linear infrastructure such as motorways (or other roads with physical barriers preventing pedestrians from crossing), railways, rivers, and canals. These barriers cause what is sometimes referred to as "static severance," to distinguish it from the "dynamic severance" caused by the number, characteristics, and speed of motor vehicles. Roads with high volume of traffic tend to cause dynamic severance, especially when there is a high proportion of heavy goods vehicles in the traffic, or when traffic is moving at a fast speed (Anciaes et al., 2019). Fig. 7.1 shows

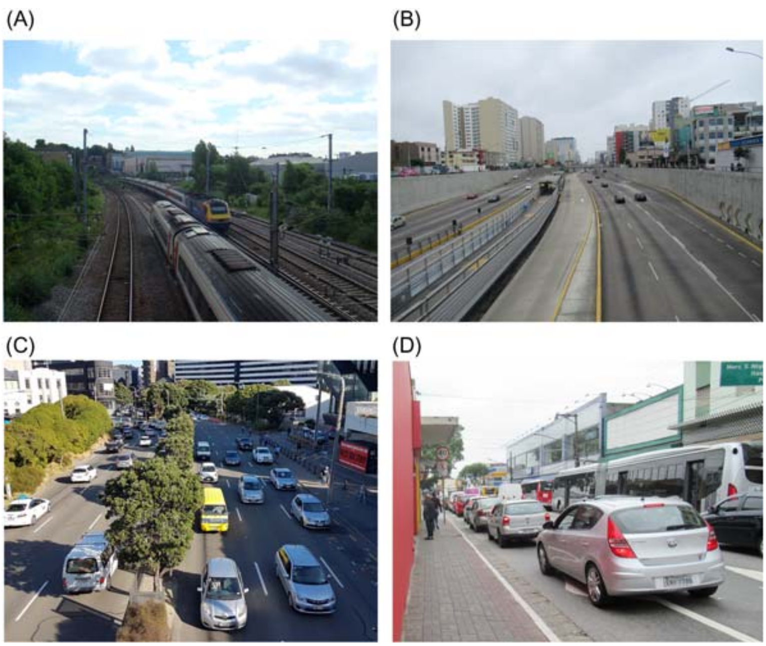


**Figure 7.1** Different types of severance.
Static severance: (A) railway and (B) road with physical barriers.
Dynamic severance: (C) busy 6-lane road and (D) congested minor road. *(A) London, UK © P Anciaes, 2016; (B) Lima, Peru © P Anciaes, 2017; (C) Wellington, New Zealand © J Mindell, 2019; and (D) São Paulo, Brazil © P Anciaes, 2017.*

examples of different types of static and dynamic severances, which can occur in high-, middle-, or low-income countries and in urban or rural areas (Bradbury, 2014).

Many definitions of community severance exist (Anciaes, 2015; Mindell and Karlsen, 2012). Three stand out through focussing on the area surrounding roads and other transport infrastructure, rather than merely on the line of the transport infrastructure itself (Box 7.1).

**BOX 7.1 Three of the many definitions of community severance**

James et al. (2005): *The existence of real or perceived barrier to people's movement through an area that is created by the transport infrastructure (such as roads or railways) or traffic.*

Quigley and Thornley (2011): *Separation of people from facilities, services, and social networks they wish to use within their community; changes in comfort and attractiveness of areas; and/or people changing travel patterns due to the physical, traffic flow, and/or psychological barriers created by transport corridors and their use.*

Street Mobility team: *The variable and cumulative negative impact of the presence of transport infrastructure or motorized traffic on the perceptions, behavior, and well-being of people who use the surrounding areas or need to make trips along or across that infrastructure or traffic* (Anciaes, 2015; Mindell et al., 2017).

Community severance caused by linear infrastructure is particularly impactful in urban neighborhoods that are near other large single-use areas, such as non-linear transport infrastructure (e.g., airports, ports, and stations), industrial estates, and even hospitals and university campuses, which tend to have poor permeability for pedestrians (Héran, 2011). In some extreme cases, residential neighborhoods become "locked-in" because they are surrounded by transport and non-transport barriers on all sides.

While most existing research has focused on the role of transport infrastructures as physical barriers that are difficult to cross, these infrastructures may also be perceived as psychological barriers even when it is easy to cross them, due to their negative visual impact.

## What are the effects of community severance?

### Travel

Fig. 7.2 shows the hypothesized deterrent effects of *dynamic severance*, namely motorized traffic, on travel and the use of streets as social spaces. Traffic volume and speed increase the length of trips across the road, especially by walking and cycling, as people detour from the shortest paths in order to cross the road in safe places.

For people traveling along, across, or near a busy road, the noise and air pollution from motor vehicles also result in an unpleasant environment that reduces the likelihood of making trips on foot or by cycle, decreasing physical activity and leading either to journeys not made or to journeys made by motor vehicle (Duncan et al., 2005; Jacobsen et al., 2009; Saelens and Handy, 2008). The unpleasantness of busy streets also combines with a fear of road travel collisions to reduce permissions for children to travel independently and the use of social spaces for people of all ages, but particularly the old and the young.

As shown in the Fig. 7.2, the negative effects on physical activity, journeys not made, and use of streets as social spaces may be associated with indirect effects in terms of a reduced level of access to services, goods

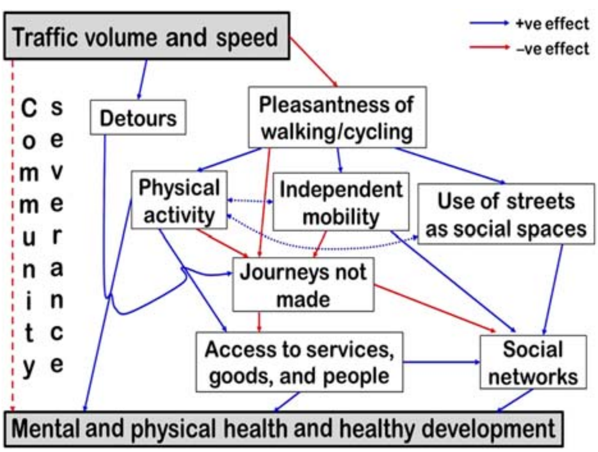


**Figure 7.2** Theoretical paths from traffic-related severance to health impacts. Figure 1 in *Mindell, J.S., Karlsen, S., 2012. Community severance and health: what do we actually know?. J. Urban. Health 89, 232–246. Available from: https://doi.org/10.1007/s11524-011-9637-7*.

and people, and weaker social networks. These effects are then associated with mental and physical health and healthy development.

*Static severance* caused by transport infrastructure such as motorways and railways has similar effects except that the impact on the pleasantness of active travel is perhaps less relevant (because pedestrians and cyclists are usually not allowed to use that infrastructure). However, the detours are generally longer than in the case of dynamic severance, sometimes extending to many miles. In the case of railways, any crossing points that are available will generally be footbridges or underpasses. There are plans in several cities to remove a large proportion of unsignalized level crossings across railway lines to improve safety (see, e.g., https://levelcrossings.vic.gov.au/projects). However, in some cases, these plans may have the effect of exacerbating community severance (Mepham, 2016). In the United Kingdom, 1100 level crossings were removed in 2009–17 (https://www.networkrail.co.uk/communities/safety-in-the-community/level-crossing-safety/).

## Independent mobility

Older people's independent mobility is a prerequisite for independent living in one's own home (Siren et al., 2015). Relating to the lack of mobility, Murray (2015) has differentiated between unmet demand, suppressed demand, systematic barriers to mobility, and aspirational mobility. Others refer to primary mobility—relating to the capacity to walk—and secondary mobility, reliance on motor vehicles, whether private or public transport (Silverstein et al., 2017). Those who are housebound are at high risk of both loneliness (a subjective feeling) and of isolation.

Children's independent mobility has been curbed dramatically over the past five decades in many countries. In England, 55% of children under 10 were allowed to walk to local places other than school in 1971 but by 2010, hardly any children were given such permission (Shaw et al., 2015). The proportion traveling to school without an adult or being allowed to play outdoors varies (Carver et al., 2014). A comparison across 16 countries in three continents found wide variation. Children in Finland and Germany had the greatest freedom to cycle on a main road, cross main roads, travel home from school, or go out after dark alone. The strongest predictor affecting permissions for children was motor traffic, with only a weak effect of concerns about "stranger danger" (Shaw et al., 2015).

## Economic effects

Barriers to walking and cycling can limit easy access to employment, with direct economic consequences. Reduced access to education has indirect economic effects, as educational attainment and subsequent income are so closely linked.

In general, pedestrianization and reductions in car traffic increase expenditure in local businesses (Mindell, 2015). Pedestrianization is associated with a 20%–40% increase in visits to local retailers and a 10%–25% increase in retail turnover (Tolley, 2011). The travel mode is associated with spend on a single visit in some (TfL, 2011, 2013) but not all studies (Wooller, 2010). However, studies consistently find more frequent visits by non-car users, so expenditure over time is lower for car users than for those using active travel or public transport (Mindell, 2015). Thus the deterrent effects of community severance that result in journeys not made at all or not made by walking or cycling are likely to have noticeable adverse effects on local businesses.

Trips not made by older people can also result in losses to the economy, not only from direct expenditure not made but also through volunteer work and childcare not provided due to the lack of travel options (Mackett, 2015).

## Social cohesion

There is consistent evidence that barriers to pedestrian mobility caused by busy roads reduce social interaction between people living on opposite sides of the road (Appleyard et al., 1981; Hart and Parkhurst, 2011; Sauter and Huettenmoser, 2008; Wiki et al., 2018). There is also some evidence that large transport infrastructures contribute to the discontinuity of urban space and induce the relocation of people from different income and ethnic groups, reinforcing spatial segregation (King and Blackmore, 2013; Mitchell and Lee, 2014; Noonan, 2005). They may also induce social problems such as crime due to low footfall in the surrounding areas (Jacobs, 1961).

## Long-term effects

In all these cases the effects of a change, such as construction of a new railway or road, may be different from the long-term effects of an existing barrier, due to adaptation by local residents or migration of people after the barrier existed. For example, Lee and Tagg (1976) compared communities that were separated by roads built in different periods and found that over time the communities responded to the barrier by reorienting themselves away from the road, that is, by making more trips to places on their side of the road.

Some of the effects mentioned previously may also only appear in the long term. This is, for example, the case of economic effects. Jacobs (1961) noted that neighborhoods bordering barriers tend to decline economically because the poor accessibility and its indirect effects lead, over time, to a flight of residents and businesses.

## Secondary effects

In addition to the *primary effects* of the original barrier, there are also *secondary effects* caused by inadequate, though well-intentioned, mitigation measures that either do not relieve the severance or have other unintended consequences (James et al., 2005; Jones and Lucas, 2012).

Footbridges and underpasses are generally disliked by pedestrians and cyclists (Rankavat and Tiwari, 2016; Räsänen et al., 2007; Tao et al., 2010; Villaveces et al., 2012) and avoided when another option exists, even when this implies extra walking time to use at-grade signalized crossings (Anciaes and Jones, 2018) or crossing in places without any crossing facilities (Obeng-Atuah et al., 2017; Sinclair and Zuidgeest, 2016).

This may be explained by the fact that even when they are sited along desire lines, footbridges and underpasses are often inaccessible for, or difficult to use by, some pedestrians. For users of wheelchairs and those with difficulties in climbing or descending steps, footbridges and underpasses can be even more of a barrier than the infrastructure it is bypassing. Even where a ramp is provided, this can take too much effort. As an example, the force required to push a wheelchair up a ramp to access a bus can require pressures equivalent to two to three times the body weight to be transferred through the shoulders (Velho et al., 2016).

Due to poor design or maintenance, crossing facilities can also be inaccessible or unpleasant in flooding or icy conditions. Underpasses (and, to some extent, also footbridges), especially if poorly lit, are also avoided primarily through fear of crime as well as on esthetic grounds, as they are often used as public toilets. Fig. 7.3 shows examples of footbridges and underpasses with obvious problems of poor accessibility and attractiveness. Women and older people are particularly likely to be deterred from using footbridges and underpasses, contributing to the inequalities engendered


**Figure 7.3** Example of footbridge and underpasses with poor conditions: (A) footbridge and (B) underpass. *(A) London, UK © P Anciaes, 2016 and (B) Chisinau, Moldova © P Anciaes, 2018.*

by community severance (Bradbury, 2014), although a study in Tanzania found that women were more likely than men to say that they preferred to cross roads above or below ground level (Mfinanga, 2014).

In addition, neglect encourages—or does not remove—graffiti or litter. Pitner et al. (2011) describe graffiti, vandalism, and litter as *physical incivilities*, and noisy neighbors and criminal activities as *social incivilities*; occurring together in public spaces where the community feels no ownership of the area, they are associated with increased perceptions of crime, referred to as the *broken window* theory. These incivilities combine to deter walking wherever they occur, not just on severance mitigation measures. However, the lack of people walking along the street or using streets as social spaces increases the likelihood of these neighborhood incivilities.

## What are the health impacts of these effects?

### Travel

#### *Physical activity and sedentary behavior*

Walking and cycling for travel are among the easiest and cheapest ways to incorporate physical activity into everyday life. Walking and cycling can provide the same health benefits as sports or other exercise, reducing the risks of obesity, diabetes, heart disease, stroke, many cancers, depression, osteoporosis (thinning of the bones), and improving mental well-being. Walking or cycling to work can be as effective as a training program, can increase cardiorespiratory fitness, and can fulfill the recommendations for physical activity.

People who commute by car gain more weight than those who do not, even in those who meet the physical activity recommendations with leisure time activity (Sugiyama et al., 2013). Because most public transport journeys start and/or end with walking or cycling, public transport can be considered as active travel. The study of Martin et al (2015) in the United Kingdom found that people who changed from car commuting to public transport lost weight, with those changing to walking or cycling losing more weight. Weight increased in those who switched from active travel to car commuting. A study in Canada found that people who perceived both walkability and social connectedness of their neighborhood as high walked more, both for travel and leisure. One estimate from a small study of closing a road to motor vehicles estimated health economic benefits from increased physical activity of around £500,000 over 20 years (Aldred and Croft, 2019).

### Independent mobility

Apart from issues of access to health-promoting destinations, independent mobility is inherently important. In older people, it is associated with well-being and maintenance of social networks (Murray, 2015). It also promotes healthy aging and helps to maintain function through providing opportunities for physical activity and movement, with benefits for circulatory and respiratory capacity, muscle strength, and balance (Rantanen, 2013). Independence for mobility is also important for self-esteem and mental well-being, to avoid dependence on others and feelings of control (Siren et al., 2015). Even where journeys could be made by public transport, community severance may prevent access to the bus stop or station if access involves crossing a busy road.

Freedom to travel and to play independently of adult supervision is also associated with levels of educational attainment of children (Shaw et al., 2015). Children who are not allowed to travel independently or to play outside have delays in their mental and physical development and lower self-esteem (Hüttenmoser, 1995). Other effects on social isolation and curtailment of children's independent mobility and activities have been reviewed elsewhere (Mindell and Karlsen, 2012).

### Social isolation

Social contacts are very important for health. In their classic Almeida Study, Berkman and Syme (1979) found that age-adjusted mortality was two to three times higher for the most isolated adults compared with those with the most social contacts, even after adjusting for socioeconomic position, use of preventive healthcare, obesity, and health risk behavior such as smoking, alcohol, and physical activity. A meta-analysis of 148 studies found that the greater the social network, the lower the mortality, with an overall 50% lower mortality for those with stronger social connections. Importantly, in the context of community severance, the effect was much larger for those with a greater extent of social integration (Holt-Lunstad et al., 2010). The effects of objective measures or subjective feelings of loneliness are very similar: mortality increased by 26%–32% for those reporting loneliness, with social isolation, or living alone (Holt-Lunstad et al., 2015).

## Subjective well-being

Living near motorways and busy roads is also associated with lower subjective well-being. A study in Glasgow found that people living near a motorway had lower well-being than people living further away (Foley et al., 2017). This impact may be explained by higher levels of exposure to noise and air pollution. In a study in London, Anciaes et al. (2019) also found an association between living near a busy road and lower subjective well-being, but in this case the association was explained by people's perceptions of the negative impact of the road on walking.

## Air pollution

The health impacts of air pollution are relevant to community severance because motor vehicle emissions contribute to the unpleasant environment that deters people from walking or cycling near busy roads.

In many countries, motor vehicles are the leading and/or only increasing source of air pollution. The main vehicle-related pollutants are products of combustion, particularly oxides of nitrogen, particulates, and oxides of carbon. Oxides of nitrogen drift and combine with volatile organic compounds also emitted from fuel to form ozone in a reaction catalyzed by sunlight. Carbon dioxide is the most widely found greenhouse gas that contributes to climate change. The health impacts of air pollution have been summarized recently (RCP and RCPCH, 2016) and include increasing the incidence and severity of mortality from heart disease, stroke, asthma, and other respiratory diseases, as well as contributing to obesity and to dementia. The health impacts of global climate change have also been summarized (Watts et al., 2017). Other pollutants include heavy metals from catalytic converters and particulates from tires and brakes. It is important to note that these nonexhaust particulates are emitted just as much by electric as conventional vehicles.

### Noise

Motor vehicles are the main cause of noise in most countries. In Europe, noise is second only to air pollution in the impacts of environmental factors on disability-adjusted life years (Stansfeld, 2015). As well as being unpleasant and thus contributing to the deterrent effect of community severance on local nonmotorized travel, noise has a range of impacts on health. One of the most important is increasing blood pressure, thus increasing the risks of stroke and heart disease. While the effects of noise on reducing concentration and cognition (and thus educational achievement) and impairing sleep are important health impacts of motor vehicles in general, they are experienced more by those working, studying, or living near busy roads rather than by travelers. However, measures to reduce community severance, particularly those operating through reducing traffic speed and/or volume, can mitigate these health impacts.

### Injury

Globally, there were 1.35 million road travel fatalities in 2018 (WHO, 2018). Road travel injury and fatality rates vary widely by country. Static severance is seldom related to travel injuries except for level crossings of railways, for example. However, dynamic severance can have a complicated relationship with injury risk. Where severance is very high, the deterrent effect of high collision and injury risk may predominate, with few pedestrians crossing the road if they have other options. Where severance is less extreme, or where the need to cross overrides safety concerns, pedestrians are likely to take a chance and collisions are likely. The highest fatality rates are in low-income countries with rising motorization, a predominance of non-motorized traffic, and poor infrastructure. Casualty rates are particularly high in rural areas (Bradbury, 2014).

## Cumulative impacts and inequalities

Many of the effects of community severance are cumulative and tend to create or reinforce inequalities. For example, severance generally affects poorer people the most. This is because more affluent people can choose not to live in areas with less severance and usually have better access to a car, which can protect the individual against most of the harmful impacts of severance. In addition to greater exposure, poorer people are often more susceptible to air pollution, which particularly affects people with preexisting cardiorespiratory disease.

In the case of dynamic severance, age inequalities may also occur because walking speed restricts people's ability to cross busy roads. Even where there are signalized crossings, the time allowed is often too short for many people. For example, where *pelican*[1] crossings are used, the *invitation to cross* (see footnote 1) is a set number of seconds, depending on the width of the road. The *clearance time* (see footnote 1) before the lights turn green for motorists uses 1.2 meters/second as the assumed minimum speed of pedestrians in Brazil, the United Kingdom, and the United States (Asher et al., 2012; Duim et al., 2017; Webb et al., 2017). However, the mean walking speed of a nationally representative sample of men and women in England aged 65 + was 0.9 m/s and 0.8 m/s, respectively (Asher et al., 2012). In a similar study in São Paulo in Brazil, 96% of adults aged 60 + walked more slowly than 1.2 m/s; 70% walked more slowly than 0.9 m/s (Duim et al., 2017). These results suggest that the dynamic severance caused by roads, and the use of signalized crossings to reduce that severance generate inequalities between older and younger pedestrians. In addition, all three studies cited previously found that the decline of walking speed with age is greater in poorer people and in less healthy people. For example, 15% of the richest and 3% of the poorest men aged 60 years old in an English study were predicted to be able to cross the road in time (Webb et al., 2017).

Where the barrier effect means that journeys cannot be made or are difficult to make except by car, those who are too young, old, ill, or poor to own or drive a car become dependent on others to drive them. Where nuclear families live in different areas from their extended family, where there is less social cohesiveness, and in poorer neighborhoods, there are probably fewer people able to give lifts to others. There are also gender inequalities, as women are less likely than men to have access to a car even in car-owning households.

[1] A pelican crossing has a light on the other side of the road showing a person. When it is red, the signals are green for motor vehicles. A green person is an invitation to cross; a green flashing person indicates that those on the crossing should continue (clearance) but no one should start to cross.

Community severance may also reinforce spatial inequalities, as residents in some areas may be more vulnerable to the loss of accessibility caused by the barrier effect of transport infrastructure. This is, for example, the case of isolated suburban areas and rural areas with poor public transport access and few options of pedestrian destinations (e.g., villages with just one shop, located on the other side of the barrier). An extreme example is some rural areas of sub-Saharan Africa where children need to cross streams to access school but the streams can become hazardous rivers (Bradbury, 2014).

These inequalities are often greatest in low-income countries. Rapid motorization may lead to a focus on increasing the infrastructure for cars at the expense of other travelers (Bradbury, 2014). However, there have been calls to prioritize provision for pedestrians (de Langen, 2005; Mitullah et al., 2019).

## What tools are available to assess community severance?

Anciaes et al. (2016) have summarized the measures that have been used or proposed in a number of different countries. These include pedestrian time spent waiting to cross, multiplied by the number of crossings, and then ascribed monetary values. National-level guidance in Switzerland and the United Kingdom have suggested a simple qualitative classification, for example, slight, moderate, or severe. The article then describes more complicated measures that have been proposed by researchers, most of them being adaptations of walkability and accessibility indicators that are usually used to analyze other issues. There is also a growing number of studies estimating the economic value of community severance using stated preference surveys, that is, surveys that ask people to choose among different scenarios for road designs, traffic conditions, and an hypothesized personal benefit or cost (e.g., Anciaes et al., 2018; Grisolía et al., 2015).

The authors are part of the Street Mobility team that developed a toolkit to assess community severance using a range of approaches. These include participatory mapping and a pen-and-paper survey of local residents, enquiring about ease of walking around the local area; use of video surveys to assess motor and pedestrian traffic and pedestrians' crossing behaviors; a walkability model; a severance index; and a tool for economic appraisal of current severance and proposed changes. Existing tools that are also a part of the toolkit include spatial analysis (using space syntax), and street audits, to assess the quality of provision for pedestrians and wheelchair users both at junctions and along links between junctions. The tools were designed to be used independently or in combination, by local communities, local government, or researchers; they can be downloaded freely (www.ucl.ac.uk/street-mobility/toolkit). The toolkit website also includes information on how to run a survey and analyze the resultant data.

## Policies to remove or reduce community severance

### Remove the infrastructure

Radical solutions to completely remove the transport infrastructure have become more politically acceptable in recent years, due to an increasing priority given by city authorities to street liveability. A 2012 report (ITDP and EMBARQ, 2012) describes a series of cases around the world where urban highways were removed. One of the most well-known cases is the demolition of the Cheonggyecheon Expressway in Seoul and its replacement with a park alongside a stream that was previously underground.

Compared with completely removing the infrastructure from the transport network, solutions that simply separate the infrastructure from the pedestrian network are less desirable:

- Burying the infrastructure (i.e., building a tunnel) is not always technically or economically feasible.
- Flyovers can restore street connectivity but are visually intrusive and do not reduce exposure to noise and air pollution (Future of London, 2018).
- Sinking (without burying) the infrastructure reduces exposure to noise and air pollution and allows for the replacement of grade-separated pedestrian crossings with surface crossings, but pedestrian movement is still limited by the number of these crossings.
- Bypasses tend to shift the problem to other areas. In addition, projects to build bypasses are often met with protest for economic or environmental reasons (see https://www.theguardian.com/environment/2013/jan/12/combe-haven-green-protesters-trees).

## Add or modify crossing facilities

When completely removing the infrastructure is not politically or financially viable, community severance can still be reduced by adding more crossing facilities for pedestrians. This reduces the detours to walking trips and allows pedestrians to cross the road safely, reducing the perceived danger and unpleasantness of crossing the road.

Another possibility is to change the type of existing crossings. In comparison with pelican crossings, puffin[2] crossings and nonsignalized (zebra) crossings have the advantage that pedestrians are not limited in how long they take to cross the road; the disadvantages are a lack of understanding of the camera-controlled lights at puffin crossings, leading to fear that motor vehicles will resume, and dependence on drivers stopping at zebra crossings. The latter is a problem in many areas, that is, dealt with in differing ways. A survey in Japan found that 90% of drivers do not stop; education is being proposed as the solution (https://japantoday.com/category/national/more-than-90-of-vehicles-dont-stop-at-crosswalks-without-lights-despite-presence-of-pedestrians). In France a new law has increased the penalty for drivers who fail to stop at an unsignalized crossing to 6 points on their license for (https://www.connexionfrance.com/French-news/France-decrees-new-laws-on-pedestrian-and-road-safety). In New Zealand, there have been calls by transport planners to remove zebra crossings. A more sensible approach would be to deal with driver behavior and to add more visible flashing beacons.

Another possibility is to change the characteristics of the existing crossing facilities. For example, in signalized crossings, reducing the assumed walking speed used for clearance times would allow pedestrians with lower walking speeds to cross the road safely. Until camera-controlled signals based on detection of a person crossing the road are universal, the current default 1.2 m/s is too far quick for almost all older people, as well as many others with mobility impairments, young children, or luggage. Reducing the waiting time for pedestrians in signalized crossing facilities can also reduce delays to pedestrian trips, reducing the perceived barrier effect of the road.

Improvements to grade-separated facilities can also increase their attractiveness to pedestrians, reducing the perceived barrier effect. For example, there are ways where good and innovative design can make

[2] A puffin crossing is a signalized crossing controlled by sensors that detect if pedestrians are crossing. The green phase for vehicles starts only when all pedestrians have finished crossing. Unlike pelican crossings the lights for pedestrians are on the nearside of the road.

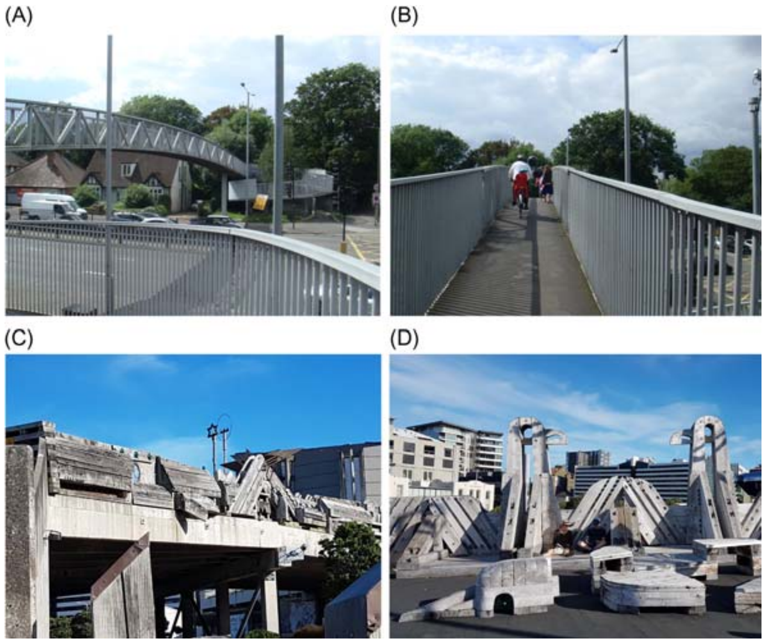

**Figure 7.4** Traditional and innovative approaches to pedestrian bridges across busy roads:
(A and B) traditional footbridge and (C and D) innovative carved bridge. *(A and B) London, UK © P Anciaes, 2016 and (C and D) Wellington, New Zealand © J Mindell, 2019.*

footbridges desirable places to spend time and use as social spaces (Fig. 7.4). Improving the design and maintenance of underpasses can also mitigate their general unpleasantness.

## Road redesign and traffic policies

In the case of the dynamic severance caused by busy roads, possible solutions include modifying the road design or implementing policies to change the characteristics of road traffic.

Changes to road design that could reduce severance include the following:

- Reducing the number of lanes for motorized traffic—this reduces the total width of road that pedestrians need to cross.
- Adding a central reservation (i.e. a median strip) or widening existing central reservations—this allows pedestrians to cross in two stages, stopping in the central reservation.

- Removing physical barriers (such as walls or guard railings)—this increases the number of places where pedestrians can cross.

Changes to the characteristics of road traffic include the following:

- Reducing traffic levels, using economic policies (e.g., road pricing) or regulations (e.g., restrictions based on license plate numbers).
- Changing the composition of the traffic, by restricting the circulation of some types of vehicles at all or some times of the day or days of the week.
- Reducing traffic speeds, by imposing lower speed limits.

## Improve conditions for pedestrians walking along the road

The barrier effect of the road on pedestrian mobility can also be reduced by improving conditions for pedestrians walking along (and not necessarily across) the road. This could be achieved by

- providing pavements (sidewalks) where they do not exist;
- widening existing pavements, including removing obstructions;
- improving the pavements' surface quality;
- adapting the design of pavements to increase their accessibility to people with disabilities (e.g., by adding dropped kerbs, tactile information, and color contrast);
- other measures, such as providing places to sit and rest and improving lighting conditions, soft landscaping, and cleanliness.

Governments around the world have been attaching more priority to the interventions mentioned previously, aimed at creating more equitable road and street design. For example, in the United States, the Complete Streets Act (2009) aimed to change car-centric street design by creating "complete streets" that address the needs to all users, including pedestrians, cyclists, and people using streets as places (e.g., for socializing, relaxing, and window-shopping). Inclusion of pedestrian falls in the street within the definitions of road travel injuries (Methorst et al., 2017a,b; Schepers et al., 2017) might also help decision-makers to prioritize better facilities for pedestrians.

## Summary

This chapter reviewed the state of the art of the relationship between transport and community severance, defined as the "barrier effect" of transport infrastructure and motorized traffic on the movement of pedestrians and cyclists. Community severance affects travel behavior because people may avoid walking due to the risk and inconvenience of crossing busy roads and other transport infrastructures and/or due to the exposure to noise and air pollution when crossing or walking along those infrastructures. This reduces the independent mobility of some groups (such as older people and children) and has potential negative economic and social effects. Facilities to cross the road do not always relieve severance, especially in the case of bridges and underpasses, which are generally disliked by pedestrians and cyclists.

Community severance is related to health as it tends to reduce physical activity, independent mobility, social contacts, and subjective wellbeing, and is also associated with other negative health impacts of transport, such as exposure to noise and air pollution and increased probability of injuries. Many of the effects of community severance are cumulative and often generate or reinforce inequalities, as they are particularly impactful for certain age and socioeconomic groups.

A range of different tools have been proposed by researchers to assess community severance. These tools can also be used to assess the effectiveness of possible policies to remove or reduce the problem. This includes removing the transport infrastructure, adding or modifying crossing facilities, road redesign, traffic policies, and general improvements of the conditions for pedestrians walking along roads.

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CHAPTER EIGHT

# A justice perspective on transport and health

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## Contents



## Introduction

In its broadest sense, transport is fundamental to a person's health. It is only because of transport that people can engage in a range of activities, ranging from work, to education, to leisure, social contacts. Participation in these activities is fundamental to human flourishing and human flourishing, in turn, is a key determinant of a person's physical and mental health. In this sense, transport and health are fundamentally interlinked. At the same time, transport has also detrimental effects on health, as it is a major cause of death and injury and generates a host of pollutants that are detrimental to people's health.

This broad understanding of transport as being fundamental to people's life and thus health, however, provides little insight into the extent to which different people experience the health benefits or the burdens related to transport. People do not benefit to the same extent from the

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transport infrastructures and services available in society. Some may have access to virtually all available services, while others may be able to use only few of the available transport options, severely limiting their ability to participate in activities. Likewise, the adversary effects of transport are not equally distributed over people. Some population groups may live along major road arteries and thus be exposed to high levels of air pollution, while others may live in lush suburban areas with virtually no transport-related air pollution. Moreover, even if exposure is identical, some people may be more affected than others.

These issues of distribution are at the heart of a justice perspective on transport and health. More specifically, it is possible to distinguish between four dimensions of the relation between transport and health, each of which can work out differently for different population groups (compare van Wee and Ettema, 2016).

The first dimension concerns the extent to which the transport system enables people to participate in health-enhancing activities and destinations. As already mentioned, if the term "health-enhancing" is conceived broadly, this includes virtually all activities. For instance, the social exclusion literature shows that poor transport can prevent people from obtaining employment (Lucas, 2012) and a host of studies has shown the detrimental effects of unemployment on bodily and mental health (see e.g., Mathers and Schofield, 1998; Modini et al., 2016). Thus access to employment can be seen as part of the transport and health literature and the existing differences in access to employment potentially turn it into an issue of justice. However, it makes more sense to limit the transport and health literature to a narrower set of activities and destinations more directly linked to health. This set obviously includes access to health care itself (hospitals, clinics, prenatal care, etc.), but it also encompasses access to destinations with a typically positive impact on health, such as parks and nature, sport facilities, and (healthy) food.

The second dimension concerns the extent to which the transport system enables people to engage in travel behavior that is conducive to their health. This is a burgeoning research topic that not only includes the rapidly expanding body of literature on active travel but also encompasses studies into the relationship between travel and well-being.

The third dimension encompasses the extent to which the transport system exposes people to pollution and risks detrimental to a person's health. This includes air pollution, noise pollution, as well as injury and risk from traffic. These externalities can affect the traveler herself, other fellow travelers, as well as people who are not engaged in travel.

Each of these three dimensions takes travel as their starting point and health as the "dependent" variable. The fourth dimension, in contrast, takes a person's health as its starting point and travel as the "dependent" variable. This dimension concerns the impact of people's health status on their ability to reap the benefits generated by the transport system. The most well-developed literature under this rubric includes the literature on motor-related and sensory-related impairments and travel. More recently, there is increasing attention for the extent to which the transport system is manageable for people experiencing cognition-related impairments and a range of disorders (e.g., Mackett, 2019). The latter does not only include severe impairments or disorders but may also cover more limited problems such as the difficulty in comprehending written materials. Furthermore, the relation between health status and travel is clearly not limited to people with a chronic health problem but may affect people who are "temporally encumbered with no disabilities," such as people recovering from an injury or operation or some women in the later stages of pregnancy (Casullo, 2016).

The four dimensions of the nexus between transport and health are obviously interrelated. For instance, in a neighborhood that is surrounded by major roads, residents may not only be exposed to high levels of air pollution, but they may also experience restrictions on walking and cycling, thus limiting their ability to maintain active lifestyles. Furthermore, the barrier effect created by wide roads may hinder people, and especially children and the elderly, to access destinations with beneficial health impacts, such as sport facilities or local parks.

Each of these dimensions has been extensively studied and is also addressed in various chapters of this book. In many cases, too, studies map and analyze the differences between people in terms of the extent to which they benefit or suffer from the transport system, thereby touching on the topic of justice. Often, indeed, the literature equates differences with inequalities and inequalities with inequities. These terms, however, have a distinct meaning and should not be used interchangeably. Hence, before continuing, it is important to discuss the difference between these notions.

## Disparities, inequalities, inequities, and justice

A substantial share of the literature on transport and health seeks to uncover, explain, and understand the relationships between these two phenomena, without much concern for how these relationships play out across different groups. Yet, given the increasing concerns over equity in society and academia, it may come as no surprise that the majority of the research actually explicitly explores how health-related benefits and burdens of transport work out differently for various population groups. These studies typically employ the word disparities to describe these observed differences. Studies are usually interested in the disparities between population groups along dimensions of socioeconomic status or other population characteristics. Such studies often find quite large differences between population groups, for instance, in terms of risk of traffic injuries, exposure to traffic-related air pollution, or travel-related well-being. These studies employ the concept of disparities in a descriptive sense.

There are, however, also many studies employing the word disparities to implicitly or explicitly identify observed differences as "unfair," "inequitable," or "unjust." One reason why disparity in exposure or outcomes is often perceived as unfair, lies in the (implicit) use of the normative benchmark of equality. Given the strong intuitive appeal of the principle of equality, this may come as no surprise. Against this background, the step between observing disparities and (implicitly) criticizing them because they imply a deviation from equality is then but a small one. This typically goes hand in hand with a concern for the protection of vulnerable population groups, for instance, in terms of socioeconomic position, age, gender, ethnicity, disability, or disadvantaged residential location. The fact that vulnerable groups already tend to be disadvantaged in other dimensions, such as income, social status, or discriminatory treatment, further adds to a sense of injustice regarding the observed disparities.

The assessment of equity requires, however, more than an intuitive understanding of injustices. It requires an explicit normative standard. Studies that employ the word disparities to implicitly or explicitly identify observed differences as "unfair" often fall short of presenting such an explicit standard for assessment and thus fail to acknowledge that the mere observation of disparities does not, by itself, raise issues of equity or necessarily indicate injustices (Lucas et al., 2019). Whether disparities are actually unjust or unfair requires a moral, or normative, assessment of those disparities. For instance, the observation that a household's income is inversely correlated to air pollution exposure points at a recurring pattern of disparity, and this raises concerns. It only becomes a matter of injustice if this pattern is at odds with an agreed-upon moral principle. If the agreed-upon moral principle is equality in exposure, the identification of disparities is sufficient to uncover injustices. If, however, the agreed-upon principle is that exposure should not surpass a certain level, then additional analyses are necessary to determine whether the disparities actually reflect an injustice. In the latter case, remaining disparities may well go hand in hand with a just state of affairs (but see the next discussion).

Research exploring the nexus between transport, health, and equity could clearly benefit from a willingness of researchers to explicitly engage with normative questions: what constitutes a fair distribution of the health-related benefits and burdens of travel and transport? Since there is no easy answer to this question, I will now briefly review the notion of social justice in a general sense, before turning to justice in health.

## Social justice

In everyday parlance the terms justice, fairness, and equity are often used interchangeably. For instance, in one online dictionary the term "equity" is described as "the quality of being fair or impartial; fairness; impartiality" or "something that is fair and just" (https://www.dictionary.com/browse/equity). Hence, in this chapter, I will use the terms social justice, equity, and fairness interchangeably (see also Hay, 1995).

In the philosophical literature the term "social justice" is most commonly used. In this literature the notion of social justice encompasses three interrelated dimensions: distribution, recognition, and representation. Distribution or distributive justice relates to the allocation of goods and bads over members of society (more on this below). Recognition is a complex term, but in essence in is concerned about the way people relate to each other, as individuals and as members of a group (see McBride and Seglow, 2009 for a brief introduction). Recognition not merely implies that a person acknowledges that someone else or another group has a particular feature (for instance, speaks a particular language), but it also brings

with it obligations to treat that person or that group with respect and as a free and equal person or group (Stanford Encyclopedia of Philosophy; https://plato.stanford.edu/entries/recognition/#RecNeiCon).
Representation, in turn, relates to the ability of persons and groups to codetermine the decisions that shape their lives. It concerns participation in decision-making about issues of common concern, with political thought on representation typically requiring processes and procedures of involvement that go well beyond typical forms of representative democracy, as well as representation in other domains than merely the political, most notably the workplace.

Social justice requires performance in all the three dimensions: societies can only be free of all forms of domination and oppression, if goods and bads are fairly distributed, if there is full recognition of differences between persons and groups, and if all voices are adequately represented in decisions of common concern.

Virtually, all literature on the relationship between transport and health relates in some way to the distributive dimension of social justice. While the other two dimensions may also be of relevance to the interrelationship, I will also focus on the notion of distributive justice in what follows.

Social justice narrowed down to distributive justice has been defined as "the morally proper distribution of goods and bads over members of society" (Miller, 1999). This definition consists of three distinct components: (1) the goods and bads, or benefits and costs, that are distributed; (2) the members of society between whom goods and bads are distributed; and (3) the distributive principle that determines whether a particular distribution is fair (see also Martens, 2011).

The first component relates to what is termed in the philosophical literature the "focal variable" of an equity analysis. In that literature the focal variable is understood in abstract terms and the debate among philosophers relates to the question whether the focus should be on resources, on opportunities, on some objective set of outcomes, or on welfare or well-being (see also Martens et al., 2019). This debate also resonates in the health domain, as I will discuss later. The largely empirical literature on transport and health is more pragmatic in nature (as may be expected) and covers a wide range of goods and bads, as briefly discussed earlier and explored more in-depth later.

The second component of the definition of distributive justice relates to members of society. Here, two key issues need to be addressed.

The first relates to the delineations of the people that count as members of society. This is not merely a philosophical issue but also a practical one. For instance, it is not at all clear where to draw the boundaries when analyzing the impacts of transport-related air pollution on health, certainly not if the complex chain from transport's greenhouse gas emissions to global warming to extreme weather events to health impacts is studied. But the issue of delineating the members of society also arises when analyzing less complex issues, as every analysis is typically bounded to a particular geography and thus to a particular subset of the population. For instance, when analyzing possibilities for active transport or measuring the costs of traffic injuries, it is easy to overlook nonresidents in the analysis, even if they may be a substantial share of the affected population. The second issue concerns how to distinguish between groups within the members of society. This is of key importance, as in order to carry out a distributive analysis, the population needs to be divided into meaningful groups. In most analyses a distinction is made between groups based on income, gender, age, ethnicity, or immigrant status. But it may sometimes be more relevant to use other groupings than these demographic and socioeconomic distinctions, such as groupings based on vulnerability for particular kinds of pollutions (e.g., a distinction between people suffering from respiratory diseases and others) or groupings based on mode use (as is typically done in analyses of traffic injuries and deaths).

The third component of the definition of distributive justice is obviously the most complex, as delineating what is "morally proper" requires normative and philosophical reasoning, something that empirically oriented researchers tend to be uncomfortable with (discussed previously). Both in the philosophical literature and the empirical literature, equality, that is, an equal distribution of goods or bads irrespective of the characteristics of a person, is often seen as the default option (Kolm, 1996). From a philosophical perspective, an equal division of benefits or costs over different population groups is indeed considered as fair or just, unless convincing arguments can be provided for an alternative distribution (Smith, 1994). Depending on the focal variable, that is, the good or bad under consideration, and depending on the philosophical argument that has been developed, other distributive principles have been proposed, such as the principles of need, sufficiency, and of proportionality (see Martens et al., 2019).

Related to the delineation of the proper principle of justice is the question whether the principle is part of an "end-state" theory or a "transitional" theory (Rosenberg, 2014). The difference relates to the theoretical debate "whether a normative political theory should aim at identifying an ideal of societal perfection, or whether it should focus on transitional improvements without necessarily determining what the 'optimum' is" (Valentini, 2012, p. 654). If the latter, transitional, position is upheld, equalization can be adopted as the pragmatic principle delineating steps toward justice, without necessary claiming that absolute equality is the ultimate goal. Within a transitional theory, equalization merely requires that interventions reduce existing disparities based on the understanding that these disparities are clearly unfair because they are beyond an acceptable level. In this case the question what is "a morally proper distribution" is left to be answered in a later stage, when steps have been made to narrow the gaps and the question emerges whether equality should indeed be the ultimate goal or whether a less demanding ideal can be accepted (e.g., proportionality, maximum gap, or minimum standard) (see again Martens et al., 2019). The problem of the principle of equalization is that it does not clarify when disparities surpass an acceptable level, nor regarding the priority to be given to reducing disparities vis-à-vis other societal goals. For instance, when applied to traffic injuries and deaths, it is unclear whether the principle of equalization allows most funds to be spend on reducing overall traffic risk without taking into account affected groups, or whether most funds should be spend on reducing the disparities in traffic risk, even if that would be less effective to reduce the total number of traffic-related deaths and injuries.

Adopting a distributive approach to social justice may lead to the proliferation of many equity analyses conducted in parallel. As may be clear from the beginning of this chapter, there is a broad range of transport-related health effects that could be subject of an equity analysis. Each of these effects could be adopted as a "focal variable" and could be studied separately in an equity analysis, with the normative assessment of the observed differences being based on a selected, "tailor-made," principle of justice. This raises the question whether it is possible to identify a more integrative framework for equity analysis. This topic is taken up in the next section.

## Social justice approaches to health

The literature on health and justice is substantially more developed than the literature on transport and justice. This is in part a reflection of wider societal debates, in which concerns over adequate health care are an important issue and justice in health-care provision features prominently on the political agenda. Walzer argues that this prominent position is related to the advent of modern medicine. He argues that with modern medicine's success in curing people, health care became an extremely desirable service and thus became the object of justice concerns. Capturing the popular understanding of justice in health care, he summarizes the distributive logic of the practice of medicine briefly as follows: "care should be proportionate to illness and not to wealth" (Walzer, 1983, p. 86).

In the philosophical literature the debate on justice in the domain of health obviously runs deeper than this popular understanding. For one, contemporary health care "involves a complex and heterogeneous framework of institutions, services, and policy measures that aim at prevention of disease and disability, restoration of health where possible, and personal and social support and care for the long-term ill or disabled" (Denier, 2005, p. 225). Thus health care is not merely about cure but also about prevention and care when cure is no longer possible. This broader understanding is also reflected in the debate about the proper focal variable for an analysis of the distribution of health care. By and large, three distinct possibilities can be distinguished: access to health care, health-care uptake, and health outcomes or health status (Denier, 2007; Daniels, 2008). These three different perspectives are also reflected, albeit often implicitly, in the literature on transport and health, as I will show next.

The use of the first focal variable, access to health care, implies the most narrow understanding of justice in health. While it includes all three elements of health services—prevention, cure, and care—it is perhaps best understood as a negative criterion specifying that there should be no barriers that hinder people who need health care from receiving it (see https://plato.stanford.edu/entries/justice-healthcareaccess/#ConcMeasAcceCare). Typically, three important barriers to health care are distinguished: financial, geographical, and discriminatory barriers. In line with the Hippocratic Oath, which represents the ideal of unconditional health care, discrimination by gender, ethnicity, or other irrelevant personal characteristics is typically legally banned in most countries. Furthermore, the health-care systems in most advanced economies (with the notable exception of the United States) are designed in such a way that financial barriers are minimized as much as possible, although limited financial barriers (such as out-of-pocket payments for some health services) tend to exist because of concerns over efficient and prudent use of health care. Geographical barriers to health-care access are typically addressed through policies and restrictions regarding the location of hospitals, clinics, general practitioners, and so on.

It is this latter barrier where health-care justice and the literature on transport and health touch on each other. Indeed, physical "[a]ccess to care was one of the earliest themes in health geography and remains a core issue for study" (Rosenberg, 2014, p. 467). The typical study in this tradition has equated the notion of physical access with proximity to health services, resulting in analyses of the geographical distribution of services, such as hospitals or general practitioners, across space or vis-à-vis the spatial distribution of the population. Furthermore, in these studies, social justice was typically "reduced to a simple formula: individuals and groups who had no or poor access to health resources (...) were assumed to be treated unjustly in their communities and their societies" (Rosenberg, 2014, p. 466). The notion of "no or poor access," in turn, was typically understood in a relative sense, with poor access being equated with (large) negative deviations from the average. These analyses thus implicitly employed a principle of equality or proportionality in the assessment of injustices. I will return to the suitability of these standards later in this chapter.

The second possible focal variable for justice in health is health-care uptake. The argument in support of this focal variable is that financial, discriminatory, and geographical barriers are not the only factors that may constrain the actual use of health-care services. This claim is supported by research showing that especially disadvantaged groups make less use of health-care services than other groups, even in societies with advanced health-care systems formally providing access to all. These differences are ascribed to a range of "softer" barriers, including the complexity of the health-care system, cultural norms regarding the appropriateness of requesting professional help, language barriers, cultural distance between patient (client) and health-care provider, and so on (e.g., Gulliford et al., 2002; Levesque et al., 2013; Purnell et al., 2016). These barriers may come on top of remaining financial, discriminatory, and geographical barriers to access. By measuring actual health-care uptake, it is possible to determine whether the health-care system is really successful in providing adequate service to all—and, hence, it is argued that health-care uptake is the proper focal variable to assess justice in health.

This concern about formal versus actual access to health care is reflected to some extent in the transport and health literature. Where the initial health geography studies equated geographical access with proximity, more advanced studies explicitly acknowledge that it is not so much proximity that determines access, but the actual ability to reach health-care services within a reasonable budget of time, money, and effort. Hence, more recent studies assess the degree to which different population groups can reach health-care services, given their specific characteristics and especially their residential location and personal access to transport modes on the one hand, and the location of health services and the available transport network on the other. Such studies typically use (advanced) accessibility measures and thereby provide a much richer understanding of the disparities in physical access to health care between different groups than mere proximity-style studies (Neutens, 2015). Like in the literature analyzing spatial dispersion and proximity of health-care services, this type of analysis typically uses equality as the standard of justice, either explicitly or implicitly.

More important is that few studies on accessibility to health services make a link with actual health-care uptake. The studies that do provide insight into this relationship fall into one of two categories. The first category encompasses studies in the uptake of particular health-care services, which often include transport as one of the barriers for people to access health care or attend meetings (e.g., Harrison and Wardle, 2005; Brual et al., 2010). This research is often qualitative in nature and tends to remain out of sight of researchers on accessibility of health care. The second category encompasses the literature on transport and social exclusion. These studies typically explore the transport problems of disadvantaged population groups in a broad and qualitative manner, as well as the impacts of these problems on activity participation, without a particular focus on health care (Lucas, 2012). Since these studies focus on transport as a barrier, they do not provide insight in the relative importance of transport vis-à-vis other barriers for health-care uptake. This brief discussion underscores that more and more systematic research is needed in order to determine the role of transport accessibility in the actual uptake of health care.

The third possible focal variable for justice in health is health outcomes or health status. The focus on outcomes draws from the understanding that access to health care, or even uptake of health care, can only partially explain the large disparities in health outcomes between different population groups. Rather, health status is strongly shaped by what is termed the "social determinants of health"—the understanding that health "is produced not just by having access to medical prevention and treatment but also, to a measurably great extent, by the cumulative experience of social conditions over the lifecourse" (Daniels, 2008, p. 79). Over the past decades an impressive body of literature has shown that a person's health status is strongly correlated to factors as diverse as income, education, housing quality, autonomy in the workplace, type of work, and political participation, even though the exact mechanisms of these relationships remain to be unraveled (e.g., Adler et al., 2016; Artiga and Hinton, 2019). These factors also powerfully shape health status in countries where formal access to health care is guaranteed for all. Furthermore, it has been shown that the observed variation in health outcomes cannot be explained by differences in health-care uptake alone. In the light of this evidence, Norman Daniels argues that "[t]o the extent that these social determinants of health are socially controllable, we clearly face questions of distributive justice" (Daniels, 2008, p. 81). Hence, some argue that the systematic analysis of disparities in health outcomes or health status is more likely to give a proper account of justice in health, as it provides an answer to the question whether society adequately addresses these social determinants of health. Even if equality in health outcomes across a population may not provide a meaningful benchmark, among others given the inevitable biological differences between people, the analysis of the gaps in health outcomes between population groups may provide the evidence base for mitigating the structural causes of the health disparities and thus assist in promoting health justice (Denier, 2007).

The convincing evidence about the structural factors shaping a person's health has triggered Norman Daniels to develop an elaborate theory on just health that moves beyond the mere provision of health care to include the social determinants of health. Drawing on Rawls's theory of justice as fairness, Daniels argues that health inequality "is unjust when it results from an unjust distribution of the socially controllable determinants of population health" (Daniels, 2008, p. 140). Daniels' normative theory has far-reaching implications. The approach implies that if "some groups in the population have different risks of getting ill, it is not merely sufficient to attend to their illnesses" (Daniels, 2008, p. 142). Rather, "[w]here risk of illness differs systematically in ways that are avoidable, (justice) requires that we try to eliminate the differential risks and to prevent the excess illness of those at avoidable greater risk (of course, subject to resource limits and fair process of setting limits)" (Daniels, 2008). As examples, Daniels briefly discusses water and waste treatment and risks related to dangerous work and environmental pollution and argues that just health requires that stringent regulation in all of these domains "must be part of the health-care system" (Daniels, 2008).

Daniels' work has resonated in the health domain. For instance, the World Health Organization sets up the Commission on Social Determinants of Health, bringing together a global network of policy makers, researchers, and civil society organizations. The commission was to "give support in tackling the social causes of poor health and avoidable health inequalities (health inequities)" (https://www.who.int/social_determinants/thecommission/finalreport/about_csdh/en/). In a paper summarizing the key findings and recommendations, the commission describes the need to act on the social determinants of health as follows: "If systematic differences in health for different groups of people are avoidable by reasonable action, their existence is, quite simply, unfair. We call this imbalance health inequity. Social injustice is killing people on a grand scale, and the reduction of health inequities, between and within countries, is an ethical imperative" (Marmot et al., 2008, p. 1661). The commission recommends, among others, that national governments and international organizations "set up national and global health-equity surveillance systems for routine monitoring of health inequity and the social determinants of health" and they should also "assess the health-equity impact of policy and action" (Marmot et al., 2008, p. 1662).

It may be clear to the reader that Daniels' broad approach to health and justice provides a normative framework for most of the literature on transport and health. That literature focuses de facto on a broad range of social determinants of health. This holds for the analysis of the distribution of transport-related air and noise pollution, of traffic risks, of access to healthy foods and parks, of opportunities for active travel, and so on. Each of these factors is a social determinant of health: they are part of the social conditions that shape a person's health. Indeed, it could be argued that much of the literature on health and transport that takes a distributive perspective contributes to the vision of the Commission on Social Determinants of Health to set up "surveillance systems" for monitoring of the social determinants of health.

While Daniels' sophisticated theory does provide an understanding of the just distribution of some of the socially controllable determinants of health (notably regarding income and education), his theory does not provide clear normative standards for the various social determinants addressed in the transport and health literature. Hence, in what follows, I will discuss some of these social determinants and explore what might be a morally proper distribution of that determinant—thereby shedding light on the possible equity standard to be used in empirical studies into transport and health.

## Justice standards in the assessment of health and transport

As already mentioned, much of the literature on transport and health that is framed in terms of equity or justice takes a rather straightforward approach: disparities are injustices. Daniels' framework is more nuanced. He argues that a health inequality "is unjust when it results from an unjust distribution of the socially controllable determinants of population health." In this section, I explore how to interpret this condition for a number of socially controllable determinants of heath. This is particularly important, given the tendency to equate "unequal distributions" with "unjust distributions." As I will argue, the two do not always overlap.

### Transport-related air pollution

Research shows that there is substantial difference between population groups in terms of their exposure to transport-related air pollution. Studies typically show that socially disadvantaged communities tend to experience the highest levels of traffic-related air pollution (e.g., Havard et al., 2009; Sider et al., 2015). For instance, a recent study for Ghent (Belgium) found that neighborhoods with lower household incomes, more unemployment, more people of foreign origin, more rental houses, and higher residential mobility are more exposed to air pollution (Verbeek, 2019). Likewise, in a study for Bristol (United Kingdom), Mueller et al. (2018) found that residents of weaker socioeconomic neighborhoods had the highest risks for adverse exposure. These differences in exposure to transport-related air pollution thus tend to exacerbate existing health disparities by further reducing the health status of population groups that already experience relatively poor health for other reasons (Wang et al., 2016). To what extent can these disparities in exposure to transport-related air pollution be considered unjust, if we employ Daniels' framework? There are three possible answers to this question.

One answer would start from the legal norms regarding exposure to air pollution (or other forms of pollution). Many governments around the world have set such standards for a range of pollutants. While rarely framed in terms of justice, they can actually be seen as the result of the balancing act between the observed connection between pollution and health on the one hand, and resource limitations (broadly conceived) on the other, a balancing act that Daniels sees as an inevitable part of just health. Indeed, drawing on Daniels' framework, it can be argued that any deviation from the democratically agreed-upon exposure standards implies "an unjust distribution of the socially controllable determinants of population health." Adherence to such standards thus is not merely a matter of legal justice, but it is also a matter of social justice (Martens, 2011). Hence, studies that seek to determine whether adherence to pollution standards would reduce mortality and improve health de facto address an issue of social justice, even if they do not mention equity at all and even if they do not analyze how exposure differs between different population groups. This implies that a range of epidemiological studies into the positive health benefits of adhering to air pollution standards (e.g., Pascal et al., 2013; Mueller et al., 2017) thus can be seen as belonging to the broad literature on transport, health, and equity.

The second possibility to determine whether patterns of exposure are unjust would be the adoption of the recommendations of the WHO regarding exposure levels, as these recommendations are typically based on extensive evidence of the relationship between exposure and health impact. The WHO recommendations are typically stricter than national norms and would thus typically reveal larger injustices. An equity analysis based on the WHO recommendations would largely follow the same line of reasoning as studies employing legally binding (national) norms: any exposure above the WHO recommendations regarding air pollution would be considered unjust. However, while the WHO guidelines do have a strong moral appeal, it could be argued that these recommendations do not allow for a context-sensitive balancing of the benefits and costs of these standards and thus fail to live up to requirements of democratic deliberation, as required by Daniels' framework.

A third possible answer would not start from the (legal) exposure standards but would go beyond these standards or recommendations and explore to what extend the remaining allowed air pollution levels are detrimental to health. The purpose of such studies should be to show that even when air pollution standards live up to official norms, there are significant health impacts. For such studies, it cannot be simply assumed that there is a linear connection between exposure and health, as is done in some research (e.g., Mueller et al., 2017), as the connection between exposure and health may well be different at low levels of exposure. Such studies should thus carefully select areas or population groups that experience exposure levels that adhere to the norm and compare them to areas or population groups with significantly lower exposure levels, in order to determine the impact of remaining pollution levels. Merely showing disparate exposure across population groups of below-norm pollution levels is insufficient from a health equity perspective, as the health effect cannot be assumed. Moreover, even if such studies would succeed in determining remaining negative impacts on health, they still face the challenge to show that the remaining risks are avoidable, that is, that the costs of reducing these risks are reasonable in comparison to the benefits, in line with Daniels' proposal that policies to prevent excess illness should be subject to resource limits. For studies into the impacts of below-standard levels of exposure, it is thus of particular importance to provide detailed insight into the benefits of more strict air pollution standards, for instance, in terms of reduced health costs, increased productivity, or lower welfare payments. It will then depend on the costs of further reducing pollution levels, as well as the priorities in a particular society, whether stricter pollution standards would be justified, that is, just.

Irrespective which of the three approaches are adopted in empirical research, it may be clear from the previous that equity research into transport-related air pollution is not the same as merely mapping disparities in exposure to air pollution. Quite the opposite. Each of the previously mentioned approaches de facto defines a sufficiency standard for exposure to air pollution as the standard of justice, that is, a "sufficiently clean air" standard. Whenever exposure levels are above agreed-upon standards, mapping of disparities *is* relevant, as it shows who is affected by a failure to uphold the law—and mapping disparities thus shows how a failure to deliver legal justice may also have a social justice dimension. But if no single person experiences exposure levels above such an agreed-upon sufficiency threshold, the mapping of disparities is no longer relevant, because if a proper democratic procedure has been followed to set the exposure standards, these differences can be seen as in line with the demands of justice. This holds true even though it is highly likely that systematic disparities in exposure will remain. Indeed, accepting such a sufficiency threshold de facto implies accepting that disadvantaged groups are likely to receive higher levels of pollution than their more advantaged counterparts. This is so, because the disadvantaged groups have typically less choice, notably in terms of travel mode and residential location. As a result, they tend to end up living along major roads and railway lines, where land values and thus rents and housing prices are lower precisely because of the higher levels of pollution, even if they live up to strict standards. While seemingly an injustice, these higher exposure levels are actually in line with the demands of justice, provided the standards have been set following appropriate democratic rules (with due voice given to all involved). At the same time, the opposite also holds true: a failure to adhere to agreed-upon standards implies a severe injustice, all the more so since the costs will not be randomly distributed over the general population. The adherence to agreed-upon standards is thus of the utmost importance to achieve just health.

## Traffic injuries and deaths

Much of the research on traffic safety that adopts an equity lens analyzes the disparities in traffic-related injuries and deaths between population groups. These studies typically show that vulnerable road users (pedestrians and cyclists) and disadvantaged population groups (low-income people, women, elderly, and minorities) are at a higher risk of traffic-related injury and death than other road users and population groups (e.g., Naci et al., 2009; Ameratunga et al., 2006). For instance, research from the United Kingdom shows that children from disadvantaged backgrounds are five times more likely to be killed on the roads as pedestrians than children from more affluent backgrounds (Davis and Pilkington, 2019). Such socioeconomic disparities can also be observed among adults. For example, a study for Spain showed that adults with lower levels of education are more likely to be involved in a traffic accident leading to (serious) injury than individuals with a higher level of education (Palmera-Suárez et al., 2018). Likewise, a study for Auckland (Australia) found that traffic injury rates increased with levels of deprivation in all age groups, with the steepest gradient among adults aged 25–64 years.

To what extent are these disparities in traffic risk unjust? In order to answer this question, it is important to understand the complex set of factors that can explain differences in traffic risk. For instance, Hippisley-Cox et al. (2002) argue that the reasons for increased traffic risk among children from disadvantaged socioeconomic backgrounds are related to higher exposure rates related to travel patterns (as fewer parents own cars, implying more walking), higher exposure rates due to residential location (e.g., deprived children may live closer to main roads and in neighborhoods with less safe play space), less adult supervision in the traffic environment, and educational disadvantage in understanding issues of road safety, among others (see also Davis and Pilkington, 2019). A study by Morency et al. (2012) shows significantly more injured pedestrians, cyclists, and motor vehicle occupants at intersections in the poorest areas than in the richest areas and also found that much of these disparities disappear when controlling for traffic volume, intersection geometry, and pedestrian and cyclist volumes. These studies thus point out that the disparities in traffic risk are to a large extent related to other "social determinants," including residential location, infrastructure design, and transport mode use.

So to what extent are these disparities in unjust? While much studies focus on disparities between population groups, there is a general understanding that traffic fatalities and severe injuries are fundamentally problematic, even if they would be distributed proportionally over a population (broken down by whatever characteristic). This understanding is most strongly embedded in the philosophy underlying Vision Zero and the more general Safe Systems Approach (The Royal Society for the Prevention of Accidents, 2018). Vision Zero is based on the ethical principle that "it can never be ethically acceptable that people are killed or seriously injured when moving within the road transport system" (Tingvall and Haworth, 1999). The approach thus goes beyond the principle of equality as a standard of justice. Indeed, translated to Daniels' approach, Vision Zero proposes that anything beyond zero road deaths implies an unjust distribution. In other words, traffic safety, as a socially controllable determinant of population health, is only fairly distributed if no person is exposed to risk of death or serious injury from traffic (Johansson, 2009).

This standard of justice implies that any research describing and analyzing the number of traffic-related deaths and serious injuries highlights an injustice. Yet, since traffic risks do not affect all population groups to the same extent, the mapping of disparities is of the utmost importance. Here, there is a clear relation with the distinction between ideal and transitional theory or between end-state and transitional theory. While there may be broad agreement about the end state regarding traffic safety (i.e., "Vision Zero"), in order to move forward a transitional perspective is needed that does require insight into the disparities across population groups. Without such an understanding, policies that promote traffic safety may mostly benefit population groups with relatively low traffic risk profiles, while ignoring the higher risks experienced by less advantaged groups. For instance, when traffic enforcement focuses on speed limits on freeways, it will tend to benefit drivers who tend to be more affluent than the average population, while comparable enforcement efforts on city roads would tend to enhance safety for often less affluent pedestrians and cyclists. While each life saved is morally justified, the clear disparities in traffic risk among population groups call for particular focus on disadvantaged group, in an effort to decrease the "unjust distribution of the socially controllable determinants of population health" [compare the proposal by Marmot in his seminal report *Fair Society, Healthy Lives*, where he argues that "actions (to reduce disparities in health) must be universal, but with a scale and intensity that is proportionate to the level of disadvantage"; Marmot, 2010].

## Active travel

A relatively recent branch of research into transport and health relates to the health impacts of the way in which people travel. A person's mode of travel can have both detrimental and beneficial effects on a person's health status. For instance, research has shown that travel on public transport can create stress due to crowding and unreliability of service, with possibly negative health impacts (Cox et al., 2006). Yet, the use of public transport can also have positive effects on health in comparison to travel by car, as public transport trips usually include walking or cycling at the access or egress end of a trip. The burgeoning literature on active travel focuses on these potential positive benefits of walking, cycling, and public transport use. The health benefits of engaging in active travel are a compilation of negative impacts due to increased exposure to air pollution and traffic risk and vastly positive impacts related to physical activity itself (de Nazelle et al., 2011). Research furthermore suggests that also stress levels should be taken into account in comparing the benefits of one mode against another (e.g., Ettema et al. 2016).

Research on (socioeconomic) disparities in levels of active travel show less pronounced patterns than research on differences in exposure to air pollution and traffic risk. In some respects, quite the opposite holds, with population groups that are typically to be considered disadvantaged, such as low-income groups, women, and ethnic minorities, engaging more in active travel than their more advantaged counterparts. For instance, residents of deprived neighborhoods in the United Kingdom tend to engage more in walking, cycling, and public transport use than people living in better-off neighborhoods (Goodman, 2013). Likewise, women tend to walk and use public transport more than men (Law, 1999), although the pattern is not consistent in all countries (e.g., Buehler et al., 2011). These patterns thus suggest that active travel reduces rather than exacerbates socioeconomic health disparities. However, the patterns are not only positive. For instance, women tend to cycle less than men, at least in countries with low overall levels of cycling (Prati, 2018) and in high-cycling countries, such as The Netherlands, cycling tends to be lower among ethnic minority groups than among the remainder of the population (Martens, 2013). These examples show that the disparities in active travel are less clearly related to common indices of disadvantage, such as income, gender, and ethnicity.

This brief description of the socioeconomic pattern of active travel obviously does not address the reasons why disadvantaged groups tend to engage more in active travel. There are multiple reasons for this, but one key reason is the lack of choice: disadvantaged groups tend to have a lower level of access to a car and thus have to rely more on walking, cycling, and public transport. Moreover, lower income groups and women tend to make shorter trips, both for work and other errands, which makes walking (or cycling) a more feasible option. The level of active travel is thus shaped by numerous factors, raising the question which of these factors can be seen as a social determinant of health?

One key factor that may shape engagement in active travel is neighborhood design. A host of research shows that neighborhood design can positively affect walking, cycling, and public transport use. Studies from the United States, Australia, and Europe consistently show that higher objectively measured walkability goes hand in hand with higher levels of physical activity and more active transport among adults (D'Haese et al., 2014). Research also shows a correlation between indices of walkability and health status (e.g., Su et al., 2017). For instance, research by Marshall et al. (2014) suggests that more compact and connected street networks with fewer lanes on the major roads are correlated with reduced rates of obesity, diabetes, high blood pressure, and heart disease among residents. From the perspective of Daniels, neighborhood design can thus be seen as one of the social determinants of health. The question then is whether this social determinant of health is currently unjustly distributed.

Like in the case of active travel itself, there is no clear relationship between socioeconomic status and neighborhood design features that encourage walking, cycling, or public transport. Some research does not find any relation between socioeconomic status and neighborhood walkability (e.g., Cowie et al., 2016), while others do find a positive relationship between socioeconomic status and neighborhood features that enhance walking (e.g., Sallis et al., 2011). Research for the United States does show that only around 3% of the population in metropolitan areas lives in neighborhoods that is considered “very walkable” (Talen and Koschinsky, 2013).

This is clearly a very low number, but like the mapping of disparities, it leaves open the question what would be an unjust distribution of “good” neighborhood design. Since residential location is not merely a matter of choice, certainly not for lower income households, an equity issue is clearly at stake here. The finding that children’s active mobility may be shaped by neighborhood design (D’Haese et al., 2014) and the fact that children typically have little say in a household’s residential location supports this latter claim. But the literature provides little direction for setting an explicit justice standard regarding neighborhood design that favors active transport. Should all households have the possibility to live in a walkable neighborhood if they prefer to do so? Should each (new) neighborhood at least achieve a certain level of walkability or bikeability, that is, should a minimum threshold be set? These questions are currently difficult to answer , as research on the causal path between neighborhood design, active travel, and health status is still in its infancys. Without a clear evidence about the interrelationships, it is impossible to determine whether neighborhood design as a social determinant of health is currently unjustly distributed.

## Conclusion

The nexus between transport, health, and justice is a complex one, not in the least because any equity analysis requires researchers to take a normative position. In this chapter, I have drawn on the approach of Daniels to just health to provide a framework for understanding equity in relation to transport and health. This approach underscores that much of the research on transport and health addresses the social determinants of health. According to Daniels, justice requires a fair distribution of these determinants. This approach does not solve the normative challenge. For each social determinant of health, it will be necessary to propose, and ultimately agree upon, a standard of justice, a principle of fair distribution. Empirical research into the (negative) impacts of transport on health is essential for this debate, as issues of justice only arise if a (causal) relation between exposure and health impact can be shown.

In this chapter, I have briefly explored what possible justice principle could be applied for three distinct social determinants of health: transport-related air pollution, traffic risk, and active travel. This exploration underscores that a justice approach to transport and health goes beyond the mere mapping of disparities in transport-related health impacts. Indeed, in some cases, some level of disparity may well be in line with requirements of justice. Such disparities may also be justifiable for other social determinants of health, such as access to healthy food or to health-enhancing destinations such as parks and nature. Here, as in many other dimensions of transport and health, disparities are virtually unavoidable because of the inevitable spatial nature of the phenomenon. Access to destinations will always differ across space and disparities between population groups are thus highly likely. Given the fact the advantaged groups in society typically have more choice, even in the most egalitarian society, such remaining disparities are likely (but not inevitably) to work to the detriment of disadvantaged population groups.

This, however, should be no reason for despair. The current distribution of social determinants of health is clearly at odds with requirements of justice. The systematic mapping of these injustices may induce policy makers to address unfair disparities, thereby substantially reducing the socioeconomic gradient in health status. Research on transport, health, and equity can thus contribute to a fairer world, especially if it is informed by a more comprehensive understanding of justice in health than is currently the case.

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PART III

# Recent and future developments

CHAPTER NINE

# New transport technologies and health

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## Contents



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## Introduction

New transport technologies, such as electric, shared, autonomous vehicles (AVs), and micromobility, are major disruptive technologies producing drastic changes in the transport sector and the built environment. The urban environment is an important health determinant, impacting on physical activity, air pollution, noise, traffic accidents, green spaces, and social capital, among others (WHO Regional Office for Europe, 2012; Nieuwenhuijsen, 2016). Globally, more people live in urban areas than in rural areas, with 55% of the world's population residing in urban areas in 2018 (United Nations, 2018). Recent advances in technology have led to the development of new transport models such as on-demand digitally enabled transportation (e.g., Uber or Lift), micromobility (e-scooters and e-bikes), electric vehicles, and, most recently, AVs (White House, 2016).

New transport technologies have been expanded rapidly in urban areas across the world. Uses of e-scooters, e-bikes, or services such as Uber or Lift have significantly impacted the urban mobility, changing travel behavior, and transport-related health determinants. This chapter will describe the health determinants related to new transport technologies and how these technologies are affecting public health.

## New technologies

### Electric vehicle

The electric vehicle is defined as a vehicle that uses a battery system to provide power, therefore reducing or even eliminating liquid fuel consumption during vehicle operation (NHTSA, 2016). The term "electric vehicle" covers a range of different vehicle types, including battery electric vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles.

### Shared-Use Mobility

Shared-Use Mobility encompasses transportation services that are shared among users, including public transit; taxis and limos; bike-sharing; carsharing (round-trip, one-way, and personal vehicle sharing); ride-sharing (car-pooling and van-pooling); ridesourcing/ridesplitting; scooter-sharing;

shuttle services; neighborhood jitneys; and commercial delivery vehicles providing flexible goods movement (Austin, no date).

## Shared micromobility

Shared micromobility is a shared-use fleet of small, fully, or partially human-powered vehicles such as bikes, e-bikes, and e-scooters (NACTO, 2019a). These vehicles are generally rented through a mobile app or kiosk, are picked up and dropped off in the public right-of-way, and are meant for short point-to-point trips (NACTO, 2019a). In 2018 users took 84 million trips on shared bikes and e-scooters in the United States, more than double the number of trips taken in 2017 (NACTO, 2019a,b). Of these, 38.5 million trips were taken on shared e-scooters, the newest vehicle type in the shared micromobility marketplace. E-scooters pose unique challenges and opportunities as a new vehicle type that will face multiple health impacts.

## On-demand mobility

Demand-responsive, private hire car providers are growing in popularity. They offer customer connectivity, account-based payments, intelligent routing algorithms, and a large pool of drivers (KPMG International, 2019). The most prominent example is Uber, which in the United Kingdom, by early 2017 half of the population had access to Uber services (KPMG International, 2019). However, ride-hailing is not the only on-demand model. Other models are the car-sharing schemes, such as BMW's DriveNow. Another innovation is dynamic shuttle services, also known as demand-responsive transit (such as ViaVan), that combine elements of mass transit with dynamic routing (KPMG International, 2019).

## Autonomous vehicles

A fully AV is a vehicle that has a full-time automated driving system that undertakes all aspects of driving that would otherwise be undertaken by a human under all roadway and environmental conditions (Rojas-Rueda, 2017). In 2018 "Waymo" (the Google section focused on the development of AV) introduced the first shared AVs fleet on the market (Waymo One) in Arizona (Waymo, 2019). AVs are expected to grow, personally owned AVs are expected to be on the market by 2022, and over 30 million AVs are predicted to be on the streets by 2035 (Deloitte, 2016).

## Why are new transport technologies important for health?

The potential health impacts of new transport technologies would vary depending on how the type of technology changes the travel behaviors and the urban environment. Transport technology will shape the type of vehicle use and ownership (e.g., personally own, car-shared, and ride-sharing), type engine (e.g., internal combustion, hybrid, and electric), and automation level. New transport technologies could lead to increased health risk, as in the case of on-demand mobility (e.g., Uber) using vehicles with internal combustion, where the overall vehicle miles traveled per person could increase, promoting air pollution emissions and sedentarism. On the other hand, new transport technologies could also lead to increased health benefits, as in the case of electric shared, where the number of vehicles and miles traveled could reduce, improving air quality, increasing walking and cycling, or releasing public spaces from traffic and parking. The latter one can translate into more spaces for recreational purposes (e.g., green areas and plazas), and/or more mixed land uses (e.g., increasing access to public services, or combining residential uses with services). Finally, in the case of AVs independently of the ownership status, use, or type of engine, the main health claim of such technology is the reduction of traffic injuries and fatalities on a major scale.

## How are new transport technologies related to health?

Multiple health determinants, such as traffic accidents, air pollution, noise, electromagnetic fields, physical activity, land use, green spaces, and social capital, among others, can be linked to new transport technologies (Fig. 9.1).

### Road safety

Traffic safety is the most common health determinant related to the transport sector. New technologies such as electric vehicles have been associated with less noise. Noise produced by vehicles can help to increase awareness of such vehicles in public spaces. In recent years, these have

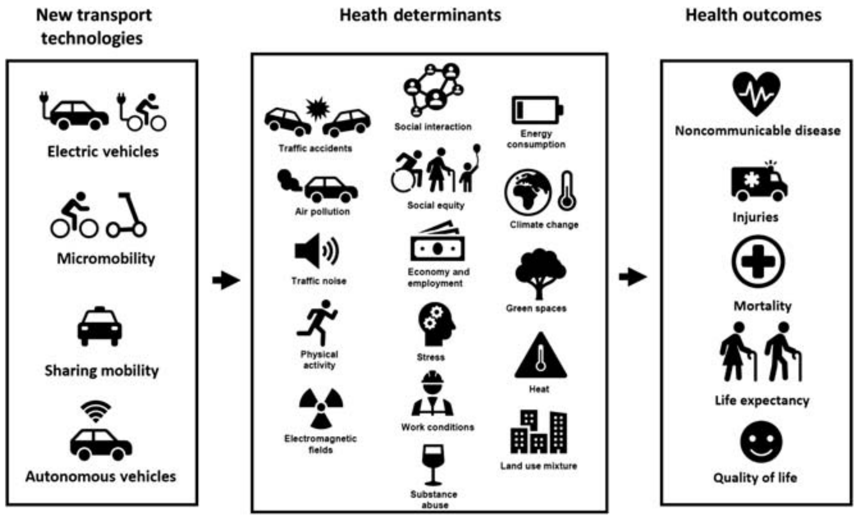


**Figure 9.1** New transport technologies and health.

been suggested to add noise electric and hybrid vehicles to increase awareness of such vehicles in public space and reduce the risk of traffic injuries, especially between pedestrians and cyclists (Dalrymple, 2013). In terms of micromobility, electrification of bikes and scooters has also resulted in higher speeds of such modes. More speeds between e-bikes and e-scooters have also been associated with a higher risk of traffic incidents (Siman-Tov et al., 2017). On the other hand, sharing mobility that reduces the miles traveled could lead to fewer vehicles on the roads and fewer traffic accidents. Finally, traffic safety has been the major beneficial impact claimed by the AVs industry and authorities (General Motors, 2018; NHTSA (National Highway Traffic Safety Administration), 2019). Of all serious motor vehicle crashes, 94% involve driver-related factors, such as impaired driving, distraction, speeding, or illegal maneuvers (U.S. Department of Transportation, 2018). Automated vehicles that accurately detect, recognize, anticipate, and respond to the movements of all transportation system users could lead to reducing those motor vehicles driver-related crashes (Luttrell et al., 2015). The authors estimated that if 90% of the automobiles in the United States became autonomous, 25,000 lives could be saved.

## Traffic-related air pollution and noise

Motorized vehicles are a major source of air pollution in urban areas (Amato et al., 2014; Rojas-Rueda and Turner, 2016). Most of the current on-demand vehicles (e.g., Uber and Lift) and tested versions of AVs have internal combustion engines that could contribute to noise and air pollution emissions. Some studies have suggested that current on-demand vehicles and future private AVs could result in an increment of vehicle miles traveled (Soteropoulos et al., 2019), possibly leading to more noise and air pollution emissions if those vehicles are not fully electric. In contrast, if new transport technologies are implemented in a model of shared electric vehicles integrated with public and active transportation, such model could lead to reducing vehicle miles traveled and the subsequent reduction of noise and air pollution (Soteropoulos et al., 2019). Fully electric vehicles will reduce exhaust emissions, but the nonexhaust emissions (wear emissions and air pollution resuspension) will remain. In Europe the total nonexhaust contribution to particulate matter air pollution is comparable to that of tailpipe emissions (Amato et al., 2014).

Regarding noise, low speed and electric features promise to be quieter, contributing to reduced noise pollution that would reduce traffic noise and their health impacts. But it has been suggested, as mentioned before, that quiet vehicles can be a traffic safety risk, especially for those with visual impairments (Brown, 2015; Clendinning, 2018). In some countries, such as the United States and Japan, authorities are considering compelling manufacturers of hybrid- and electric cars to install an artificial warning sound (Dalrymple, 2013).

## Electromagnetic fields

Electric and magnetic fields (EMFs) are invisible areas of energy (also called radiation) that are produced by electricity, which is the movement of electrons, or current, through a wire (National Cancer Institute, 2019). Electric, concocted, and AVs are expected to be a new source of EMF. Numerous epidemiological studies evaluating the possible associations between exposure to EMFs and the risk of cancer in children lack conclusive results (National Cancer Institute, 2019). However, a recent study of the National Toxicology Program in the United States saw clear evidence when male rats exposed to high levels of radiofrequency radiation (a type of EMF like that used in 2G and 3G cell phones) developed cancerous heart tumors (National Toxicology Program, 2018). Due to the lack of evidence in humans and without a clear mechanism of action, more research is needed in this area to understand the possible health risks.

## Physical activity

Some studies have modeled the impacts of micromobility, electric, shared, and AVs on modal share and have suggested that these types of vehicles could absorb some trips from other modes of transport such as active and public transportation. If these projections are correct, more sedentarism could be expected between the populations that will substitute transport-related physical activity by AVs trips (Langford et al., 2017; NACTO, 2019a). On the other hand, if new transport technologies are integrated with public transportation and active transportations, it could help multi-modality and lead to an increase in physical activity.

## Substance abuse

In 2013, 10.9% of Americans age 12 or older admitted to driving under the influence of alcohol at least once in the past year, and 9.9 million people reported driving under the influence of illicit drugs (National Safety Council, 2017; NHTSA, no date). Traffic laws in most countries prohibit driving under the effects of certain levels of alcohol or drugs, and this discourages drivers from overdosing on such substances (U.S. Department of Health and Human Services (HHS), Office of the Surgeon General, no date). Early drinking and driving policies created public awareness on the negative impacts of alcohol and drugs (U.S. Department of Health and Human Services (HHS), Office of the Surgeon General, no date). With the use of on-demand mobility or the implementation of future AVs where driving responsibilities are not needed, it could lead to reduced awareness of substance abuse and result in increased cases of alcohol and drug consumption.

## Stress

A recent review provided evidence to suggest that driving for long hours elicits a stress response over an extended period of time (Antoun et al., 2017). Stress is known to affect the immune system, cardiovascular health, and brain physiology, among others (Mariotti, 2015). Without the need to drive in on-demand mobility or the implementation of future AVs is likely that stress during commuting could decrease, leading to improved health (Cottrell and Barton, 2013).

## Work conditions

A growing body of evidence suggests that long working hours adversely affect the health and well-being of workers (Dembe et al., 2005). On-demand mobility and future AVs will not require passenger attention to driving tasks. This could lead to introducing new activities, including work-related ones, during travel times. There is not an available prediction on work schedules and activities related to AVs, but we have considered two main scenarios. The first is that the commuting time in on-demand mobility and future AVs grows as an extension of the unpaid and unofficial working times, resulting in overtime and long working hours. The second scenario, on the contrary, is that commuting time could transform into an official working schedule (and place), resulting in shorter working hours at the office.

## Land use, green spaces, and heat island effects

Shared vehicle fleets, especially future shared AVs, could have positive impacts on land use. It has been estimated that if AVs are implemented in ride-sharing mode, parking spaces could be reduced up to 90% (Soteropoulos et al., 2019). As mentioned before, if the freed-up public space is reoriented to a healthy urban design, social interactions and physical activity could be expected to increase within the urban populations. In addition, more urban greenness could also lead to lower extreme weather, reducing the heat island effects that are so common in urban areas.

## Social interaction

On-demand mobility and future AVs could increase access to social venues that could lead to more social interactions and support systems (Soteropoulos et al., 2019). But nonshared AVs could also increase isolation during travel periods (de Nazelle et al., 2011). There is evidence suggesting that increasing car use and time spent in cars are associated with less social interaction and cohesion between neighbors (de Nazelle et al., 2011). On-demand mobility and shared AVs supporting public and active transportation could stimulate social interaction between travelers and improve social networks.

## Social equity, employment, and economy

Some equity priorities in transportation are related to transportation costs, access to destinations, services (e.g., health services), and employment

(Curtis and Nygaard, 2017). If micromobility and shared mobility are implemented in disadvantageous populations in an accessible and affordable manner, it could reduce transport inequalities. Also, a recent AV study modeled the equity impacts in terms of job accessibility between different disadvantaged populations in Washington, DC (Cohn et al., 2019). The study found that in all the scenarios modeled, AVs increase job accessibility, and this was especially important in more disadvantaged populations where shared AVs were tested (Cohn et al., 2019). If implemented with a focus on disadvantaged populations, micromobility, shared, and AVs offer a unique opportunity to promote social equity and to stimulate employment and the economy.

### Energy consumption and climate change

If new transport technologies are implemented as fully electric and are followed by a supply chain based on renewable energy sources, they could be an opportunity for climate change mitigation, promoting a transition from fossil fuels to renewable energy sources. Furthermore, electric vehicles should be implemented, at least mainly, as a shared vehicle service to increase energy efficiencies and support active and public transportation.

## Policy and health recommendations

Policies and health recommendations are summarized in Table 9.1 and Fig. 9.2. In general, new transport technologies require thoughtful planning and an intersectoral vision to consider expected and unexpected impacts on travel behaviors, urban planning, and health outcomes. Form

**Table 9.1** Health-related recommendations for policy and research on new transport technologies.

| |
|---|
| Prioritize new transport technologies in rideshare and ridesplitting formats |
| Prioritize fully electric vehicles and implementation of renewable energy sources |
| Integrate new transport technologies with public and active transportation (walking and cycling) |
| Prioritize new transport technologies implementation on vulnerable and disadvantaged communities |
| To improve air quality, consider exhaust and nonexhaust emissions |
| To improve road traffic noise, prioritize electric vehicles |

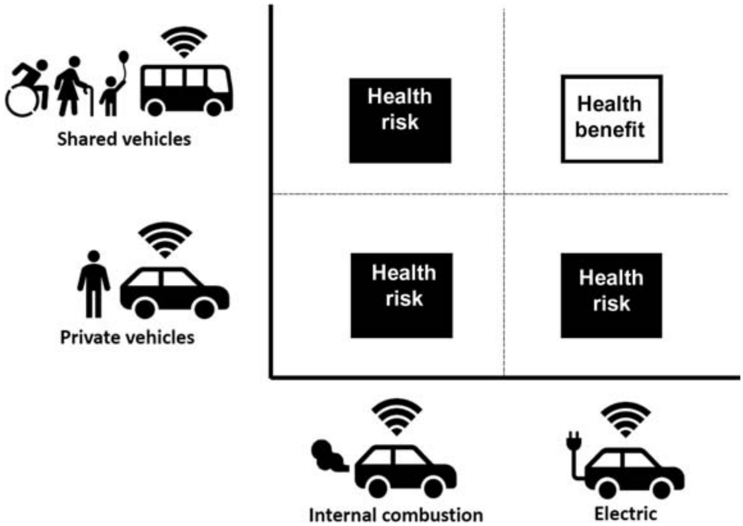


**Figure 9.2** New transport technologies implementation, health risk, and benefits.

the health sector, clear consideration of health risks and benefits of new transport technologies is the first step. New transport technologies form the health perspective should be implemented and promote full-electric shared vehicles based on ride-sharing and ridesplitting, using renewable sources of energy.

## Conclusion

Implementation and legislation of new transport technologies require taking health perspective into account. Research is needed to understand the health implications of new transport technologies. Policies and regulations prioritizing shared electric vehicles in a format of ride-sharing or ridesplitting could offer an opportunity to enhance health. New transport technologies should be considered to support public and active transportation, being prioritizing in the more disadvantageous communities, and should lead to an urban planning revolution with the aim of a healthy urban environment.

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CHAPTER TEN

# Bike-sharing systems and health

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## Contents



## Introduction

Interest in urban cycling is increasing, and the number of bike-sharing programs has grown rapidly over the last 10 years or so. Bike-sharing programs have existed for almost 50 years, but the recent change in the technology used and interest in more active and livable cities has a more widespread use of the programs. Wuhan and Hangzhou, China currently have the world's largest public bicycle-share schemes, with 70,000 and 65,000 bikes, respectively (China News, 2011; Meddin, 2011). In 2007 Paris launched Europe's largest scheme, with more than 20,000 bicycles. New York City launched North America's largest bike-share program, with 10,000 bicycles in 2013. The benefits of bike sharing are flexible mobility, emission reductions, physical activity benefits, reduced congestion and fuel use, individual financial savings, and support for multimodal transport connections (Shaheen et al., 2010). These factors have acted as catalysts for the development of bike sharing globally.

Bike-sharing systems (BSSs) have been implemented in several cities around the world as policies to mitigate climate change, reduce traffic

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congestion, and promote physical activity and thereby health. Also they do not produce air pollution and noise and help toward the last mile trips. A BSS or bike-share scheme is a system in which bikes are made available for shared use to individuals on a very short-term basis. Often the time used is limited to allow multiple users per bike and rapid turnaround. BSS allow people to borrow a bike from one point and return it to a different point. BSSs have become very popular in cities across Europe, Asia, and America, and in 2013 more than 500 BSSs were implemented around the world (Larsen, 2013).

The first bike share began in Europe in 1965 with fairly simple technology, and the first large-scale bike-sharing program was launched in 1995, in Copenhagen as Bycyklen (City Bikes) with 1100 bikes (Shaheen et al., 2010). Currently, the BSS in Paris, called "Vélib," is the biggest in Europe with 23,600 bikes and 1800 stations; other BSSs have also reached a considerable large size as London (12,000 bikes), Barcelona (6000), Lyon (4000) or Valencia, Seville, and Milan or Brussels with more than 2000 bikes. In some countries such as Spain, there has been a rapid increase in the number of BSS, almost doubling the number of systems implemented from 58 to 97 between 2008 and 2009 (Oortwijn, 2015). But, as mentioned before, China still has the largest system.

Bike-share programs can provide safe and convenient access to bicycles for short trips, such as running errands during lunch, and transit-work trips. Users do not need parking at their home, and maintenance of the bikes is taken care of making it convenient for the users. Until recently, bike-share programs worldwide had experienced limited success; in the last 10 years or so, innovations in technology have given rise to a new (third) generation of technology-driven bike-share programs. These new bike-share programs can dramatically increase the visibility of cycling and lower barriers to use by requiring only that the user have a desire to bike and a credit card or phone.

Bike-share programs help increase cycling mode share, serve as a missing link in the public transit system, reduce a city's travel-related carbon footprint, and provide additional "green" jobs related to system management and maintenance. They have had limited success though to get people out of the car and onto the bike; to a large extent, new users are coming from the public transport system or previously walked. In the United States, many cities are looking into bike-share programs, but they have not yet been widely implemented. The United States has a strong car dependency and limited infrastructure for cycling, which makes it harder. Some recent systems failed (e.g., Seattle) and were abandoned. Not only poor design, underutilization, and a lack of maintenance are among the potential pitfalls faced when building and implementing a bike-share system, but also the lack of safe infrastructure for cyclists.

For a bike program to be successful, it is important that the correct technology and package of services involved be mated to the unique challenges that each program faces. Furthermore, there needs to be the political will and also the necessary infrastructure for safe cycling. It is, therefore, recommended that each city considering implementation of a bike-share program have an independent assessment of the political backing, community needs, economics, technologies, logistical issues, service area, infrastructure, and other challenges faced by a final system.

A key aspect of any bike-share program is system and fleet maintenance and management. These activities can help to ensure the bike-share system is in top operating order and sufficient bikes are available to accommodate all users. To ensure that bicycles are available at all stations, it is likely that bicycles will have to be redistributed from one station to another from time to time. Past performance of systems in Lyon and Paris indicates that many locations experience peak times of business when a rack will be either completely full or completely empty, making the rental or return of bikes impossible. Information about bicycle demand should be gathered through GPS units, radio frequency identification tags, and any other means used to track bicycle locations.

Innovative dockless mobile public-bike-sharing programs have the potential to bring cycling back to places where cycling was common before but disappeared like China. On the basis of GPS travel data from their bikes and a survey of more than 100,000 Mobike users, by April 2017—less than a year after the company's launch in Shanghai, China—Mobike Global estimated that of all journeys made by their users, the percentage of journeys by bicycle had increased from 5.5% to 11.6% (with the majority of journeys done to link with buses and trains) and the number of car journeys had halved (Ding et al., 2018).

However, mobile public-bike-sharing programs without docking stations are inherently subject to vandalism, misuse, and loss of bicycles. Cluttering of footpaths with bicycles and increasing traffic violations by cyclists have also been frequently reported. Despite the problems and challenges, mobile public-bike-sharing programs exemplify an alignment between private-sector interests and public health and sustainability and offer unique opportunities to promote physical activity on a large scale. By the end of 2017, mobile public-bike-sharing programs had spread to hundreds of cities across Asia, Europe, North America, and Australia, but unfortunately failed in many places due to competition, the abandoned bikes, and lack of a sustainable business model.

BSSs may help normalize the image of cycling and reduce perceptions that cycling is "risky" or "only for sporty people." Goodman et al. (2014) sought to compare the use of specialist cycling clothing between users of the London bicycle-sharing system (LBSS) and cyclists using personal bicycles. They observed 3594 people on bicycles at 35 randomly selected locations across central and inner London. The 592 LBSS users were much less likely to wear helmets (16% vs 64% among personal-bicycle cyclists), high-visibility clothes (11% vs 35%), and sports clothes (2% vs 25%). In total, 79% of LBSS users wore none of these types of specialist cycling clothing, as compared to only 30% of personal bicycle cyclists. This was true of male and female LBSS cyclists alike. They concluded that bicycle-sharing systems may not only encourage cycling directly, by providing bicycles to rent, but also indirectly, by increasing the number and diversity of cycling "role models" visible (Fig. 10.1).


**Figure 10.1** Picture of the bike-sharing system in Lima, Peru (David Rojas).

## Health benefits of bike-sharing systems

It is well known that cycling is healthy due to physical activity but also may be risky because of accidents and increased inhalation of air pollution. A number of studies have assessed the health implications of BSSs. As epidemiological studies are hard to conduct, they have mainly used health impact assessment methodology and have taken into account not only health benefits coming from physical activity but also risks from increased inhalation of air pollution and accidents.

The first to do so were Rojas-Rueda et al. (2011) in Barcelona. They estimated the risks and benefits to health of travel by bicycle, using a bicycle-sharing scheme, compared with travel by car in an urban environment in the new public bicycle-sharing initiative, Bicing, in Barcelona, Spain. At the time the system had 181,982 subscribers. The primary outcome measure was, all cause mortality for the three domains of physical activity, air pollution [exposure to particulate matter (PM) <2.5 μm (PM2.5)], and road traffic incidents (Fig. 10.2). The secondary outcome was changed in the levels of carbon dioxide emissions. Compared with car users, the estimated increase annual change in mortality of the Barcelona residents using Bicing ($n = 181{,}982$) was 0.03 deaths from road traffic incidents and 0.13 deaths from air pollution. As a result of physical activity, they estimated 12.46 avoided deaths (benefit:risk ratio 77).

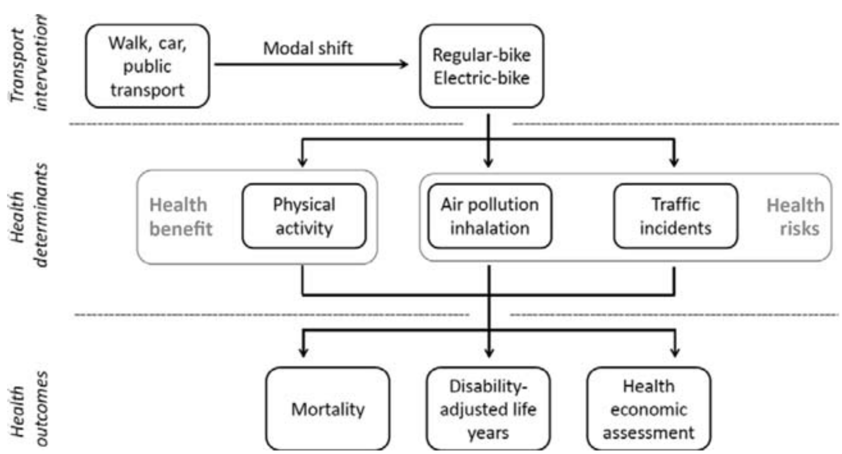


**Figure 10.2** General framework used by health impact assessments on bike-sharing systems.

Overall, taking into account risk and benefits, the total estimated health impact of the Bicing in Barcelona was that it could avoid 12.28 annual deaths. As a result of journeys by Bicing, annual carbon dioxide emissions were reduced by an estimated 9,062,344 kg in Barcelona.

Woodcock et al. (2014) modeled the impacts of the bicycle-sharing system in London on the health of its users. They used total population operational registration and usage data for the London cycle-hire scheme (collected April 2011–March 2012), surveys of cycle-hire users (collected 2011), and London data on travel, physical activity, road traffic collisions, and particulate air pollution (PM2.5) (collected 2005–12). The system had 578,607 users. Over the year the examined users made 7.4 million cycle-hire trips (estimated 71% of cycling time by men). These trips would mostly, otherwise, have been made on foot (31%) or by public transport (47%). They found that the population benefits from the cycle-hire scheme substantially outweighed harms [net change −72 disability adjusted life years (DALYs) (95% credible interval −110 to −43) among men using cycle-hire per accounting year; −15 (−42 to −6) among women; note that negative DALYs represent a health benefit]. When they modeled cycle-hire injury rates as being equal to background rates for all cycling in Central London, these benefits were smaller and there was no evidence of a benefit among women [change −49 DALYs (−88 to −17) among men; −1 DALY (−27 to 12) among women]. This sex difference largely reflected higher road collision fatality rates for female cyclists. At older ages the modeled benefits of cycling were much larger than the harms. Using background injury rates in the youngest age group (15–29 years), the medium term benefits and harms were both comparatively small and potentially negative.

Otero et al. (2018) performed a multinational health impact assessment study to quantify the health risks and benefits of car trips substitution by bikes trips (regular-bikes and/or electric-bikes) from European BSS with >2000 bikes. It is the first health impact assessment including the impact of electric bicycles, taking into account the differences between physical activity, speed, and injury risk compared to regular-bikes. Four scenarios were created to estimate the annual expected number of deaths (increasing or reduced) due to physical activity, road traffic fatalities, and air pollution. A quantitative model was built using data from transport and health surveys and environmental and traffic safety records. In addition, an economic assessment was included to translate mortality impacts in economic values using the value of statistical life. The study populations were adults

BSS users between 18 and 64 years old. Twelve BSSs (Barcelona, Brussels, Hamburg, Lille, Lyon, Madrid, Milan, Paris, Seville, Toulouse, Valencia, and Warsaw) were included in the analysis. The study found that between those 12 larger BSS in Europe the car substitution impact was very low (ranging from 4.5% to 12% of the BSS trips). In all scenarios and cities the health benefits of physical activity outweighed the health risk of traffic fatalities and air pollution, with a benefit:risk ratio ranging between 9 (Milan) and 204 (Seville). It was estimated that 5.17 (95% CI 3.11−7.01) annual deaths were avoided in the 12 BSS, with the actual level of car trip substitution, corresponding to an annual saving of 18 million of Euros. It was also estimated that if all BSS trips replaced car trips, 73.25 deaths could be avoided each year (225 million Euros saving) in the 12 cities. This study also estimated that although the electric bikes resulted in less health benefits, compared to the regular-bikes, electric bikes trips still providing more health benefits than traveling by car in those cities.

## Helmet use and bike-sharing system

The use of bicycle helmets to prevent or reduce serious head injuries is well established. However, it is unclear how to effectively promote helmet use, particularly in the context of bicycle-sharing programs. The bike-sharing programs have the potential to increase physical activity and decrease air pollution, but anecdotal evidence suggests helmet use is lower among users of bicycle-sharing programs than cyclists on private bicycles. Kraemer et al. (2012) conducted a cross-sectional study to assess helmet use among users of a bicycle-sharing program in Washington, DC. Helmet use was significantly lower among cyclists on shared bicycles than private bicycles, highlighting a need for targeted helmet promotion activities.

Grenier et al. (2013) described bicycle helmet use among Montreal cyclists as a step toward injury prevention programing. Using a cross-sectional study design, cyclists were observed during 60-minute periods at 22 locations on the island of Montreal. There were one to three observation periods per location. Observations took place between August 16 and October 31, 2011. A total of 4789 cyclists were observed. The helmet-wearing proportion of all cyclists observed was 46% (95% CI 44−47). Women had a higher helmet-wearing proportion than men

(50%, 95% CI 47–52 vs 44%, 95% CI 42–45, respectively). Youth had the highest helmet-wearing proportion (73%, 95% CI 64–81), while young adults had the lowest (34%, 95% CI 30–37). Visible minorities were observed wearing a helmet 29% (95% CI 25–34) of the time compared to Caucasians, 47% (95% CI 46–49). BIXI (bike-sharing program) riders were observed wearing a helmet 12% (95% CI 10–15) of the time compared to riders with their own bike, 51% (95% CI 49–52). They concluded that although above the national average, bicycle helmet use in Montreal was still considerably low, given that the majority of cyclists did not wear a helmet.

In a pilot study, Basch et al. (2014) estimated the prevalence of helmet use among a sample of Citi Bike program users in New York City. A total of 1054 cyclists were observed over 44 hours and across the 22 busiest Citi Bike locations. Overall, 85.3% (95% CI 82.2, 88.4%) of the cyclists observed did not wear a helmet. Rates of helmet nonuse were also consistent whether cyclists were entering or leaving the docking station, among cyclists using the Citi Bikes earlier versus later in the day, and among cyclists using the Citi Bikes on weekends versus weekdays.

In a larger study, Basch et al. (2015) studied further the NYC's public bicycle-share program, Citi Bike, the fastest growing program of its kind in the United States, with nearly 100,000 members and more than 330 docking stations across Manhattan and Brooklyn. The purpose of this study was to assess helmet use behavior among Citi Bike riders at 25 of the busiest docking stations. The 25 Citi Bike stations varied greatly in terms of usage: total number of cyclists ($N = 96$–342), commute versus recreation (22.9%–79.5% commute time riders) and weekday versus weekend (6.0%–49.0% weekend riders). Helmet use ranged between 2.9% and 29.2% across sites (median = 7.5%). A total of 4919 cyclists were observed, of whom 545 (11.1%) were wearing helmets. Incoming cyclists were more likely to wear helmets than outgoing cyclists (11.0% vs 5.9%, $P = .000$). NYC's bike-share program endorses helmet use but relies on education to encourage it. The data confirmed that, to date, this strategy has not been successful.

Mooney et al. (2019) counted cyclists over several hours at four locations in Seattle, WA. They categorized each rider according to whether he or she was wearing a helmet and to whether or not he or she was riding a bike-share bike. Although 91% of riders of private bikes wore helmets, only 20% of bike-share riders wore helmets. Moreover, in locations where a greater proportion of riders were on bikes-share bikes, fewer riders of private bicycles wore helmets ($r = -0.96$, $P = .04$). The impact of bike-sharing programs on helmet wearing norms among private bike riders warrants further exploration.

Molina-García and Queralt (2016) analyzed changes in the frequency of cycling to school and helmet wearing after the introduction of a mandatory helmet law and attempted to identify factors associated with the acceptance of helmet use. They used a mixed-method study designed with a 7-month follow-up period (April to November 2014). The initial sample included 262 students (aged 12–16 years) from Valencia, Spain. The data were collected by questionnaire and two focus-group interviews were conducted. No significant changes in cycling-to-school behavior were found during the study period. Cycle helmet use improved, especially among boys, those who used their own bike, and among adolescents who lived within 2 km of school ($P < .05$ in all cases). The most common reasons given for not using a helmet were social factors. Peer-group pressure had a negative influence on helmet use among adolescents. Participants also indicated that helmet use is inconvenient, in particular, among students who used the public bicycle-sharing program. They concluded that the implementation of the helmet-use law did not have a negative impact on the frequency of cycling to school.

## Bike-sharing system user profiles

Ogilvie and Goodman (2012) sought to examine inequalities in uptake and usage of London's Barclays Cycle Hire (BCH) scheme. They obtained complete BCH registration data and compared users with the general population. They examined usage levels by explanatory variables including gender, small-area income-deprivation, and local cycling prevalence. A total of 100,801 registered individuals made 2.5 million trips between July 2010 and March 2011. Compared with residents and workers in the Central London area served by the scheme, registered individuals were more likely to be male and to live in areas of low deprivation and high cycling prevalence. Among those registered, females made 1.63 (95% CI 1.53, 1.74) fewer trips per month than males and made under a fifth of all trips. Adjusting for the fact that deprived areas were less likely to be close to BCH docking stations, users in the most deprived areas made 0.85 (95% CI 0.63, 1.07) more trips per month than those in the least deprived areas. They concluded that females and residents in deprived areas were underrepresented among users of London's public bicycle-sharing scheme. The scheme's planned expansion into more deprived areas has, however, the potential to create a more equitable uptake of cycling.

Hosford et al. (2018) examined the sociodemographic and transportation characteristics of current, potential, and unlikely users of a public bicycle-share program and identified specific motivators and deterrents to public bicycle-share use. They used cross-sectional data from a 2017 Vancouver public bicycle-share (Mobi by Shaw Go) member survey ($n = 1272$) and a 2017 population-based survey of Vancouver residents ($n = 792$). They categorized nonusers from the population survey as either potential or unlikely users based on their stated interest in using public bicycle-share within the next year. Public bicycle-share users in Vancouver tended to be male, employed, and have higher educations and incomes as compared to nonusers and were more likely to use active modes of transportation. The vast majority of nonusers (74%) thought the public bicycle-share program was a good idea for Vancouver. Of the nonusers, 23% were identified as potential users. Potential users tended to be younger, have lower incomes, and were more likely to use public transit for their main mode of transportation, as compared to current and unlikely users. The most common motivators among potential users related to health benefits, not owning a bicycle, and stations near their home or destination. The deterrents among unlikely users were a preference for riding their own bicycle, perceived inconvenience compared to other modes, bad weather, and traffic. Cost was a deterrent to one-fifth of unlikely users, notable given they tended to have lower incomes than current users.

## Conclusion

BSSs have gained popularity over the recent years and can now be found in many cities around the World. Different technological improvements have been implemented (electric bikes, dockless, etc.) to make it more attractive and easier for users. Although often introduced to reduce congestion and for climate mitigation reasons, they have only been able to absorb a small portion of car trips across cities. Despite the small impact on mode shift, they have been able to provide many health and health economic benefits, due to the increase of physical activity, and helping to normalize urban cycling through cities. BSSs are facing many challenges and opportunities, that should be tackled to improve their health benefits, such as provide more equally distributed bikes throughout the population, increase the use of helmets, and being able to attract more users from private motorized modes such as cars or motorcycles. In general, BSSs should be seen as a tool for public health promotion and prevention.

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CHAPTER ELEVEN

# E-bikes—good for public health?

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## Contents



## Introduction

E-bikes represent the fastest-growing segment of the transport system. Combining more bicycle-friendly cities and rapid advances in technology has facilitated the rise of the e-bikes in recent years (MacArthur et al., 2014). In Europe, the sales of e-bikes increased from 588,000 in 2010 to 1,667,000 in 2016 (CONEBI, 2017). In general, e-bikes in European, North American, and Australian context refer to bicycle-style e-bike design (i.e., the bicycle has functional pedals but is assisted with an electric motor) as opposed to scooter-style e-bike design (with no pedals) (Fishman and Cherry, 2016). E-bikes following the regulations made by the European Union are formally known as EPACs (electric pedal-assisted cycle) but are also known as *pedelecs*. The EU regulations mean that the motor assistant is limited to 250 W, and that the motor stops assisting beyond 25 km/h (European Committee for Standardization, 2011). Pedelecs are in most countries legally classified as

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bicycle, as they require pedaling for the electrical assistance to be provided (Fishman and Cherry, 2016). A key difference of the pedelecs compared to the conventional bicycle (CB) is that they can maintain speed, with less physical effort due to the electric-motor support. Following this, pedelecs have been highlighted as an alternative method of active travel that could overcome some of the common barriers to cycle commuting (de Geus and Hendriksen, 2015). In the following, we use the term *e-bike* to denote a bicycle of the pedelec type.

## Active transport and health benefits

Increasing cycling as mode of transport is a political goal in several European countries (e.g., Department for Transport, 2017; Norwegian Ministry of Transport and Communications, 2016), in part due to the potential for overall increased physical activity (PA) and subsequent population health benefits (Oja et al., 2011). The mechanisms happening when being physically active (i.e., any bodily movement produced by skeletal muscles, which requires energy expenditure) have both an acute and long-term effect and reduces risk of several noncommunicable diseases (Warburton and Bredin, 2017). Too little PA can have a negative effect on health and increase the risk of diseases such as heart attack, cancer, and diabetes (Bauman, 2004; Warburton and Bredin, 2017). Increasing PA levels as part of our daily travel routine, notably through active transport, can potentially give many individuals an adequate level of PA (Ainsworth et al., 2011; de Geus et al., 2007) and over time, also contribute to greater total PA (Sahlqvist et al., 2012). Active commuting is associated with a lower risk of all-cause mortality and cancer incidence (Celis-Morales et al., 2017).

The health benefits of PA depend on the individual's baseline cardiorespiratory fitness (i.e., weight and maximal $O_2$ uptake) and the frequency, duration and intensity of the activity performed (Gjerset, 1992). Maximal oxygen uptake ($VO_2$ max) is the amount of oxygen that the body can utilize in 1 minute. The intensity of PA is categorized in low, moderate and vigorous intensity. It is indicated by the metabolic equivalent of the task (MET), where 1 MET is defined as the energy used at rest (resting metabolism). The exercise intensity should be at least 3 METs (threshold for moderate intensity) in order to promote and maintain health (Haskell et al., 2007). To accrue health benefits The World Health Organization (WHO) (2016) recommends that healthy adults engage in at least 150 minutes of moderate PA or 75 minutes of vigorous PA per week. Behind these recommendations lies an understanding of the physiological mechanisms in which the higher the intensity, the shorter the duration is needed for the same health gain. If an individual has "low" baseline fitness, less duration, frequency and/or intensity is needed for enhanced health effect (Gjerset, 1992; Åstrand and Rodahl, 2003). The greatest gains in health outcomes from active travel are reported in the least active individuals (Oja et al., 2011).

## Intensity of physical activity when using e-bikes

As stated previously, it is well established that PA can be accumulated through active travel. As it is through the pedaling that e-bikes may serve to increase PA, we need to understand their potential to promote PA. Is the pedaling sufficiently strenuous to gain clinical benefit?

The intensity of an activity can be measured by means of oxygen uptake, metabolic equivalents, energy expenditure per minute, heart rate, and power output (Åstrand and Rodahl, 2003). Some acute studies have tested physiological parameters across different levels of assistance, from none to maximum electrical power (Simons et al., 2009; Sperlich et al., 2012). However, due to the weight difference, cycling on an e-bike with no assistance does not fairly represent cycling with a CB. Others have therefore investigated the direct comparison between cycling on an e-bike and a CB (e.g., Berntsen et al., 2017; Gojanovic et al., 2011; Theurel et al., 2012). A Swiss study in sedentary subjects ($N = 18$) found intensities of $VO_2$ max during cycling with an e-bike (high assistance), e-bike (standard), and CB, to be 54.9%, 65.7%, and 72.8%, respectively. The subjects performed all trips at a self-selected pace. For all comparisons, there was a significant difference ($P < .05$) (Gojanovic et al., 2011). In France, Theurel et al. (2012) found average $O_2$ uptake and HR to be significantly ($P < .05$) lower during e-bike cycling compared to CB ($N = 10$). In this study the bicycles were loaded with 20 kg, in order to simulate the weight of postal mail. A Norwegian randomized crossover study ($N = 8$) found lower exercise intensity (8.5 METs) on the e-bike compared to CB (10.9 METs). In total, 19.9 min was spent in moderate and vigorous activity when using an e-bike, as compared to 23.9 min on a CB. The travel time, when riding an e-bike, was reduced by 35% on hilly routes and 15% on flat routes, resulting in shorter duration of activity (Berntsen et al., 2017). In an American field study ($N = 17$), energy consumption per mile was reported to be 24% lower when pedaling an e-bike, compared with riding a CB, reflecting the shorter travel time. Per minute, there were no statistically significant differences in energy expenditure and ventilation rates between e-bikes and CB (Langford et al., 2017). The differences between e-bikes and CBs are most pronounced in the uphill segment (Berntsen et al., 2017; Gojanovic et al., 2011; Langford et al., 2017), representing a possible adaption by the individuals. When given the choice to self-select pace and intensity, individuals may select a similar physiological intensity across activities regardless of the assistance (CB vs e-bike), thereby resulting in similar physiological outcomes on flat and downhill segments. In hilly terrain, there is less opportunity to adjust effort levels to produce comparable intensity levels. Given the same pace and cycle distance, e-cycling requires a lower level of physical exertion (i.e., expenditure of energy during PA), compared to a CB.

All these findings are summarized in the systematic review by Bourne et al. (2018). Regardless of the difference to CBs, the review shows evidence that cycling with electrical assistance provide PA at least of moderate intensity, for both inactive and active individuals.

## Can e-bikes improve cardiorespiratory fitness?

Previous research has shown that cycling on a regular basis (at least three times a week) with a CB positively influences physical fitness (de Geus et al., 2009; Hendriksen et al., 2000; Moller et al., 2011; Oja et al., 2011). As the previous section showed, e-bike users spend less energy than CB users, but they still reach moderate PA intensity. The percentage of peak $VO_2$ max (i.e., the maximum amount of oxygen that the body can utilize in 1 minute) has been reported to range from 51 to 75 for e-cycling (Bourne et al., 2018). These values exceed the hypothesized minimum of intensity threshold (45% of $VO_2$ max) required for improvement in cardiorespiratory fitness in healthy adults (Swain and Franklin, 2002).

Acute studies give an indication of the potential of the e-bike to promote PA at an adequate level. The question then arises; can e-bikes improve people's cardiorespiratory fitness?

Several intervention studies have looked at e-cycling in a population over time (De Geus et al., 2013; Höchsmann et al., 2018; Lobben et al., 2018; Peterman et al., 2016), but only a few of these included control groups. A longitudinal study in The Netherlands ($N = 20$) looked at the influence of commuting by e-bike and found that e-bikes may have the potential to improve cardiorespiratory fitness similar to CBs (De Geus et al., 2013). However, the intervention period was too short (6 weeks) to show any significant effect. In a recent Swiss pilot study, physically inactive and overweight participants ($N = 32$) were randomly assigned to ride an e-bike or a CB for a period of 4 weeks. The participants were instructed to use the allocated bicycle for their active commute at a self-selected pace at least three times a week. They found an increase in peak oxygen uptake of 10% [3.6 mL/(kg min)] in the e-bike- and 6% [2.2 mL/(kg min)] in the CB-group. The e-bike users enabled higher speed and elevation gain, potentially outweighing the power assist (Höchsmann et al., 2018). Moreover, a Norwegian pilot study showed an average 7.7% increase in $VO_2$ max after equipping 25 inactive adults with an e-bike for eight months, an increment being positively associated with cycling distance (Lobben et al., 2018). Accordingly, Peterman et al. (2016), conducting a study in 20 sedentary commuters, found 4 weeks of e-bike commuting to cause significant improvements in 2-hour postoral glucose tolerance test glucose, $VO_2$ max (8% increment), and maximal power output. These results indicate that for inactive individuals, cardiorespiratory fitness could be improved.

The systematic review by Bourne et al. (2018) points out that future research using rigorous design is needed on long-term health impacts (i.e., changes in cardiorespiratory fitness) of e-cycling.

## Substitution effects

From a public health perspective, we are interested in the net volume of health-enhancing PA per week. A key issue in this respect is whether the health effect of increased cycling is canceled out by a reduction in other physical activities—a *substitution effect* (Thomson et al., 2008). The degree to which existing exercise is substituted is of great importance when the cost–benefit account of a given measure or investment is considered. Health benefits account for a large portion of the total benefits for cycling investments; according to a much-cited study as much as 55%–75% of all benefits from cycling infrastructure (Sælensminde, 2004). However, this figure is much debated, and an important part of this debate is the substitution effect. In general, the empirical evidence for substitution is weak (Thomson et al., 2008). Previous estimates of the substitution effect are based on cross-sectional studies (Börjesson and Eliasson, 2012), without sufficient control for population characteristics.

In an attempt to quantify the effect, a Swedish study asking people if increased cycling would lead to a reduction in other forms of exercise found that quite a number of the respondents appeared to have a time budget from which increased time spent traveling would imply decreased time spent on other activities (Börjesson and Eliasson, 2012). Given that the study used people's own estimations concerning alternate activities, the validity of these results is highly questionable. Further, and especially in the case of e-bikes, the fundamental assumption underlying the concept of active mobility is that it does not consume time spent on other activities. In some instances, cycling or walking might take longer time than non-active travel, but in most cases, especially in urban areas, it does not. For illustration, e-bikes are found to be speed competitive with both public transport and private cars (Plazier et al., 2017), meaning that riding an e-bike does not necessarily result in longer travel time than using motorized modes. Still, we cannot rule out that people have a total (physical or psychological) "budget" for PA, and that increased cycling would cause physical or mental fatigue affecting engagement in other activities negatively.

Related to this, it has been suggested that active transport, being more regular and of moderate intensity, has larger public health benefits than the typical infrequent higher intensity activities it replaces (Praznoczy, 2012). Moreover, fitness gains from increased cycling could inspire individuals to be more active in other domains, hence increasing *overall* PA, as has been suggested by studies on health behavior and motivational impacts (Mata et al., 2009; Sniehotta et al., 2005).

Few studies have assessed e-bikes and substitution effects. In a recent study, including data from seven European studies, Castro et al. (2019) found PA (measured as MET minutes per week) from travel-related activities to be similar for e-bike and CB, implying that use of e-bike does not necessarily reduce other PAs. Another study, conducted in Norway, found that for those starting to use an e-bike, other PAs were not significantly affected, that is, indicating no substitution effect (Sundfør and Fyhri, 2017).

## Effects on travel behavior

The net volume of PA from starting to use an e-bike depends almost entirely on the transport mode it replaces, and the changes in travel patterns and other PAs (Fyhri and Fearnley, 2015; Sundfør and Fyhri, 2017). A person replacing his regular trip on a CB with an e-bike will have a negative health benefit, given no other adjustment. A person replacing a passive mode of transport (e.g., car) will have a positive health benefit, as the energy expenditure (indicated by METs) is higher when riding an e-bike (Berntsen et al., 2017) compared to when driving a car (Haskell et al., 2007).

Most novel e-bike users are motivated by the power from the engine, leveling out hilly terrain thereby making cycling easier (Fyhri et al., 2017). A Dutch study showed that e-bike users cycled 30 km a week, compared to 18 km a week for conventional cyclists (Fietsberaad, 2013). However, the study did not assess usual cycling distance prior to purchase, making it difficult to draw conclusions regarding changes in travel mode. A Swedish study (Hiselius and Svensson, 2017) appraising self-reported change in transport behavior, indicated that a great proportion of new e-bike trips replaced earlier car journeys. Due to being a retrospective study, asking people to estimate previous behavior, such an estimate is subject to great uncertainty. Many of the e-bike owners have had the e-bike for a long time, up to 3 years.

A British study has undergone research results on the effect of e-bikes on the number of trips traveled by car, and on the number of kilometers traveled (Cairns et al., 2017). The article summarizes findings from European studies on the effect of e-bikes on bicycle trips, replacement of car journeys, etc. In total six studies reported that the proportion of car journeys had been replaced by bicycle journeys as a result of access to an e-bike, with the proportion replaced ranging between 16% and 76%.

Newly, Castro et al. (2019) compared PA levels of e-bike users and CB users (cyclists), as well as across e-bike users grouped after mode substitution, using data from the PASTA project, including over 10,000 participants in seven European cities. PA levels, measured as MET min per week, were found to be similar among e-bike users and cyclists (4463 vs 4085). E-bike users reported significantly longer trip distances for both e-bike (9.4 km) and regular bike trips (8.4 km), compared to users of CB (4.8 km). Also, longer daily travel distances were found for e-bike compared with cyclists for regular bike (8.0 vs 5.3 km per person, per day, respectively). In addition, a decrease of about 200 MET min per week in travel-related activities was revealed for e-bike users who switched from cycling, while those switching from private cars and public transport gained about 550 and 800 MET min per week, respectively. In turn, this indicates that e-bike use could entail substantial increases in PA levels in e-bike users shifting from private car and public transport, while net losses in PA for e-bike users switching from cycling were much less because of increased overall travel distance. However, all of these studies have the same methodology as the before mentioned Swedish study, entailing being retrospective, showing what people remember what they did, or suppose they did before they got the bike.

A scarce number of studies have looked at changes in transport behavior by measuring before and after having access to an e-bike (with a control group). In a Norwegian study, a group of 66 people got access to e-bikes for 2 or 4 weeks. This study showed that the number of cycling trips increased from 0.9 to 1.4 per day, distance cycled increased from 4.8 to 10.3 km, and cycling shares out of all transport increased from 28% to 48%, while a control group ($N = 160$) did not have any changes (Fyhri and Fearnley, 2015). In another study, 669 participants that applied for, and received subsidies for e-bike purchase (from the Oslo municipality's subsidy scheme) were measured before, and one month after the purchase of the e-bike. (Fyhri et al., 2016). The results of this study confirmed those of the previous study and found that e-bike owners cycled between 12 and 18 km more each week (compared to a control group) if they replaced a CB with an e-bike, which meant that the initial cycling share was doubled. Those who received e-bike support increased their use of bicycles by 30% at the expense of walking (down 4%), public transport (down 10%), and driving (down 16%). It should be noted that this study was conducted in a Scandinavian context, in a situation where the e-bike was still quite unusual, and the bicycle share is quite low. The effect of e-bikes may be less in a country or a city where many already use bicycles.

## Psychological outcomes from riding an e-bike

Previous studies find that cycling to work on a CB elicit more positive affect and enjoyment compared to other modes of travel (Gatersleben and Uzzell, 2007; Rissel et al., 2016). Cycling also happens outdoors and often in green space, and research on exposure to nature shows well-established findings with regard to cognitive benefits, including restoration from mental fatigue (Barton and Pretty, 2010). Research also indicates that there may be a synergetic effect on health from the combination of PA and nature experience (Barton and Pretty, 2010), and cycling to work may have implications for perceived vitality and thereby cognitive performance and work capacity (Calogiuri et al., 2016). Recently, four reasons why cyclists seem to be the most happiest commuters were proposed: (1) greater extent of commuting control and "arrival-time reliability," (2) sensory stimulation reaching enjoyable levels, (3) the mental effects of moderate-intensity PA making one feel better, and (4) more likely for social interaction to occur (Wild and Woodward, 2019).

There are a few studies that have looked at e-bikes and psychological outcomes. A British intervention study by Page and Nilsson (2017) found that people who change their behavior to active commuting by e-bike report more positive affect, better physical health, and more productive organizational behavior, compared with passive commuters. Some studies report enjoyment and positive experiences of the user (Fyhri and Fearnley, 2015; Plazier et al., 2017; Popovich et al., 2014), as well as favorable effects on mental well-being (Jones et al., 2016), and others conclude that due to the decreased amount of effort needed, it might be easier to concentrate (Theurel et al., 2012).

The impact of psychological health arising from riding an e-bike is according to the systematic review by Bourne et al. (2018) inconclusive.

## What about accidents?

It has been claimed that an increased use of e-bikes may lead to more traffic accidents (Papoutsi et al., 2014; Schepers et al., 2014; Weber et al., 2014). To be able to discuss this claim, it is important to distinguish among a mere *exposure effect*, an *increased risk*, and differences in *injury severity*.

Regarding the exposure effect, people tend to ride longer when they switch from a CB to an e-bike, as shown in the previous section. Few of the accident studies conducted account well for possible changes in number of e-bikes in traffic and for differences in usage between conventional and electric bicycles. Another limitation with many of the existing studies is that they are based on official injury data or trauma registers. The benefit of this is that the measure of an accident follows a protocol, and hence is less vulnerable to individual assessments. A challenge with these data is that they only cover a small share of all accidents. Underreporting of bicycle accidents is well known (Shinar et al., 2018). In a study from Norway, 10% underreporting of bicycle traffic accidents was found (Bjørnskau, 2005).

A study that accounted for exposure found a small, but significant increase in *accident risk* for e-bikes (Schepers et al., 2014), but in a follow-up study (Schepers et al., 2018), no increased risk of accidents was found. The authors themselves claimed the difference to be methodological, and that the latter result was the most valid. Weiss et al. (2018) found that the risk of a bicycle accident increased with age, but not with bicycle type. Most studies looking at injury severity conclude that there is no difference between e-bikes and CB (Otte et al., 2014; Papoutsi et al., 2014; Weber et al., 2014).

The abovementioned studies lack adequate control with exposure (i.e., distance traveled on the bicycle) to be able to compare accident risk between electric and CBs. And quite importantly, as we have shown, user groups differ, which might influence both accident risk and injury severity.

A Dutch study indicated elevated risk for old women while riding e-bikes (Fietsberaad, 2013). Another study, carried out in Norway ($N = 7752$), combined three data sets to compare conventional and electric bicycles, while at the same time controlling for age, gender, and exposure (Fyhri et al., 2019). The study found an overall risk increase for e-bike users but suggests that all of this risk can be attributed to female cyclists. In other words, women have a higher risk on e-bikes, whereas men do not. Men have a higher total risk. Some, but not all, of this elevated risk can be attributed to experience with the bicycle. Looking at type of injury, e-bikes are not more likely to cause serious accidents than CBs. As opposed to previous studies, no age differences were found.

The health benefit of increased PA accumulated though cycling is found to outweigh the risk of injuries (Andersen et al., 2018; De Hartog et al., 2010). Also, the World Health Organization has developed a tool for Health economic assessment for walking and cycling (HEAT). The tool is based on the best available evidence and estimates the value of reduced mortality that results from specified amounts of PA from cycling (and walking). It also takes into account the health effects from road crashes and air pollution, and effects on carbon emissions (WHO, 2019).

## The net public health effects of e-bikes

So, e-bikes, are they good for public health? Well, it depends. It is well established that PA is health enhancing, and that active travel can increase total PA. The e-bike demands lower levels of intensity for the same pace and distance as a CB, due to the assistance of the electrical motor. Depending on fitness level, the intensity when riding an e-bike will differ between inactive and active individuals (i.e., an individual with "high" fitness needs more strain to gain the same intensity level). Still, the e-bike provides PA of *at least* moderate intensity, for both inactive and active individuals.

The net volume of PA from starting to use an e-bike depends almost entirely on the transport mode it replaces, and the changes in travel patterns and other PAs (i.e., substitution effect). Overall, people tend to ride longer and more often when they switch from a CB to an e-bike. The e-bike could entail substantial increases in PA levels for e-bike users switching from a passive mode of transport (i.e., car). For e-bike users switching from previous cycling (CB), there would be net losses in PA (i.e., less effort needed for the same pace and distance), but the overall increased travel time will to a large degree reduce this effect. Other PAs are found not to be significantly affected when starting to use an e-bike, implying that there might not be a substitution effect.

The e-bikes potential to make it "easier" to bicycle motivates novice cyclists and increase the likelihood that these individuals will continue cycling. It could also facilitate use among groups where the CB is no option, such as among elderly and sedentary individuals. For these groups, replacement of trips previously made by CB would be no issue, but their lack of previous cycling experience might be. Most studies looking at injury severity conclude that there is no difference between CBs and e-bikes. For total accident risk, there might be an elevated risk for female e-bike users. Some, but not all, of this can be attributed to experience with the bicycle (novice cyclist). The health benefit of increased PA accumulated through cycling is overall considered as higher than the risk of injuries.

## Future trends

In the last 10 years the number of e-bikes in Europe has increased from approximately 600,000 to over 1.7 million. The electric cargo bike, a pedal-assisted e-bike designed and constructed specifically for transporting loads, is an emerging vehicle in many cities these days. Due to the freight aspect, these bicycles might have the potential to compete with the car to a larger degree than regular e-bikes, among both private individuals and companies.

Other devices, becoming more popular these days, are small electrical scooters (classified as bicycles) and boards (e.g., hoverboard). The motor of these are not pedal assisted, and no activity for the rider is needed. Hence, the potential for promoting PA is removed, making them not favorable from a public health perspective.

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CHAPTER TWELVE

# Active transport to and from school

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## Contents



## Introduction

In the past, most children and adolescents walked or cycled to and from schools, but nowadays many of them are traveling to and from school by car. This trend has been observed in many developed countries. Increased rates of traveling to and from school by car reduce children's opportunities to be physically active. Multiple intervention studies have attempted to stimulate getting children out of the car and supporting them to walk and/or cycle to school.

This chapter will provide an overview of the health benefits of active transport to and from school (ATS) and the intervention studies that have been implemented to encourage ATS in children and adolescents as the

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main parts. In addition, the definition of ATS, the ATS correlates, the current ATS prevalence and trends, as well as recommendations for future research will be discussed.

ATS is defined as traveling to and/or from school using human-powered modes of transport such as walking, cycling, and riding a non-motorized scooter or skateboarding. ATS is a low cost, accessible form of physical activity and may appeal even to those children and adolescents who dislike participating in organized sports. Walking and cycling are the most common modes of ATS. Consequently, this chapter will discuss the health effects of walking and cycling to school and the considerations and lessons learned from the intervention studies designed to promote walking and/or cycling to school among children and adolescents.

However, a new panorama of transport modes—including transport to/from school—is emerging recently in many urban areas from developed countries due to new technological developments. A diverse range of personal mobility devices, such as kick-scooters, skateboards, and electricity-powered devices (e.g., electric scooters, electric skates, electric unicycles, electric hoverboards), are becoming more prevalent among young people living in urban settings (Gitelman et al., 2019). Given the growing diversity of new transport modes that are becoming available to children and adolescents for traveling to/from school, future research should examine the physiological and health effects of those novel transport modes—especially electrically powered devices—and define whether such modes of transport should be considered active, motorized, or semi-active. Understanding the health benefits of those novel transport modes is important to determine if those transport modes should be promoted as effective means to contribute to increasing physical activity in different subgroups of the population.

The *prevalence of ATS* among children and adolescents varies across countries. A recently published Global Matrix 3.0 report showed that the average prevalence of ATS and active transport to other destinations was 40%–59% across 47 countries that reported data for this indicator (Aubert et al., 2018). The rates of active transport ranged from 20% to 26% in Canada and the United States and 80% to 86% in Zimbabwe (Aubert et al., 2018). Similar results were reported in studies that examined specifically ATS: 15% in the United States (McDonald et al., 2011); 24% in Canada (Gray et al., 2014); 40%–60% in Spain (Rodriguez-Lopez et al., 2017), Switzerland (Bringolf-Isler et al., 2008), Sweden (Johansson et al., 2012), and New Zealand (Mandic et al., 2015); and over 70% in China

(Yang et al., 2017), Denmark (Ostergaard et al., 2012), and The Netherlands (Cooper et al., 2006). In most developed countries, walking is a popular form of transport to/from school, whereas cycling is less common (McDonald, 2007; Larsen et al., 2009; Chillon et al., 2009; Murtagh et al., 2016; Leslie et al., 2010; Mandic et al., 2017b). In contrast, rates of cycling versus walking to/from school are higher in countries such as Belgium and Denmark that have long cycling tradition and extensive cycling-friendly infrastructure (Cooper et al., 2006; Van Dyck et al., 2010).

Despite the wide range of prevalence of ATS between the countries, most countries show a *trend* for declining rates of ATS, including United States in America (McDonald, 2007; Colley and Buliung, 2016), United Kingdom, Spain, Switzerland, and Czech Republic in Europe (Black et al., 2001; Chillon et al., 2013; Grize et al., 2010; Pavelka et al., 2017), Vietnam in Asia (Trang et al., 2012), and Australia and New Zealand in Oceania (Meron et al., 2011; van der Ploeg et al., 2008; Ministry of Transport, 2015). A study from the United Kingdom (Black et al., 2001) reported a 9% decrease in rates of walking to school between 1975 and 1994 among children aged 5−10 years. Similar trend was reported in Switzerland with a 7% decrease in rates of ATS from 1994 to 2005 among children aged 6−14 years (Grize et al., 2010). A greater decline in ATS rates was recently reported in Czech Republic (Pavelka et al., 2017) with a 20% decrease in the rates of ATS during the 2006−14 period among adolescents aged 11−15 years. In Spain, rates of walking to school decreased from 61% in 2001 to 46% in 2007 among adolescents aged 13−17 years (Chillon et al., 2013). In some countries, such as New Zealand, the rates of walking to school have remained relatively stable over the last few decades, whereas the rates of cycling to school decreased dramatically in children from 12% in 1989/90 to 2% in 2010−14 and in adolescents from 19% to 3% during the same period (Ministry of Transport, 2015). Low rates of ATS observed in children and adolescents in many countries emphasize the need for strategies to promote and support active modes of transport in these age groups.

A growing number of studies suggest that multiple factors influence whether children and adolescents use active transport for their school journeys. *Correlates* of ATS include children's/adolescents' demographic characteristics, family factors, social and built environment factors, and policies. Short distance to school is the strongest correlate of ATS (Mandic et al., 2015; Rothman et al., 2018; Chillon et al., 2014).

In addition, higher rates of ATS have been observed in children (vs adolescents) (McDonald, 2007), boys (vs girls) (Larsen et al., 2009; Babey et al., 2009), and those from lower (vs higher) socioeconomic status (Chillon et al., 2009; Pont et al., 2009). Individual factors such as perceptions of different transport modes and preferences and perceived barriers to walk or cycle to school (Wilson et al., 2018), school bag weight (Mandic et al., 2018) and, in case of cycling, the level of cycle skills (Mandic et al., 2017a) also have effects on children's (and their parents') choice of transport to/from school. Social factors such as encouragement from peers, parents, and school (Ikeda et al., 2018a); parental concerns related to personal and traffic safety (Carver et al., 2010; Huertas-Delgado et al., 2017); and convenience of trip chaining (Aibar et al., 2018) also influence how children and adolescents travel to/from school. Built environment features (such as presence/absence of footpaths and cycle lanes, land use mix, intersection density, and residential density) (Pont et al., 2009; Ikeda et al., 2018b; Wong et al., 2011), perceptions of the safety of the walking route to school (Pocock et al., 2019) as well as natural environment (including topography and climate) (Aibar et al., 2015) have effects on the uptake of ATS. Finally, policy factors such as school uniforms requirements (Hopkins and Mandic, 2017), cycling helmet legislation (Molina-García et al., 2018), and absence of school zoning (Mandic et al., 2017c) have important implications for ATS. Therefore the design of future interventions to promote ATS should take into account multiple factors that influence school transport decisions. Identifying factors that influence ATS behaviors in the local context is essential for designing effective interventions for promoting walking and cycling to/from school.

ATS is relatively a new *area of research*. The first publication written by recognized experts in the physical activity field and published in a specific Journal of Sports Science was in 2001 (Tudor-Locke et al., 2001), and it already emphasized ATS as a potential opportunity to increase physical activity levels in children and adolescents. The authors reported that the mode of children's transportation to and from school and to other destinations had been largely ignored in population surveys of children's physical activity up to that time. Hence, in the early 2000s, there was little evidence to conclude whether or not ATS was a potential significant source of physical activity in young people. In the following years the number of publications related to ATS increased with the main focus to examine whether ATS contributed to increasing and/or maintaining higher levels of physical activity in children and adolescents. A recent search in the

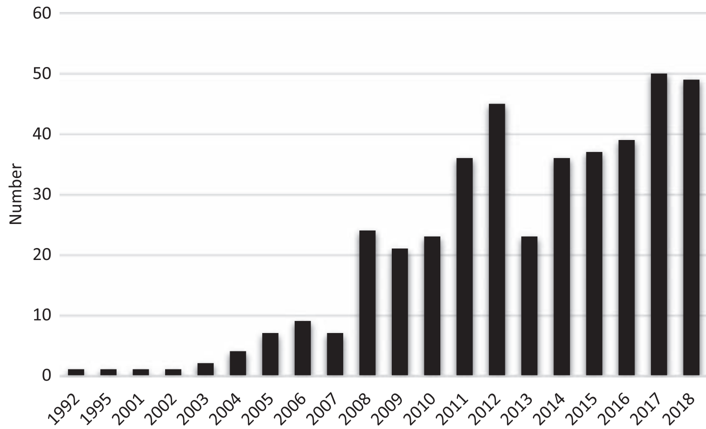


**Figure 12.1** Publications of active school transportation along the time. Electronic search: TI = (bike OR bikers OR biking OR bicycle* OR cycle OR cycling OR cyclist* OR commute* OR commuting OR transportation OR travel*) AND TI = School AND TS = Active. Time: 1900–2018. Database: web of science.

Web of Science database showed 414 published journal articles with an exponential increase in the number of ATS-related publications during the 2001–18 period (Fig. 12.1).

## Health effects of active transport to and from school

This section summarizes current evidence regarding the health effects of ATS. Four systematic reviews examining the impact of ATS on physical activity levels, body weight, and cardiovascular fitness were published between 2008 and 2014 (Lee et al., 2008; Faulkner et al., 2009; Lubans et al., 2011; Larouche et al., 2014). The most recent review published in 2014 summarized findings from 4 intervention studies, 10 prospective studies, and 54 cross-sectional studies (Larouche et al., 2014). The findings from those systematic reviews and additional studies are summarized in Table 12.1.

### Physical activity

The majority of previous studies reported higher levels of physical activity among children and adolescents who use ATS compared to those who rely solely on motorized transport to school (Larouche et al., 2014; Oliver

**Table 12.1** Summary of systematic reviews that examined health benefits of active transport to/from school.

| | Health benefits of active transport to/from school | | |
|---|---|---|---|
| | **Physical activity** | **Body weight** | **Cardiovascular fitness** |
| *Number of studies reviewed* | *n* | *n* | *n* |
| Lee et al. (2008) | 32 | 18 | |
| Faulkner et al. (2009) | 9 | 10 | |
| Lubans et al. (2011) | | 23 | 2 |
| Larouche et al. (2014) | 49 | 39 | 10 |

et al., 2016; Schoeppe et al., 2013). In the most recent systematic review, 40 out of 49 studies (81.6%) reported that children and adolescents using ATS accumulated more daily physical activity (assessed by questionnaires, pedometers, or accelerometers) compared to users of motorized (passive) transport (Larouche et al., 2014). Greater differences in physical activity between active versus motorized transport users were found in children who lived further away from their school (Van Sluijs et al., 2009; Panter et al., 2011), suggesting a possible dose—response relationship between the amount of physical activity and distance to school.

In adolescents, ATS users accumulated a greater amount of moderate-to-vigorous physical activity throughout the week (Larouche et al., 2014; Chillon et al., 2010; Saksvig et al., 2007; Chillon et al., 2011b; Kek et al., 2019; Aibar et al., 2014) and on school days (Kek et al., 2019; Alexander et al., 2005) compared to their peers who relied solely on motorized transport for their school journeys. In addition, several studies reported higher levels of physical activity during before and after school hours among active versus motorized transport users (Saksvig et al., 2007; Mendoza et al., 2011b; Saksvig et al., 2012). Recent findings from New Zealand adolescents showed higher levels of objectively measured physical activity among ATS users even if they combined active and motorized modes of transport in a single journey to/from school (Kek et al., 2019). These findings suggest that ATS can contribute to increasing and/or maintaining physical activity in children and adolescents.

## Body weight

Studies examining the association between ATS and body weight reported conflicting findings in children and adolescents. Some studies found that ATS is associated with lower body weight and healthier weight status in these age groups whereas others reported no difference (Lee et al., 2008; Faulkner et al., 2009; Lubans et al., 2011; Larouche et al., 2014). Therefore the current evidence is inconclusive regarding the impact of ATS on achieving and maintaining healthy body weight in children and adolescents, and further research is necessary.

## Cardiovascular fitness

ATS, especially cycling, is associated with improved cardiovascular fitness in young people. The systematic review by Larouche et al. (2014) analyzed 10 studies that examined the impact of ATS on cardiorespiratory fitness in children and adolescents. Five studies that examined walking and cycling separately consistently reported higher levels of cardiorespiratory fitness in cyclists compared to those using passive (motorized) transport to/from school (Cooper et al., 2006, 2008; Chillon et al., 2010; Andersen et al., 2009; Voss and Sandercock, 2010). One study showed that Danish children who began to cycle to school during the 6-year follow-up period achieved a 9% greater cardiovascular fitness at 15 years of age (Cooper et al., 2008). In the same study, cycling to school explained 3.1%−9.7% of the variance in cardiovascular fitness (Cooper et al., 2008). Only one out of five studies that analyzed walking and cycling separately found higher cardiorespiratory fitness in walkers versus users of motorized transport to school (Voss and Sandercock, 2010). Therefore cycling to/from school is associated with increased cardiovascular fitness in children and adolescents, whereas the current evidence for walking to/from school is inconclusive (Larouche et al., 2014).

## Other benefits

ATS also promotes *independent mobility* in children and adolescents. Independent mobility is defined as active transport without adult supervision. In addition to health benefits associated with active transport, independent mobility provides children and adolescents with opportunities to establish social connections with peers and connecting children, develop spatial processing skills, learn to navigate the environments with traffic, connect with their neighborhood and natural environment, and contribute to mental health (Marzi and Reimers, 2018). In addition, children engaging in independent mobility perceived their home neighborhoods to be more safe compared to children who did not engage in independent mobility (Herrador-Colmenero et al., 2017).

In addition to health benefits for an individual, increasing rates of ATS also contributes to *environmental health* by reducing traffic congestion, traffic-related air pollution and noise levels, especially around schools (Woodcock et al., 2009; Mueller et al., 2016; Sunyer et al., 2015). Reducing the rates of private vehicle travel to and from school will ultimately contribute to creating healthier urban environments and support global efforts to mitigate climate change.

Increasing ATS may also have unintended consequences related to *unhealthy eating behaviors* such as increased consumption of fast food and sugary beverages along the route to/from school (Sanchez-Vaznaugh et al., 2016; Forsyth et al., 2012). Food outlets and convenience stores tend to cluster around schools (Forsyth et al., 2012; Day et al., 2015; Cutumisu et al., 2017). The availability of fast food outlets near schools is associated with an increased intake of fast foods by adolescents (Forsyth et al., 2012). Therefore availability of food outlets and potentially unhealthy eating behaviors should be considered—and ideally addressed—in future ATS interventions to maximize the health benefits of such interventions.

Taken together, ATS contributes to increasing or maintaining physical activity and is associated with increased cardiovascular fitness (especially for cycling) in children and adolescents, whereas evidence regarding the impact of ATS on body weight is inconclusive. In addition, ATS promotes independent mobility in children and adolescents and contributes to the environmental health. However, ATS may also be associated with unhealthy eating habits that may minimize health benefits associated with active school travel.

## Intervention studies to promote active transport to and from school

Given the low prevalence of ATS in most countries and the health and other benefits associated with active transport, it is essential to design effective interventions to encourage children and adolescents to engage in ATS. This section summarizes the published ATS interventions, discusses the effectiveness and quality of those interventions, and provides recommendations for implementing effective ATS interventions in future.

The first three ATS intervention studies published in 2003 were conducted in London (Europe) (Rowland et al., 2003), Sydney (Oceania)

(Zaccari and Dirkis, 2003), and California (America) (Staunton et al., 2003). Subsequently, the number of published school-based ATS intervention studies increased to 14 by 2011 (Chillon et al., 2011a), with additional 23 ATS intervention studies published during the 2012−17 period (Villa-Gonzalez et al., 2018). Using the same electronic search in MEDLINE (PubMed) as the two previous systematic reviews, additional six ATS intervention studies were published between 2017 and May 2019 (Villa-Gonzalez et al., 2017; Tercedor et al., 2017; Rodriguez et al., 2019; Lindqvist et al., 2019; Hatfield et al., 2019; Ginja et al., 2017).

Four systematic reviews have been published to date summarizing findings from the ATS intervention studies (Chillon et al., 2011a; Villa-Gonzalez et al., 2018; Pang et al., 2017; Larouche et al., 2018). In addition, a recent meta-analysis provides a further insight into inter-study comparisons (Jones et al., 2019). The increased interest in ATS intervention studies may reflect a necessity in public health policy to implement effective interventions to reverse the declining rates of ATS as one of the interventions to increase physical activity and improve health of children and adolescents. Therefore a description of the published ATS interventions, their effectiveness and quality, and lessons learned from those interventions are summarized next.

## Description of the active transport to and from school interventions

Nearly, two-thirds of the published ATS intervention studies were conducted in North America (61%; United States and Canada), approximately one quarter in Europe (28%; United Kingdom, Belgium, Denmark, Spain) and approximately one-tenth in Oceania (Australia; 11%) (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). Most of those ATS intervention studies (73%) focused on children (from age 5 to 12 years) and were implemented in elementary schools, whereas fewer studies (27%) engaged adolescents (aged 13−18 years) and were implemented in secondary schools (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). The number of participants varied greatly across the ATS interventions studies, ranging from a very small sample in a pilot walking school bus (WSB) intervention with 11 participants in California (Sirard et al., 2008) to larger samples in multi-center studies conducted as part of the Safe Route to School (SRTS) program in the United States, involving 65,000 students and 16,000 parents (McDonald et al., 2014) from 1019 schools (Stewart et al., 2014). The average duration of the ATS interventions was

1–2 years fitting with the school year schedule, ranging from 3 weeks in a study that implemented a SRTS program in a school from Nevada (United States) (Bungum et al., 2014) to 6 years in a study that conducted a multi-state evaluation of the SRTS program in the United States (Stewart et al., 2014).

The scope and focus of the published ATS intervention studies were heterogeneous. Half of the studies evaluated SRTS interventions (19%), WSB interventions (19%), or school travel plan (STP) projects (11%) (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). Approximately 39% of ATS intervention studies were one-component interventions to encourage ATS using previously mentioned interventions (i.e., SRTS, WSB, and/or STP), cycling skills training programs, specific events (e.g., walk to school days), creation of drop-off areas from which driven children could walk to school with adult supervision, presence of crossing guards, and specific curriculum-based programs focused on ATS (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). The remaining ATS intervention studies were multi-component health interventions that included an intervention to promote ATS (11%) (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). Most of the ATS intervention studies focused on promoting walking to school. Only one-third of the ATS interventions included elements to promote cycling to school (together with promoting walking) by encouraging cycling and implementing cycling-related infrastructure changes. Few interventions focused only on cycling, by implementing cycling skills training courses (Ducheyne et al., 2014; Goodman et al., 2016), developing/improving cycling infrastructure, and providing encouragement for cycling to/from school (Ostergaard et al., 2015).

Most commonly reported ATS interventions—SRTS, WSB, and STS—are briefly described next with more details available elsewhere (Larouche, 2018).

The SRTS is a program *to create safe, convenient and fun opportunities for children to walk and bicycle to and from their schools* (Safe Routes to School Partnership, 2007). The comprehensive SRTS program originated from a Danish pilot program in the 1970s, released and implemented successfully by the city of Odense, helping to reduce the child pedestrian and bicycle collisions during the school journey by 82% (National Center for Safe Routes to School, 2015). The program was taken up by the United States, and California launched the first SRTS statewide program in 1997. SRTS programs have shown to be effective means to increase the proportion and safety of children walking and cycling to school with the community-based approach being responsible for much of the program's success (Larouche, 2018).

The WSB is an intervention in which a group of children walk together to school along a set route under the supervision of at least one adult who typically volunteers as "a driver" (or a coordinator). The concept was initially proposed by an Australian activist, David Engwicht, as a first step to increase children's independent mobility and ATS while minimizing the parental safety concerns. The WSBs' interventions were effective in increasing the rates of ATS and physical activity and reduce car travel among children attending primary schools (Smith et al., 2015). Most of the WSB studies were implemented in the United States and New Zealand, and fewer were conducted in Australia (Smith et al., 2015). The benefits of WSB included an increase in physical activity and time spent outdoors, helping children to develop road safety skills and reducing stress, traffic congestion, and pollution (Larouche, 2018; Sayers et al., 2012; Mendoza et al., 2012). The main limitation of the WSB programs is their reliance on volunteers to ensure the sustainability of the program over time and the lack of WSBs in low-income neighborhoods (Larouche, 2018). A cycling version of the WSB named the Bike Train is starting in the United States, although the evidence about the implementation and effectiveness of this intervention to promote cycling to school is currently limited (Mendoza et al., 2017).

The STP is a collaborative intervention involving stakeholders from multiple sectors (i.e., safety, transportation, municipal planning, health, and education) who assess and intervene in schools by creating a written STP. The STP typically outlines four types of strategies for promoting ATS: educational, activities and events, capital improvement projects, and enforcement initiatives (Larouche, 2018). The concept of STS was developed in the United Kingdom in 1997 and led by the Department of Transport and Education (Atkins Limited, 2010). By 2009, 81% of the schools in England had implemented a STP (Atkins Limited, 2010). Some of the strengths of STP interventions include taking into account the spatiotemporal complexity in school travel mode share and allowing schools to identify potential solutions depending on their local context. In addition, the existing evidence from Canada and New Zealand demonstrates modest effects of STP interventions on increasing rates of ATS 2–3 years after the STS implementation (Larouche, 2018).

The Active Living by Design Community Action Model provides a standardized intervention framework to identify the types of interventions and enable comparison of different intervention strategies (Bors et al., 2009). This framework includes multi-level strategies to increase physical activity and has been successfully applied in ATS interventions studies (Fesperman et al., 2008). The framework outlines five strategies for designing interventions including preparation, promotions, programs, policies, and physical changes (Bors et al., 2009). Each of those strategies is described next in more detail.

- *preparation* (time deliberately taken to plan and develop strategy for an initiative)
- *promotions* (educating and encouraging targeted individuals)
- *programs* (organized activities that engage individuals in physical activity)
- *policies* (written and unwritten rules or standards that affect physical activity)
- *physical projects* (projects to create opportunities and remove barriers for physical activity)

Almost half of the published ATS intervention studies (45%) reported using four or five of those strategies, and the same number of studies (45%) used three strategies whereas few studies (10%) used only one or two strategies (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). The three most commonly used strategies used in published ATS interventions studies were preparation, promotion, and programs.

As discussed earlier in this chapter, ATS is a complex behavior affected by multiple factors according to the socio-ecological models, including individual, interpersonal, community, built environment, and policy factors (Sallis et al., 2006). Successful interventions designed to date to increase the rates of ATS involved children and/or adolescents, schools, parents, and communities. However, most of the interventions relied heavily on the involvement of schools, whereas involvement of the community was the least frequently used (Chillon et al., 2011a).

## Effectiveness and quality of the interventions

The effectiveness of the published ATS interventions was highly heterogeneous. Most studies included in the previous systematic reviews (Chillon et al., 2011a; Villa-Gonzalez et al., 2018) reported an increase in the rates of ATS following the intervention period. However, several studies did not find increase in the rates of ATS (Rowland et al., 2003; Ducheyne et al., 2014; Goodman et al., 2016; Ostergaard et al., 2015;

McMinn et al., 2012; Gutierrez et al., 2014; Jordan et al., 2008), or some even reported lower rates of ATS (Hoelscher et al., 2016; Hunter et al., 2015) among children and adolescents after the interventions.

The degree of change in the rates of ATS following the intervention period varied greatly between the studies, ranging from 2% (Buliung et al., 2011) to 101% (Buckley et al., 2013). Most ATS intervention studies included the rates of ATS as the main outcome, and fewer reported improvements in other outcomes, such as an increased number of steps on the average way from home to school (Vanwolleghem et al., 2014), an increased physical activity level (Sirard et al., 2008; Kong et al., 2010), or longer average distances walked to school (McKee et al., 2007) after the intervention. However, since the ATS intervention studies were heterogeneous with respect to sample size, context, and duration of the intervention, comparisons between the published ATS intervention studies must be performed using an accurate and standard parameter, such as the effect size of Cohen (Nakagawa and Cuthill, 2007). When effect size was considered, one quarter of the ATS intervention studies (25%) had large and very large effects (Chillon et al., 2011a; Villa-Gonzalez et al., 2018). Among the remaining studies the effectiveness was trivial in one-third of the studies (28%) (Chillon et al., 2011a; Villa-Gonzalez et al., 2018) and poor in half of the published ATS intervention studies (47%).

The overall quality of the ATS intervention studies was weak, (Chillon et al., 2011a; Villa-Gonzalez et al., 2018; Pang et al., 2017; Larouche et al., 2018; Jones et al., 2019), although the marginal improvement in the quality of the ATS interventions studies published in the last 6 years is promising. Most studies did not include a representative sample of the school population and used quasiexperimental designs, although the number of randomized-controlled trials (Rowland et al., 2003; Ducheyne et al., 2014; Wen et al., 2008; Mendoza et al., 2009; Mendoza et al., 2011a; Christiansen et al., 2014) has increased among the recently published studies. Furthermore, most studies failed to take in account confounders and mediators and to describe their theoretical frameworks (Larouche et al., 2018). Common methods for collecting the data on ATS in the published ATS intervention studies included self-report using questionnaires completed by children, parents, or both children and their parents. In recent years, some studies used count observations to assess rates of ATS and objective measurements of physical activity using accelerometers (McMinn et al., 2012; Sayers et al., 2012) and pedometers (Vanwolleghem et al., 2014). Studies usually included the questions about modes and frequency of use of each mode of transport to school, but the actual questions varied between studies making the comparison between studies difficult. However, there has been a successful increase in the number of valid and reliable tools for assessing modes and frequency of transport to/from school in children and adolescents in the most recent intervention studies compared with the oldest ones. In most studies the unit of allocation was the school, and the unit of analysis was the individual, and some studies did not account for school clustering during the data analysis (Chillon et al., 2011a).

## Recommendations for future active school travel interventions

Insights from the intervention studies published to date provide a strong knowledge base for recommendations regarding the implementation of effective strategies to promote ATS. This section provides several recommendations for researchers, practitioners, and policy makers for designing and implementing future ATS interventions.

1. ATS is a highly contextual behavior influenced by a myriad of factors such as the built environment features and the children's and parents' perceptions. Therefore the results from the ATS intervention studies might not be easily transferrable between different settings. Therefore country- and context-specific ATS intervention studies are necessary. For example, ATS intervention studies from Asia and Africa are currently lacking.
2. Most ATS intervention studies focused on children, and fewer studies were conducted in adolescents. As the correlates of ATS including parental influence and rates of independent mobility vary by age, the ATS interventions that were effective in children (e.g., WSB) may not necessarily be effective or appropriate for adolescents (Larouche et al., 2018).
3. Effective ATS interventions should
   a. use three or more strategies from the Active Living by Design Community Action Model (at least preparation, promotion, and programs),
   b. involve all relevant groups (children/adolescents, schools, parents, community and stakeholders in a particular setting) as well as encourage the interaction among these groups (Chillon et al., 2011a), and

  c. focus on promoting ATS rather than using a broader focus such as general health programs to improve diet and physical activity behaviors in children and adolescents.
4. The quality of the ATS intervention studies should be improved. Some recommendations for achieving this goal are listed here:
   a. If possible, conduct randomized-controlled trials, including the school as the unit of randomization.
   b. Recruit a representative sample of participants.
   c. Use a theoretical model to explain the design and evaluation of the intervention studies, such as socio-ecological model (Sallis et al., 2006).
   d. Measure variables that may be moderators or mediators and include them in both the theoretical framework and the statistical analysis. For example, distance from home to school, which is the strongest correlate of ATS, should be accounted for as a mandatory confounder in the analysis and should be considered when defining the targeted sample for the ATS intervention. The inclusion of mediators allows examining other effects of the intervention in addition to the main outcome (e.g., ATS), such as the parental or children's safety perceptions, the children's confidence to cycle to/from school, or the children's social support.
   e. Use of valid and reliable tools for assessing ATS is highly recommended, including (1) standard questions to self-report school travel behaviors (Herrador-Colmenero et al., 2014; Chillon et al., 2017) asking about the mode and frequency of each mode of transport to and from school (Herrador-Colmenero et al., 2019) and (2) objective measurements (e.g., accelerometer, pedometer, GPS) to assess the duration and intensity of the physical activity performed during the school commute time. The objective measurement of school transport behaviors is less feasible in school settings, although it will provide a quantification of the school transport behaviors allowing researchers to differentiate the amount and intensity of the physical activity during the school commute time.
   f. In the multi-centre intervention studies, data should be analyzed using the multi-level analysis (e.g., level 1: participant; level 2: school; level 3: city; and level 4: country) to account for school clustering.
5. The overarching aim of the ATS intervention studies is to achieve a modal shift and reduce the rates of passive/motorized transport to/

from school among children and adolescents. However, modal shifts are challenging to achieve for example, shifting from motorized transport to ATS will have significant implications for family life of many modern families. Therefore ATS intervention studies should be of longer duration (at least 1 school-year) to help families to face the potential change in their travel behaviors. In addition, the inclusion of several follow-up assessments after finalizing the intervention period will allow researchers to examine the effects of the interventions on the modal shift over a longer period of time in order to examine the maintenance of the intervention according to the RE-AIM model (Gaglio et al., 2013).

## Future research and summary

Most of the ATS studies published to date have examined walking and cycling together under the umbrella term "active transport." Although both walking and cycling are human-powered modes of transport, they are distinct behaviors with different health effects, enablers, and barriers (Mandic et al., 2017b), and hence, require different intervention approaches. One idea for promoting both walking and cycling to/from school throughout the school years may be to design and implement a progressive teaching program where the contents to promote walking may be an initial strategy for younger children (i.e. in primary schools) and the contents to promote cycling may be an advanced strategy for older children and adolescents (i.e., in middle and secondary schools).

In addition, most previous studies examining correlates and benefits of ATS have been conducted in developed countries and mostly in urban areas, whereas research in less developed countries and in rural settings has been scarce. Future research should be extended to those different contexts, such as Asia, Africa, and Latin America and rural settings. Knowledge gained from such studies will provide a comprehensive understanding of the enablers and barriers to ATS and may help to design future context-specific interventions.

Taken together, the future interventions should include multiple strategies such as preparation, promotion, programs, policies, and physical projects and involve schools, parents, community and skateholders. In addition, the future school-based ATS interventions must be of higher quality to obtain valid results, including the definition of an underlying theoretical model, the assessment of potential mediators and mediators, the use of valid and reliable tools to assess ATS, and the use of multi-level analysis.

*In summary*, the prevalence of ATS is low and has been declining in recent years in many developed countries. Benefits of ATS include increased physical activity and improved fitness (for cycling only), while evidence on the impact on healthy body weight is currently inconclusive. In addition, ATS can contribute to independent mobility in children and adolescents and has beneficial effects on the environment. However, ATS is a complex behavior and multiple individual and environmental factors determine whether children and adolescents (and their parents) choose active or motorized transport to school. The ATS intervention studies conducted to date mostly targeted children and focused on walking to school. Those studies were heterogeneous with respect to the location, scope, sample size, and type of ATS-related interventions. However, most intervention studies showed improvements in the rates of ATS following the intervention period. Future ATS research should examine walking and cycling to/from school as distinct modes of transportation, focus on less developed countries and rural areas, and include higher quality ATS intervention studies.

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PART IV

# Tools and design

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CHAPTER THIRTEEN

# Intervention studies in transport and emerging evidence

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## Contents



This chapter critically discusses recent literature on built environment interventions and their impact on active travel. Its aim is to assess the current state of the research field, including methodological and data availability issues affecting the quality of the evidence. It covers key challenges, the growing use of epidemiological methods, and the potential for new data sources (such as "Big Data") to increase knowledge. It ends by suggesting pathways for future research to improve the quality of future evidence.

The focus is on built environment interventions while referring in passing to literature on individually delivered and/or "behavior change" interventions such as the provision of cycle training. Given the physical activity benefits, it concentrates on "active travel" (primarily, walking and cycling). This does not mean that public transport is wholly excluded. The nature of public transport means it can be an important motivator for engaging in active travel (predominantly, short walking trips to bus stops or rail stations).

Much cross-sectional literature examines built environment factors correlated with levels of walking and cycling. This evidence does suggest that good active travel environments and destination proximity are associated with more walking and cycling, but questions about causality remain (Fraser and Lock, 2011; McCormack and Shiell, 2011; Kaczynski and Henderson, 2007). For walking, with its relatively short range, the presence of local destinations is seen as particularly important for functional trips. While the presence of local "trip attractors" is indeed associated

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with more walking, it is plausible that those people who are already more disposed toward walking might choose to live in locations with many facilities close by, such as city center locations.

Other evidence covers characteristics of street or neighborhood environment qualities that are thought to make walking or cycling more attractive, such as wider footways or cycle tracks. Given the greater choice of destinations enjoyed by cyclists (with its longer range compared to walking), this research tends to focus on cycling; at least outside those places with very poor pedestrian environments, such as frequent absence of sidewalks/footways. The evidence generally suggests reasonable consensus around what constitutes a "good" walking or cycling environment (Blečić et al., 2016; Aldred et al., 2017a). For cycling, we find that people say that they want to cycle away from motor traffic, with cycle tracks separated from motor traffic seen as better than riding on-road in busy traffic.

However, this evidence often uses somewhat outdated methods. Much of it was conducted when online surveys were in their infancy and hence does not use video or even images to present alternatives. This means that we cannot be sure that people understand the same environment by the phrase "off-road cycle track" or "on-road cycle lane." But more fundamentally, expressing a preference carries no guarantee that fulfilling that preference will lead to a change in behavior. People may like the idea of there being more trees on their local streets, for instance, and this may encourage them to say, if asked, that more street trees would encourage them to walk. Or perhaps they might think that people who cycle to work must arrive in sweaty sportswear, and hence if asked, might say that showers and changing facilities would make them more likely to cycle. In neither case can we be confident that the preference expressed will be reflected in actions.

This concern exists even for those relationships having the most convincing "stated preference" evidence, such as cycle tracks. In stated preference surveys, people in low-cycling countries such as the United Kingdom tend to rank separated cycle tracks highly among changes that would make them more likely to cycle. It seems plausible that many people cycle in The Netherlands primarily because of a supportive environment, of which high-quality cycling infrastructure forms a key part (Pucher and Buehler, 2008). However, even so, we cannot necessarily assume that introducing aspects of a Dutch cycling environment will lead to rises in cycling. In the United Kingdom, post-war Stevenage was built with a Dutch-style network of cycle tracks accompanying its new roads.

However, in a UK context in which car culture was becoming dominant, building cycle tracks in Stevenage failed to stem a mode shift to driving similar to that seen in the rest of the country.

The transport situation in many rich countries is very different now from that in the post-war period. Rather than an explosion, we are seeing stagnation in car use, with some cities seeing decline, and a growing interest in active travel. But the problem remains. In urban contexts, increasing space or priority for active travel will often involve reducing space or priority given to cars. Greater disincentives to car use are associated with greater uptake of active travel; thus a combination of car restraint and active travel infrastructure is likely to be more successful than either on their own (Panter et al., 2013). Yet vociferous opposition combined with a broader public skepticism about change makes it often extremely hard to implement built environment measures that are interpreted as involving restrictions on car use (Aldred et al., 2017b). This is aggravated by the intense controversy that is associated, in particular, with pro-cycling changes in lower cycling contexts, where cycling is often stigmatized (Castillo-Manzano and Sánchez-Braza, 2013; Aldred, 2019).

Recently, we have seen a rise in intervention studies (such as longitudinal studies) and systematic reviews assessing these (Kärmeniemi et al., 2018; Smith et al., 2017), helping to fill the gap. In general, studies find the expected associations or no associations, although more and better studies are still needed, particularly for walking infrastructure (Stappers et al., 2018). Studies have found active travel infrastructure to have a greater impact on people living in households without a car (Goodman et al., 2014a), although there are still knowledge gaps related to associations between demographic characteristics, infrastructure, and uptake. Preference studies find differences in the strength of preferences expressed for "good" improvements; for instance, cycling infrastructure separated from motor traffic is perceived as particularly important by women and those cycling with children (Aldred et al., 2017a; Aldred, 2015). Walking research has similarly highlighted potential differences in perception in low-income areas, including related to microscale factors that may be related to (perceived) risk of crime (Sallis et al., 2011). However, we still know relatively little about how these may (or may not) translate into differential uptake associated with different built environment interventions (Mölenberg et al., 2019).

Transport and health agendas have come together in recent years, at an academic and a policy level. While public health is interested in any physical activity, it is increasingly recognized that our best hope of reducing dangerously high levels of physical inactivity is to build active travel into everyday life, rather than it being a separate activity that people must take time out of their lives to complete. Conversely, transport authorities are increasingly seeing health as a core part of their remit, such as the "Healthy Streets" approach developed by Transport for London (Fairnie et al., 2016). However, different disciplinary traditions have implications for what we value and measure, hence debates over what counts as evidence continue.

Transport and health fields have different traditions within which to view monitoring and evaluation. Within transport, monitoring and evaluation have traditionally depended on estimating or measuring impacts on car users, usually time savings, to the exclusion of issues from environmental damage to pedestrian delays (Beukers et al., 2012). This focus has in recent years been challenged. Many cities are seeking to improve walking and cycling infrastructure, and hence to increase levels of walking and cycling. However, they are frequently obstructed (or at least not helped) by traditional planning tools. While these offer much sophistication in assessing motor traffic throughput along links and junctions, they provide little sophistication in estimating how schemes might affect walking and cycling uptake.

Transport authorities often conduct their own monitoring of active travel schemes, and they or their consultants report on outcomes. When evaluated by academic standards, such research (understandably) suffers by comparison to "gold standard" evidence. Known issues include the lack of longer term follow-up, a lack of control sites, or comparators. This is crucial because weather affects walking and cycling levels, so without some comparator, a year-on-year change in active travel might simply be due to changes in weather. Sometimes, organizations use count data as a measure of new trip generation, whereas it could simply represent diversion (Aldred and Croft, 2019). Much of the academic transport literature uses a "case study" approach where good (or occasionally bad) practice examples are described and analyzed in depth. While often providing useful in-depth insight into policy packages and discourses (Gössling, 2013), this approach does not lend itself to evaluating and generalizing about the impacts of specific interventions.

Rising interest in active travel interventions and uptake among public health researchers has led to the identification of a range of potential biases associated with existing gray or academic literature that evaluates interventions (Yang et al., 2010). Reviews find that much of this evidence base tends to use lower quality study designs (Scheepers et al., 2014). However, adopting medical standards of evidence may not always be appropriate for built environment interventions, with randomized controlled trials generally not feasible. The researcher is usually unable to control allocation of individuals into groups, whereas this may be possible[1] for individual- or organizational-level interventions (for instance, provision of cycle training, or workplace measures). Political barriers frequently affect the introduction of built environment changes, with residents often aware of new interventions well before they happen, whether through official consultation processes or controversy and local press coverage (Aldred et al., 2019).

While not necessarily a bad thing (knowing that a new facility exists is likely to be part of its pathway to impact), this does make traditional quality measures such as blinding participants to their treatment group inappropriate. Avoiding the "placebo effect" has traditionally been fundamental to design of medical and public health interventions: but what might a "placebo effect" even mean in the context of built environment? If we can better understand "what matters" for walking and cycling uptake, we would be better placed to develop study designs that can separate this from any "placebo"-type impacts; if indeed, the "placebo" concept proves useful for the field. We might instead want to talk about a distinction between direct benefits from changes to infrastructure or facilities, and behavior change induced through broader cultural processes, whereby people are influenced by (hearing about) such changes, which send a signal that active travel is important. Such wider cultural change may happen over time and in a more diffuse manner than direct, potentially more immediate impacts (Aldred and Jungnickel, 2014), but may equally be a crucial aspect of how change happens.

Another issue affecting the interdisciplinary evidence base relates to the outcomes that are valued in different fields. While both public health and transport planning are interested in active travel, they are likely to prioritize different objectives. For transport planning, end goals are generally transport-focused. While some interventions may primarily improve conditions for existing cyclists or walkers (Skov-Petersen et al., 2017), this may not constitute a failure for the transport authority, as a key part of their remit is to improve journey ambiance for travelers (albeit this has

[1] Although not usually done, as transport authorities may not appreciate the value-added of randomizing and staggering introduction of such measures.

been poorly measured for active travel in the past). However, often a key end goal is reduction of car-driver trips; and sometimes, cities fear abstracting from public transport (Fishman et al., 2015), especially as they frequently fund and/or run extensive public transport systems. By contrast, from a public health perspective switching medium length trips from bus + short walk to cycling might create substantial benefits, due to the increased physical activity.

These different areas of interest lead to different methods for measuring behavior change. Transport planning has traditionally relied on travel diaries to measure the use of different modes, and thus transport-focused studies often use subjective measures. These travel surveys tend to focus on walking or cycling for a purpose or to a destination, rather than purely for pleasure or leisure (e.g., walking the dog in a park). Public health literature is more skeptical of self-reported physical activity (Arnott et al., 2014), due for instance to recall concerns. The extent to which the use of subjective or objective measurement matters will vary. Travel diaries are likely to be more reliable for recording cycling and main mode walk trips than for short walks made as part of multistage trips; which some travel surveys do not even seek to capture. Subjective recall of physical activity is likely to be worse than of travel.

Use of objective measurement, either through ordinary operation of a smartphone or specific apps, looks increasingly promising for measuring the use of different modes (Zhou et al., 2016; Safi et al., 2016; Shafique et al., 2016). This has been found to be less accurate for measuring the amount of physical activity (Orr et al., 2015) compared to bespoke devices (Rosenberger et al., 2016), which while more traditional are more expensive and can mean higher participant burden. Measurement accuracy is however improving (Donaire-Gonzalez et al., 2013, 2016), and the existence of "big data" opens a door to conducting large-scale studies by piggybacking onto data collection for other purposes (e.g., health and fitness apps), if ethical and access issues can be resolved. A recent article (Heesch and Langdon, 2016) suggests that aggregated data such as that from the Strava app (packaged for city use as Strava Metro, as a proprietary, paid-for product) can help one to evaluate the impact of specific infrastructure changes, while they are less useful for making broader inferences on change across a region, due to differential take-up. Such data has been recently used to estimate the impact of new cycle infrastructure in Glasgow (Hong et al., 2019). Increasingly, government bodies are using mobile phone data to study journey patterns, with the Spanish INE statistical institute recently announcing plans to use data from three mobile phone operators to replace a travel survey not carried out since 2007.

While randomised controlled trials (RCTs) may not be appropriate for built environment interventions in general, epidemiological methods are increasingly contributing to their evaluation. Natural experiments are increasingly used to study various types of intervention, including those related to cycling and walking environments (Sun et al., 2014). By treating an intervention as an experiment to be evaluated using a control (unexposed) and intervention (exposed) group, the method offers a quasiexperimental approach that can allow us to distinguish between impacts of a specific intervention and changes due to other factors. A major weakness is that because individuals are not randomly allocated to control and intervention groups, differences may exist beyond the presence of the intervention. This is very possible given potentially controversial interventions where—for instance—political support may shape where changes do or do not happen.

One fundamental challenge relates to how we characterize and define interventions. City authorities often brand interventions or use ill-defined terms to describe them; for instance, as "cycle superhighways," "complete streets," "bicycle boulevards," or "traffic calming," terms often then also used in academic literature. All are somewhat amorphous and may represent very different route environments or interventions even in the same city, let alone in different cities, countries, and regions. In the London, United Kingdom, case, a cycle superhighway might mean a wide one- or two-way cycle track separated from motor traffic and pedestrians; a designated route along side streets; a painted cycle lane; or a shared bus lane. Similarly, in the United States, "neighborhood greenways" might involve busy or quieter residential streets, or in some cases off-road routes, while "bicycle streets" in European countries may vary substantially in motor traffic speeds and volumes, and driver behavior differences may substantially affect cycling experience.

The stated preference literature suggests that different facility types and (where routes are shared) volumes and speeds of motor traffic have very different levels of attractiveness to users (Aldred, 2015), which may translate into differences in uptake. Hence, analyzing the impacts on uptake of "London cycle superhighways," for instance, as a type of infrastructure may thus tell us relatively little about characteristics of the route environment that can increase levels of cycling. More broadly, there is often a problem with generalizability. Where studies only look at commuting, can we assume that there will be changes in other types of travel? Can we assume that results of an intervention in one region, country, or city are likely to happen in another, with a different surrounding context (e.g., different types of driver behavior and different cultural barriers to cycling)?

There is also the problem of distinguishing "carrot" (pro-active travel) and "stick" (anti-driving) interventions. Although literature often assumes that these can be separated, this may in practice be difficult. Many proactive travel interventions simultaneously discourage driving: for instance, by repurposing car parking spaces as pocket parks or cycle infrastructure. Given limited space and time, more priority for walking and cycling often means less for driving; and this may make walking and cycling even more attractive in relative terms. Research suggests that if space for cars is cut, much motor traffic will often simply disappear (Cairns et al., 1998). This "traffic evaporation" may be made up of a range of behavior modifications; from changing journey time, destination, or route to simply not making a trip or ordering online; to combining trips differently; and to shifting a trip to walking, cycling, or public transport. Yet to what extent, for instance, do wider footways in themselves increase uptake (if they do) by comparison with the reduction in motor traffic that is entailed by the increased space for walking?

A further challenge is that often interventions are multifaceted; indeed, policy-makers are recommended to introduce multifaceted interventions (Winters et al., 2017) as more likely to succeed. A possible response is to define intervention areas widely, which has the benefit of making the use of existing data easier; whether through administrative data or new big datasets. Using secondary data can substantially reduce study costs and enable the analysis of more data than could be typically collected through a new longitudinal study, hence facilitating the analysis of interaction effects, a current evidence gap (Mölenberg et al., 2019). Disadvantages are the inability to discriminate between specific interventions and that existing data may not well measure travel behavior. In a UK-based study, town-wide cycling initiatives were evaluated using administrative data from the decennial Census, completion of which is mandatory (Goodman et al., 2013). This provided (changes in) travel-to-work data for almost the entire population. However, the data only relates to commuting (less than one in five of all trips) and uses a "habitual behavior" question; although the resulting measures correlate well with those derived from travel surveys.

There is a further challenge of identifying a population exposed to an intervention, given travel is often *to* somewhere (and yet that "somewhere" can potentially change for many types of trip, as people may change for instance where they shop). Studies often use distance from home address to specific interventions, such as new cycle routes or walking/cycling infrastructure (Goodman et al., 2014b; Heinen et al., 2015), but the impact of distance may vary depending on location of key destinations. For instance, a route from suburbs to center might have the highest impact in the middle, if most trips are headed toward the central area. It may be less useful for those who live in a central area and do not need/wish to journey to the suburbs, or for those living in the far suburbs for whom the trip to the center is too far to cycle. A single distance measure implicitly assumes that these differences do not matter.

A study of London "mini-Holland programmes" (Aldred et al., 2019) in three boroughs (municipalities) used a subjective approach to exposure, asking local stakeholders in each borough to define "high-dose areas" (repeated annually) within their borough, where they thought that interventions might have a direct impact on travel behavior. This allowed analysis to draw on expert knowledge of how, for instance, a new route might serve some areas through which it passed better than others (for instance, because of the differing quality of existing infrastructure to which the route connected). The study found an increase of 41 minutes weekly active travel (mostly due to increased walking) after 1 year among those living in the high-dose area. However, there was no statistically significant increase among those living within low-dose areas in intervention boroughs where no local changes had been made. Hence, there seemed to be a clear impact associated with specific built environment changes, rather than simply from the broader borough-level program in general (e.g., through borough-wide publicity or promotion).

Despite all the methodological challenges, the natural experiment approach does provide a possible model for how public health approaches can be adapted for use in studying the built environment. Studies have advanced the evidence base by providing better evidence around causality than that which can be delivered through cross-sectional studies, case study research, and stated preference studies. They are not the only useful studies, and they need to be supplemented, including by innovative qualitative work, and by attempts to develop more rigorous classifications of intervention typologies and their likely effects. Other work needs to be done to strengthen the underlying models shaping our understanding of travel behavior (Ahern et al., 2017). Much work relies on an assumption that intention precedes action; however, a recent study of behavior change during the London Olympics found that over half of those who were not considering making a change did go on to do so (Parkes et al., 2016). We need to do more to investigate longer term shifts in shopping patterns (for instance) that may be set in train by disruptions, and potential unintended consequences of interventions (for instance, is increased safety sometimes at odds with increased perceived safety?)

More in-depth, qualitative research about responses to interventions could, in turn, help one to shape how and what we measure. Length of follow-up is currently often relatively short even in academic studies, and yet changes in infrastructure might take some time to reveal their ultimate impacts. The London study of "mini-Holland schemes" referred to previously (Aldred et al., 2019) found no change in car use after 1 year, suggesting that increased active travel represented additional journeys, rather than having replaced car travel. However, after 2 years within specific high-dose areas changes were found (Transport for London, 2018). Perhaps, people initially increased active travel trips without cutting car use (e.g., more local leisure walking) but over time this settled down and new active travel trips replaced some car trips. However, without qualitative investigation into these changes, it is difficult to understand these trajectories and how they might vary.

Research could usefully do more to explore and separate the possible impacts of different components of the built environment that affect walking and cycling. Given the variety of factors affecting how, when, and where we travel, this is hard, especially given cross-cultural variation in design of different aspects of the street environment. However, there is a role here for relatively low-cost preference-based research. Asking people what types of environment they would prefer to walk or cycle in does not necessarily tell us about take-up. It might, however, allow us to better understand what components of a walking or cycling environment are perceived as more or less important, and why, by different subgroups and in different contexts. This, in turn, can allow a more systematic approach to categorizing and evaluating interventions. The use of visual material (from computer-generated photos to video clips) within online or computer-assisted surveys means that such research can be done in a much more sophisticated manner than in the past, where people were simply asked their views on "a cycle lane" (Ghekiere et al., 2018).

Finally, more work could be done considering evidence hierarchies and the extent to which medical research models could and should be adapted to deal with transport research and policymaking. The contribution of public health disciplines has enhanced the field, highlighting the sometimes biased and/or limited nature of evidence within the transport field. But should transport research be adopting the same hierarchy of evidence to that developed within medical science? For individual-level interventions, presumed to operate independent of knowledge and belief (paradigmatically, a pill), the double-blinded RCT may represent the pinnacle of research excellence, by isolating the impact of the intervention from 'irrelevant' context.[2] Yet does the transport field, where interventions are often *not* individual-level and beliefs and perceptions are not simply bias but part of the ways in which interventions (or do not) work, need equally rigorous yet different ways of conceptualizing relationships between different factors and pathways to change?

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CHAPTER FOURTEEN

# Health impact assessment of transport planning and policy

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## Contents



## Introduction

Health impact assessment (HIA) is an important tool to integrate evidence in the decision-making process and introduce health in all policies (WHO, 1999; Ståhl et al., 2006; NAS (National Academy of Sciences), 2011). Multiple international and national organizations proposed HIA as a tool to promote and protect public health in multiple sectors (WHO, 1999; Ståhl et al., 2006; NHS, 2002; IFC (International Finance Corporation), 2009). However, HIAs, particularly quantitative ones, in transport planning are still rare.

A key driver for transport policy making are transportation investment appraisals, including cost-based appraisal schemes. These economic

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evaluations are based on economic costs or resource costs and economic benefits. These instruments are produced with a great focus on economic appraisal and an emphasis on the cost benefit analysis (CBA) method as the most reliable and most used instrument to determine whether a certain transport project is better than another. The CBA method attempts to quantify effects expected from a transport project and assign those a monetary value to include in the overall economic appraisal of the total value of the project in monetary terms. Monetized items include, for example, changes in travel times and related consumers' surplus, changes in employment and business activity and earnings, motor vehicle crashes, carbon emissions and noise impacts, and are input for a partial CBA to estimate a benefit to cost ratio (Geurs et al., 2009). As such, CBA and similar instruments *attempt* to measure all the aspects of new transport projects in terms of financial gains or costs to society, but regularly do not achieve this, as various aspects are left out because of a variety of reasons.

HIAs, that is, the assessment of health impacts of certain transport projects would be a natural component of the CBA; however, they are often not included or are overlooked to a large extent. For example, the physical activity benefits of more sustainable transport modes, such as walking and cycling, are often overlooked in CBAs, and it has been only a few years that experts started thinking about including health benefits of more cycling and walking in CBAs. Realizing the critical need to account for these health benefits, the World Health Organization have now developed a tool called Health Economic Assessment Tool (HEAT) that estimates the health impacts of schemes that increase walking or cycling and can be integrated in the CBAs (http://heatwalkingcycling.org/ and see Chapter 15).

In transport planning, HIAs have been used generally to qualitatively assess the transport planning schemes rather than offering more useful/powerful and objective estimations to stakeholders through quantitative approaches (Shafiea et al., 2013). In addition, many HIAs do not entail stakeholders' and citizens' visions and necessities, losing the opportunity of successful implementation or policy utility.

Comprehensive HIAs can be an important tool as they bring together all the available evidence on the impacts of transport on health. As where qualitative approaches provide a more general impact of the potential important exposures and health outcomes, quantitative HIAs provide actual numbers of the people that may end up with disease or die prematurely. HIAs can shape policies making them healthier because they examine the impacts of health under different potential scenarios, based on the best available evidence, and provide an overview of what scenarios are associated with the least health impacts and which have the largest health impacts.

HIAs could answer various pressing questions such as follows: what are the best and most feasible transport planning and policy measures to improve public health in cities? Also, the process on how to get the estimates is often as important as the actual output of the HIA, as the process may provide answers to important questions as to how different stakeholders can effectively work together and develop a common language, how to best incorporate citizens' and stakeholders' visions, and how different modeling and measurement methods can be effectively integrated.

As it stands, the use of quantitative HIA is generally limited to research and academic purposes, and the scenarios used in these models are usually judged to be plausible but are optimistic and often not under consideration by local authorities or policy makers. This, in part, is perhaps a reflection of a communication gap between the sectors where nonacademic stakeholders lack the tools, knowledge, and interest to carry out a quantitative HIA. On the other hand, academics/researchers lack the expertise and understandings as to what extent certain scenarios are plausible, realizable, and acceptable to local authorities or policy makers. In this chapter, we focus on quantitative HIAs. The aim of the chapter is to provide an overview of what is currently being done in quantitative HIAs of transport planning and provide some examples of quantitative HIAs.

## Quantitative health impact assessment

Quantitative HIAs follow a comparative risk assessment approach estimating first the baseline/reference burden of disease (BoD) [e.g., cases of disease, premature deaths, or disability adjusted life years (DALYs)], and then comparing this BoD with the health impacts of a future change associated with a proposed intervention or policy (i.e., counterfactual scenario) (Briggs, 2008, WHO 2015, Nieuwenhuijsen et al., 2017). The aim is to provide a quantitative estimate of the expected health impact (e.g., number of cases of disease, premature deaths, and DALYs) and the distribution thereof for the exposed population that is attributable to an environmental exposure and/or policy. HIAs normally follow six steps (WHO, 2019):

1. *Screening*. Determine whether an HIA is warranted and would be valuable in the decision-making process.
2. *Scoping*. Decide on the scope of the assessment, including data sources to use, affected groups/populations to cover, likely areas of health consequences to investigate, and methodology to employ.
3. *Assessing*. Develop a health profile of the community, including baseline conditions for various health conditions, literature reviews, and quantitative methods to assess likely effects of the proposed project. Use community input to provide nuance, context, clarification, prioritizing, and reality checks to the technical partner's work who conduct the actual work.
4. *Recommending*. Generate a series of recommendations on how to optimize the health benefits and reduce the health risks of the proposed plan. To maximize the chances that they will be adopted, recommendations should be practical, taking into account constraints on decision makers.
5. *Reporting*. Produce a written report and disseminate what was learned to the community in question through varied methods, such as radio press releases, community meetings, or going door to door.
6. *Monitoring and evaluating*. Monitor implemented recommendations to see if they are working as expected. Evaluate the process itself, rate of implementation of recommendations, partnerships formed, and outcomes for health and systems over time.

Quantitative assessments of health impacts are based on combining exposure data with exposure–response information. Such assessments require (1) the compilation of exposure data, (2) a systematic review of evidence from epidemiology and other scientific disciplines concerning the association between environmental factors and human health, and (3) the combination of exposure and exposure–response information (WHO, 2019). Quantitative assessments include the following steps: (1) specify the baseline situation and counterfactual scenario(s), (2) specify the health risk to be addressed in the impact assessment, (3) specify the measure of exposure and the range of exposure to be considered, (4) estimate the population exposure distribution, (5) select appropriate health outcome(s) and determine the total burden (TB) of this health outcome among the population under study, (6) select exposure-response relationship for the population under study from the scientific literature or available guidance, with a risk estimate that quantifies the strength of association between the health risk and the health outcome of interest, (7) combine exposure and exposure–response relationship data for each population group under consideration (e.g., by age and gender), (8) calculate the population attributable fraction (PAF) of disease(s) multiplied by the total health burden of the disease(s) (TB) under study to obtain the attributable burden (AB), and (9) quantify uncertainty of the estimate (range of potential effect).

Most epidemiological studies report a relative risk (RR) as the risk estimate of their exposure–response function (ERF), which is the ratio of incidence observed at two different exposure levels. The risk estimate is scaled to the difference in exposure level resulting of the comparison of the baseline exposure level with the counterfactual exposure level (Fig. 14.1).

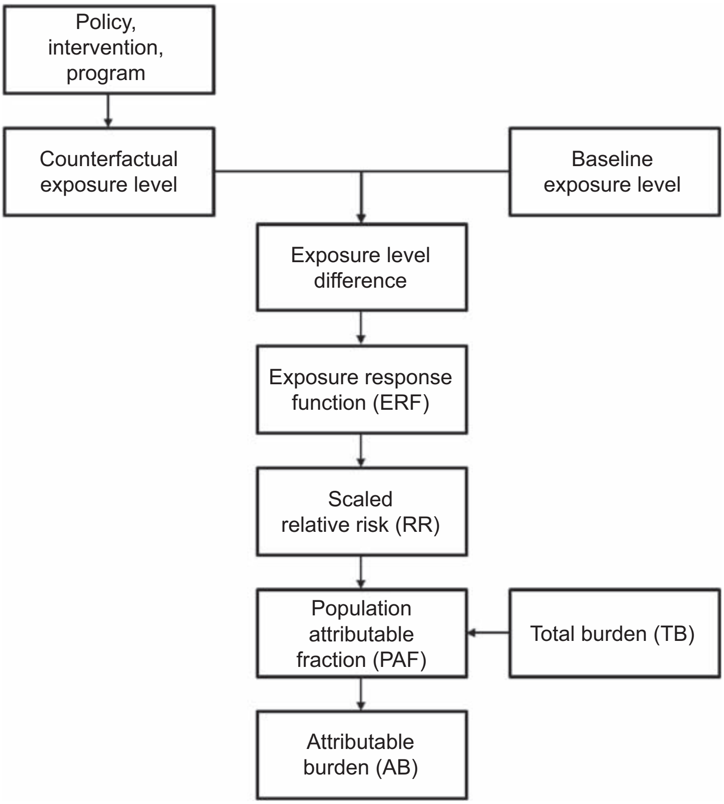


**Figure 14.1** Quantitative health impact assessment framework.

The quantitative approach is described in the following formulas:

$n$ is the number of exposure categories (e.g., census tracts, districts, and cities)

$i$ is an element of the set $i \in \{1, \ldots, n\}$

$$\mathrm{RR}_i = e^{\left((\ln(\mathrm{RR}_E)/E) \times \mathrm{ED}_i\right)}$$

where $\mathrm{RR}_E$ is the relative risk obtained from the ERF, $E$ is the exposure unit that corresponds to the $\mathrm{RR}_E$ obtained from the ERF, and

$\mathrm{ED}_i$ is the exposure level difference, which is the difference in the exposure level resulting of the comparison of the baseline exposure level with the counterfactual exposure level.The PAF defines the proportional health burden of the health outcome of interest that is attributable to exposure level difference $\mathrm{ED}_i$.

The PAF is calculated as follows:

$$\mathrm{PAF}_i = \frac{P_i \times \mathrm{RR}_i\text{-}1}{P_i \times \mathrm{RR}_i}$$

where $P_i$ is the proportion of exposed population and $\mathrm{RR}_i$ is the previously scaled relative risk.The AB describes the TB of the health outcome of interest that is attributable to the exposure level difference $\mathrm{ED}_i$.

The AB is calculated as follows:

$$\mathrm{AB} = \sum_{i=1}^{n} \mathrm{TB}_i \times \mathrm{PAF}_i$$

where $\mathrm{TB}_i$ is the total burden of the health outcome of interest and $\mathrm{PAF}_i$ is the previously calculated proportional health burden of the health outcome of interest that is attributable to the exposure level difference $\mathrm{ED}_i$.

After the estimation of cases of disease or deaths, if the stakeholders request, the health estimates can be translated into a different BoD measures. The most common BoD measure in HIAs are DALYs which combines in one measure the time lived with disability and the time lost due to premature mortality. The following formulas describe how DALYs can be estimated:

$$\mathrm{DALY} = \mathrm{YLL} + \mathrm{YLD}$$

where YLL is the years of life lost due to premature mortality and YLD is the years lived with disability.

The YLL corresponds to the number of deaths multiplied by the standard life expectancy (from the geographical location) at the age at which death occurs. The basic formula for calculating the YLL for a given cause, age or sex, is

$$\text{YLL} = N \times L$$

where $N$ is the number of deaths and $L$ is the standard life expectancy at age of death (in years).

To estimate YLD on a population basis the number of disability or disease cases is multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). The formula for YLD is

$$\text{YLD} = I \times \text{DW} \times L$$

where YLD is the years lived with disability and $I$ is the number of incident cases, and DW is the disability weight, $L$ is the average duration of disability (years)

In general, DALYs, YLL, and YLD can be included as a unit of result in quantitative HIAs. These BoD units are especially useful for policy comparisons, that include different causes of death and different disease diagnoses. The BoD gives the stakeholders a unit of comparison that summarizes mortality and morbidity, comparing different diagnosis, and helping them to understand in a more comprehensive manner the magnitude and direction of a specific intervention, plan, program, or policy. The main disadvantage of these measures (DALYs, YLL, YLD) is their difficulty to be interpreted for nonhealth practitioners, such as transport or urban planners, who are, in most cases, the final audience of the HIA.

Furthermore, when input is obtained from stakeholders including, for example, citizens and businesses, we refer to the HIAs as being participatory HIAs. Participatory HIAs have the advantage that make use of much wider views on urban and transport besides the "expert" and, if integrated well, may result in a wider support for any proposed measure.

## Examples of urban health impact assessment studies

Here, we provide a number of examples of quantitative HIAs which showed the health benefits or risks of different (hypothetical) transport planning initiatives. McKinley et al. (2005) quantified cost and health benefits from a subset of air pollution control measures (taxi fleet renovation, metro expansion, and the use of new hybrid buses replacing diesel buses) in Mexico City. The authors found that the measures reduced air pollution by approximately 1% for $PM_{10}$ and 3% for $O_3$. The associated health benefits were substantial and their sum over the three measures was greater than the measures' investment costs (benefit to cost ratio was 3.3 for the taxi renovation measure; 0.7 for the metro expansion measure and 1.3 for the new hybrid buses measure). Woodcock et al. (2009) estimated the health effects of alternative urban land transport scenarios for two settings: London, United Kingdom and Delhi, India. The authors found that a combination of active travel and lower emission motor vehicles would give the largest benefits (7439 DALYs in London, 12,995 in Delhi). Creutzig et al. (2012) provided scenarios of increasingly ambitious transport policy packages, reducing greenhouse gas emissions from urban transport by up to 80% from 2010 to 2040. Based on stakeholder interviews and data analysis, the main target was a modal shift from motorized individual transport to public transit and nonmotorized individual transport (walking and cycling) in four European cities (Barcelona, Malmö, Sofia and Freiburg). The authors reported significant concurrent cobenefits of better air quality, reduced noise, less traffic-related injuries and deaths, increased physical activity, alongside less congestion and monetary fuel savings. Ji et al. (2012) compared emissions ($CO_2$, $PM_{2.5}$, $NO_x$, HC) and environmental health impacts (primary $PM_{2.5}$) from the use of conventional vehicles, electric vehicles (EVs) and electric bikes (E-bikes) in 34 major Chinese cities. E-bikes yielded lower environmental health impacts per passenger km than gasoline cars ($2\times$), diesel cars ($10\times$), and diesel buses ($5\times$). Perez et al. (2015) modeled various scenarios in Basel including particle emission standards for diesel cars, increase in active travel and EV introduction. The authors estimated that the first measure would result in a reduction of premature mortality by 3%, the second one would have little effect and the third one would have the largest effect, as the electricity would come from renewable resources. Xia et al. (2015) estimated that the shifting of 40% of vehicle kilometers traveled to alternative transport in Adelaide, South Australia, would reduce annual average $PM_{2.5}$ by a small margin of 0.4 $\mu g/m^3$; preventing 13 deaths a year and 118 DALYs. Stevenson et al. (2016) estimated the population health impacts arising from alternative land-use and transport policy initiatives in six cities. Land-use changes were modeled to reflect a compact city in which land-use density and diversity were increased and distances to public transport were reduced with the objective to reduce private motorized transport and promote a modal shift to walking, cycling, and public transport use. The modeled compact city scenario resulted in health gains for all cities modeled.

There are also larger number of studies that have evaluated specific transport policy measures in cities. A range of HIA studies evaluating mortality and other health impacts of increases in active transport were recently reviewed and estimated considerable reductions in premature deaths and other negative health outcomes with most benefits attributable to increases in physical activity and low risks of motor vehicles crashes and air pollution for those who switched to public and active transport (Mueller et al., 2015; Tainio et al., 2016). In a large European study, Mueller et al. (2018) conducted a HIA of cycling network expansions in 168 European cities. The authors modeled the association between cycling network length and cycling mode share and estimated health impacts of the expansion of cycling networks. First, they performed a nonlinear least square regression to assess the relationship between cycling network length and cycling mode share for 167 European cities (Fig. 14.2). Then, they conducted a quantitative HIA for the seven cities of different scenarios (S) assessing how an expansion of the cycling network [i.e., 10% (S1); 50% (S2); 100% (S3), and all-streets (S4)] would lead to an increase in cycling mode share and estimated mortality impacts thereof. They quantified mortality impacts for changes in physical activity, air pollution, and traffic accidents. Third, they conducted a cost-benefit analysis. The cycling network length was associated with a cycling mode share of up to 24.7% in European cities. The all-streets scenario (S4) produced greatest benefits through increases in cycling for London with 1210 premature deaths (95% CI: 447−1,972) avoidable annually, followed by Rome (433; 95% CI: 170−695), Barcelona (248; 95% CI: 86−410), Vienna (146; 95% CI: 40−252), Zurich (58; 95% CI: 16−100), and Antwerp (7; 95% CI: 3−11). The largest cost-benefit ratios were found for the 10% increase in cycling networks (S1). If all 167 European cities achieved a cycling mode share of 24.7% over 10,000 premature deaths could be avoided annually. In European cities, expansions of cycling networks were associated with increases in cycling and estimated to provide health and economic benefits.

Most models have been static (e.g., no feedback loops) and thus insensitive to feedback loops and time delays. Few exceptions emerge in the literature, such as the work of Macmillan et al. (2014). These authors used

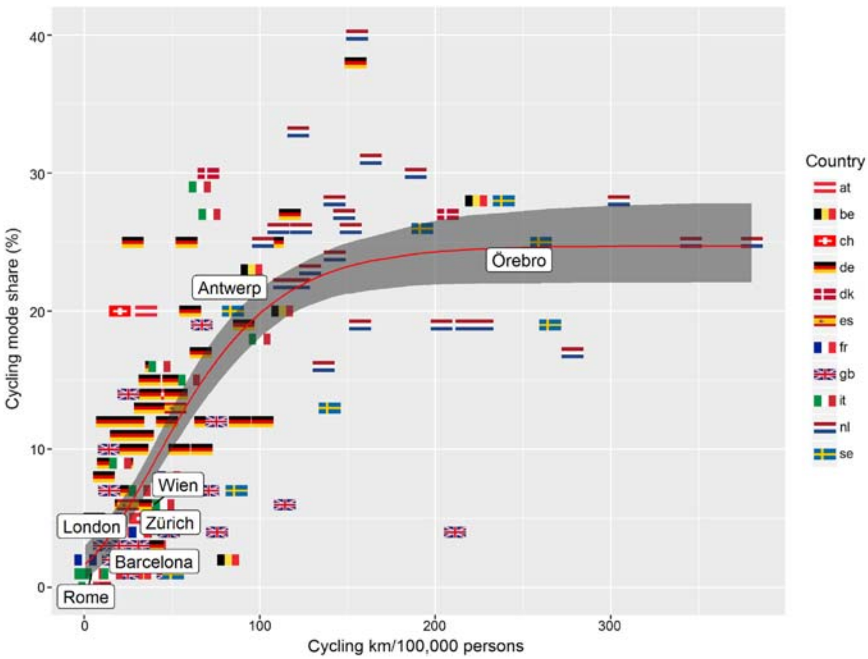


**Figure 14.2** The relationship between cycling lane infrastructure and mode share of cycling in European cities.

participatory system dynamics modeling (SDM) to compare the impacts of realistic policies, incorporating feedback effects, nonlinear relationships, and time delays between variables in a study on cycling and societal costs including those related to health impacts. Participatory SDM involves citizen, academic, and policy stakeholders in a process that explores the dynamic effects of realistic policies (Richardson, 2011).

Finally, there is a general lack of integrated full-chain HIA models. In integrated full-chain HIA modeling for urban and transport planning, the work considers the full-chain from exposure source, through pathways to health endpoints, considering multiple exposures and complexities, interdependencies and uncertainties of the real world, and often examining multiple scenarios (Fig. 14.3).

Full-chain models are important for policy making as the contribution of different sources to the overall environmental exposures is often unclear and is highly variable depending on source and context. For example, car traffic contributes to a significant proportion of ambient air pollution in cities, but the extent varies depending on factors such as car density, car fleet make-up, traffic conditions, street design, city design, and dispersion

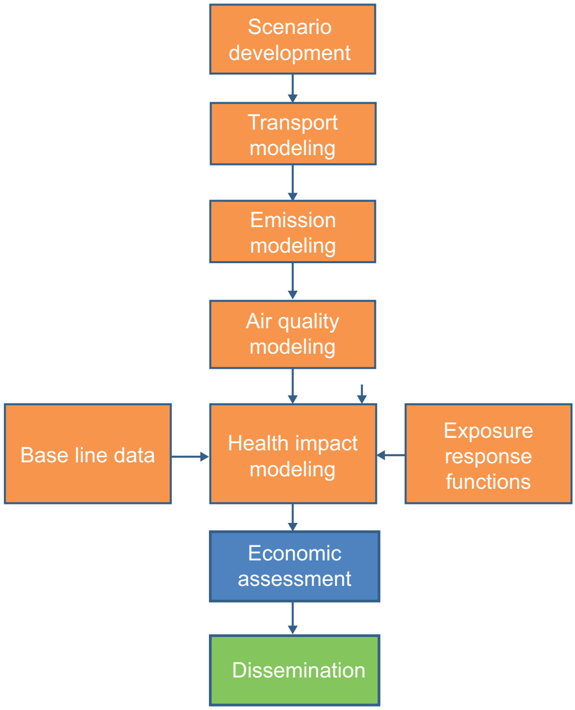


**Figure 14.3** Full-chain health impact assessment with an example for air quality.

factors (e.g., wind speed and direction and cloud cover). Traffic contribution to urban $PM_{10}$ and $PM_{2.5}$ levels in Europe are on average 39% (range 9%–53%) and 43% (range 9%–66%), respectively, and are up to 80% for $NO_2$ (Sundvor et al., 2012).

To improve understanding and target the right sources with the right mitigation policies, it is important to understand the full-chain of events from sources, through pathways to health, but very few have done so. For example, in the case of air pollution exposures, the common lack of full-chain assessment limits disentangling the health impacts of traffic-related air pollution (TRAP) from the health impacts of other emission sources, and vice versa (Khreis et al., 2017). It also limits the comprehensibility of, and confidence in, recommending fleet specific and traffic planning or management specific interventions which would be valuable and desirable for policy makers.

Full-chain assessments could be obtained by coupling existing models of source activity, source emissions, and pathways of exposure, to predict final human exposures and associated health impacts. Again, in the case of

TRAP, as an example, this can be done by integrating existing models of traffic activity, traffic emissions, and air dispersion to predict air quality and people's exposure and subsequently estimate associated health impacts (Fig. 14.3). Data on traffic counts, origin and destination zones and fleet composition can be used to construct traffic activity models for cities (Van Vliet, 1982; SATURN Manual, 2015). The outputs from traffic activity models, most importantly the traffic flows and average traffic speeds on the road network of interest, are then linked with vehicle emissions models such as the European leading emission model known as COPERT (Gkatzoflias et al., 2007). Vehicle emission inventories are calculated from this data and are then entered into air dispersion models such as ADMS-Urban (McHugh et al., 1997), which uses this data alongside terrain, meteorological and boundary layer data, to estimate seasonal and/or annual air pollution concentrations in cities.

Studies which undertake this full-chain assessment, however, are very few (e.g., Namdeo et al., 2002; Hatzopoulou and Miller, 2010; Wang et al., 2016). Often, such assessments can be problematic as the referred to models are data and labor intensive and also require expertise from different scientific disciplines. These models are also not easy to obtain or run due to their high commercial prices, their complex set-ups and the occasional need for specific arrangements such as dedicated UNIX workstation. Furthermore, there are challenges regarding the performance and accuracy of the multiple models used in the exposure assessment chains. Traffic activity models such as SATURN, which are used to provide input data for emission models, tend to underestimate congestion and over predict the average traffic speeds over the road network lending inaccuracy to the final emission estimates which are generally higher at the lower average speeds due to frequent stops and starts. Vehicle emission models, especially at lower average speeds which incorporate significant proportions of high emitting, fuel consuming, stop-start driving, are uncertain (Health Effects Institute (HEI), 2010; Khreis, 2016) and tend to underestimate TRAP emissions. Air dispersion models can over or under predict air pollution levels, in part due to inaccurate traffic and emission inputs, but also due to inherent limitations in these models (Williams et al., 2011) and the incompletion and/or inaccuracy of input data, including meteorological data. This causes a propagation of uncertainties and inaccuracies through a complex chain of models involved and is a problem which implications are not fully understood and is not yet addressed in practice and policy.

## Existing models

There are already a few quantitative HIA models and tools that have been used in specific case studies, for example, the HEAT for walking and cycling (Chapter 15), the Integrated Transport and Health Impact Modeling Tool (Woodcock et al., 2009), the Transportation, Air pollution and Physical Activities model (Rojas-Rueda et al., 2012), the Blue Active tool (Vert et al., 2019), and the Urban and TranspOrt Planning Health Impact Assessment model (Mueller et al., 2017). Except for HEAT, these tools and models still tend to be research tools that are being further developed and improved but have the potential to be used in practice. The way these studies have been performed also shows how multidisciplinary teams of academics, both from qualitative and quantitative backgrounds, can take the process through all its phases.

## Citizen and other stakeholder involvement

HIAs could be conducted just by experts, but changes in transport planning and policy are difficult to achieve and sustain without direct support of politicians, decision makers, and citizens. Therefore it is desirable, if not necessary, to involve stakeholders in the process, that is, conduct participatory HIAs. There is a considerable body of literature that stresses the importance of citizens' participation in improving planning and decision-making in a number of aspects and today participation is recognized to be a fundamental requirement for sustainable development and environmental decision-making (Banister, 2008, Linzalone et al., 2016).

However, the overall implementation of participatory approaches within HIA is not widespread, particularly not in quantitative HIA. The literature reports only a few studies in which stakeholders have been consulted during HIA (e.g., Kearney, 2004; Creutzig et al., 2012; Macmillan et al., 2014; Linzalone et al., 2016), among which only very few used participatory methodologies in combination with quantitative assessments. For example, Linzalone et al. (2016) integrated a quantitative HIA based on epidemiological study of plausible causes of mortality and morbidity with the Agenda21 methodology for participation, based on focus groups and meetings with community stakeholders all along the process. With this methodology the authors prepared the terrain for new forms of HIA to overcome the barriers between various forms of technical knowledge and this local knowledge. Following this, it is clear that there is a need for citizens and stakeholder participation in HIA, especially those parties with vested interest that may be affected by the proposed or investigated scenarios. We advocate for it, being, however, aware that participation can have its shortcoming and can be not as effective as expected especially when lacking adequate time and resources or when not specifically addressing power unbalances and communication issues (Elvy, 2014).

In HIA, citizens and stakeholder participation should occur in the selection of the scenarios, identification of health effects and vulnerable populations, selection periodization of recommendations, identifying the best channels of dissemination and monitoring and evaluation (Table 14.1). Particularly important is to include more vulnerable groups such as those with low socioeconomic status, children, pregnant women, and the elderly who all have their specific needs and are more susceptible. More and more often, new kind of citizen participation, as citizen's science, have begun to offer new tools to assess and include the citizens' perspective in the public health arena.

New models of HIA need to take advantage of these innovative citizens' participation approaches to improve the utility, social acceptance, and impact of their results. As such, the HIA process is capable of build dialogue among different sectors and actors and avoiding to reproduce the pattern in which the use of quantitative HIA is limited to academia settings. Incorporating other views can indeed enhance the understanding of how plausible, realizable, and acceptable scenarios developed by HIA practitioners are and whether authorities would ever consider them for implementation.

## Challenges

HIAs encounter many challenges in terms of data availability and assumptions that need to be made and are sensitive to the contextual setting and underlying population parameters. Some of the main problems conducting quantitative HIAs on a city level are the lack of baseline data for some of the exposures and health outcomes, the implied need to make assumptions of these parameters, and how to deal with and best

**Table 14.1** General description of examples of transport policies/interventions/scenarios that could be modeled using health impact assessment.

| Policy area | Description | Types | Examples |
|---|---|---|---|
| Land-use planning | Land-use systems that increase density, diversity of uses, and connectivity | Density | Compact cities |
| | | Diversity | Increase horizontal land-use |
| | | | Increase vertical land-use |
| Public transport | Investment in and provision of transport network space for rapid transit/public transport infrastructure | Infrastructure | Improvement and increase of public transport infrastructure |
| | | Management | Improve public transport service |
| | | | Reduce public transport costs |
| | | Promotion | Public transport promotion |
| Active transport (walking and cycling) | Investment in and provision of transport network space for pedestrian and cycle infrastructure | Infrastructure | Improvement and increase of active transport infrastructure |
| | | Management | Improve active transport service |
| | | Promotion | Active transport promotion |
| Traffic regulation | Reduce car use | Infrastructure | Reduce public space for cars (car lanes and parking) |
| | | Management | Road use an parking pricing |
| | | Promotion | Promote alternative modes of transport |
| Vehicles and fuels | Invest in new technologies and fuels | Infrastructure | Create city grid for electric vehicles |
| | | Management | Technology and fuels pricing |
| | | Promotion | Promote technological transitions (e.g., electric car or autonomous cars) |
| Traffic safety | Engineering and speed reduction measures to moderate the leading hazards of road transport | Infrastructure | Built environment changes to reduce speed |
| | | Management | Speed regulations |
| | | Promotion | Traffic safety campaigns |

quantify uncertainty. Furthermore, there may be a lack of good exposure—response relationship data. Previous models and tools have been solving these challenge accessing input data through multiple official databases from public entities, identifying information on health, exposures and population. What stands out is also the importance of developing a comprehensive search strategy for input data, from different data sources, languages and time periods, and also the importance of data quality assessment and final comprehensive models' validation and in the case of full-chain assessments, the need for models' validation at each step. The input data identification is without doubt one of the most important steps in the quantitative HIA process and cannot be achieved without a close collaboration with the stakeholders. The participation of different stakeholders, approached with a variety of methods and participatory tools, is crucial for the identification of specific and high-quality data.

With regard to epidemiological input data on the ERFs, performing a systematic review of the literature will be the key point for identifying the most robust evidence to quantify the attributable health impacts. Quantitative HIA have limitations in assessing the complexity of real policies or scenarios, mainly because of the unavailability of the needed amount of quantitative evidence and the difficulty in projecting far into the future, limiting the results of a quantitative HIA to those exposures and outcomes that can be quantified. Quantitative HIA can highlight these limitations and also be combined with qualitative HIA, so as to generate recommendations able to involve and inform the stakeholders in a broader dimension.

A further challenge is how to make models accessible and readily available, so that they can be used outside the research community by practitioners and policy makers. Only in this way we can ensure that HIAs have the needed wide uptake in cities across countries. Simplification without losing the essence may be the answer and this is, for example, the approach in the PASTA project (Gerike et al., 2016). Similarly, models that are coupled with qualitative evidences and built with the collaboration of stakeholders might have wider impact on the policy realm and as such be more easily disseminated across different actors and cities, becoming best practice in the process of policy transfer and policy learning.

Finally, most of the work so far has been done in high-income countries. There is a need for this type of work outside high-income countries, where urbanization rates are the highest, where there is the greatest BoD related to noncommunicable diseases and where many cities are in the process of being shaped leaving room for timely interventions. This also brings forward specific challenges because often there is a real lack of data to conduct this work in low and middle-income countries (Gascon et al., 2016), in combination with a lack of vision on the future health necessities and the lack of governance and institutional strength. Yet, at the same time low- and medium-income regions and countries have a real opportunity ahead, to improve and consider public health in the urban and transport development, avoiding the mistakes made by developed countries.

## Uncertainty

An important issue in undertaking and communicating HIAs is how to deal with uncertainty. Uncertainty may occur when conceptualizing the problem, during analysis and/or while communicating the results (Briggs et al., 2009). Much focus has been placed on characterizing and quantifying the uncertainty in analysis, and various statistical methods have been developed to estimate analytical uncertainties and model their propagation through the analysis (Mesa-Frias et al., 2013). As described before, transport, emission, and air quality modeling each have their uncertainties, and these are propagated through the chain. Validation and uncertainty assessment is needed at every stage but is rarely conducted. On the other hand, larger uncertainties may be associated with the conceptualization of the problem, that is, the scenarios building and communication of the analytical results, both of which depend on the perspective and viewpoint of the observer (Briggs et al., 2009). Therefore more participatory approaches to investigation, and more qualitative measures of uncertainty, are needed, not only to define uncertainty more inclusively but also to help those involved better understand the nature of the uncertainties and their practical implications (Briggs et al., 2009).

## Conclusion

HIA of transport projects and planning practices can potentially suggest transport scenarios and future visions that are better for health. The field is still growing, but there are already quite a number of studies out there. In practice, qualitative HIAs are more prevalent while in research circles quantitative HIAs are generally conducted. Bringing the practitioner and research sectors together and promoting the application of mixed methods of qualitative and quantitative HIA approaches would be optimal to improve communication, consider more viewpoints, and finally improve public health outcomes of transport projects. Further improvements are needed, for example, through the development of participatory full-chain quantitative HIA methods, models, and tools to improve evidence-based decision-making and to obtain and implement the most feasible and acceptable transport policy measures to improve public health.

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CHAPTER FIFTEEN

# The WHO health economic assessment tool for walking and cycling: how to quantify impacts of active mobility

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## Contents



## The health economic assessment tool for walking and cycling: rationale and development process

Next to many positive effects on societies, transport also has a range of negative effects, including air pollution, crashes, congestion, and noise

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and emission of greenhouse gases. Environment and health impact assessments are a standard feature of transport planning processes in many countries. However, until about 15 years ago these assessments did not include the positive health effects from regular physical activity provided by walking and cycling. On the one hand, this is likely due to a bias in the transport system that tended to focus more on motorized transport, not recognizing cycling and walking as equal modes. On the other hand, the quantification of the health effects of physical activity in general and of cycling and walking in particular is a relatively recent field of research. Evidence on the substantial positive health effects from regular walking and cycling has been accruing only over the last two decades (Andersen et al., 2000; de Hartog et al., 2010; Kelly et al., 2014; Götschi et al., 2016; Dinu et al., 2019). Thus the importance of promoting such forms of everyday physical activity beyond more classic, sport-related approaches to address the mounting burden of inactivity became more and more recognized by international policy frameworks on physical activity (WHO Regional Office for Europe, 2015) as well as on environment and health (WHO Regional Office for Europe, 2010; United Nations Economic Commission for Europe and WHO Regional Office for Europe, 2014). In recent years the political developments around sustainable development, climate change, and the New Urban Agenda (United Nations, 2016) have promoted greater interest among policymakers, particularly at the urban level, in the so-called "cobenefits." These result from policies that promote cycling, walking, and public transport, given their potential to reduce emissions of air pollutants and greenhouse gas while reducing the risk of noncommunicable diseases (World Health Organization, 2016). Most recently, 3 out of 20 policy objectives in the Global Action Plan on Physical Activity adopted in 2018 addressed aspects related to transport planning policies, walking and cycling infrastructure (World Health Organization, 2018).

However, to achieve changes in the physical environment to encourage walking and cycling, partnerships with the transport and urban planning sectors are required. Thus providing practical guidance for transport and urban planners on how to integrate the health benefits from regular physical activity has been seen as a promising route to foster collaboration and to make cycling and walking "visible" in discussions related to policy options for urban transport and urban development. This has led, however, to the emergence of many questions that transport and urban planners were not well equipped to answer. For example, which health endpoints should be included in an assessment? Which relative risks could be used? How do we quantify the health benefits of walking and cycling? Are these benefits out-weighted by the risks posed by cycling or walking in a polluted environment, and/or by the risk of road traffic fatalities?

In response to this need, in 2007 the WHO Regional Office for Europe started a project to develop methodological guidance and eventually, a practical tool for transport and urban planners allowing the inclusion of physical activity benefits in transport appraisals. Four main project phases have been completed to date:

- 2007–10: methodological guidance on assessing the health benefits of walking and cycling (Cavill et al., 2007) and development of a practical, Excel-based assessment tool for cycling (HEAT 1.0) (Rutter, 2007), which was launched in 2009 along with a summary and user guide (Cavill et al., 2008a);
- 2010–11: development of health economic assessment tool (HEAT) for walking and launch of online versions for walking and cycling (HEAT 2.0) (Kahlmeier et al., 2011);
- 2013–14: update of the relative risks and the background values used for the economic valuation in the online version (HEAT 3.0) (Kahlmeier et al., 2014), and discussion of options to include the negative effects of air pollution; and
- 2014–17: development of modules on air pollution, crashes and carbon emissions and move to a new development platform (HEAT 4.0) (Kahlmeier et al., 2017).

In carrying out these steps the HEAT process adheres to an agreed set of key principles:

- scientifically robust and based on the best available evidence
- as user-friendly as possible
  - minimal data input requirements
  - availability of default values
  - clarity of prompts/questions
  - design and flow of the tool geared to maximize usability
  - fully transparent regarding the assumptions and approaches taken
- based in general on a conservative approach to avoid overestimation whenever possible
- adaptable to local contexts
- modular

The main goal of the HEAT project led by the WHO Regional Office for Europe was to equip transport planners across the WHO European Region with often limited capacities, resources and access expertise and data sets with a robust yet user-friendly tool, requiring minimal data input and providing default values wherever possible. This distinguishes HEAT from other, more sophisticated impact assessment tools (Woodcock et al., 2013). Until today, as a minimum to run a simple impact assessment of the effects of a given amount of cycling or walking on total mortality, HEAT requires only two quantitative input values, the volume of walking or cycling to be assessed and the number of people carrying out this level of walking or cycling.

Coordinated by WHO, steered by a core group of multidisciplinary experts, and supported by ad hoc invited international experts, the HEAT project follows a standardized, iterative process to address methodological updates and new features of HEAT (see Fig. 15.1).

When a new functionality is considered, the core group first agrees on directions of work and main research questions to address. If necessary, a systematic review of the scientific literature is commissioned. Based on the results, options for integrating the new feature into HEAT are developed. These are discussed at regular consensus meetings, to which relevant international experts are invited. These consider the presented evidence, discuss the proposed approaches, and take a decision on the integration of a new feature or any additional work needed. The consensus meeting also agrees upon any assumptions taken and/or default values offered. Afterward, the core group implements the decisions, and functionality and usability are tested before a new HEAT version is launched.

Throughout the HEAT development, systematic reviews have been carried out on economic transport approaches, including a health component (Cavill et al., 2008b), on health effects of walking and cycling (Kelly et al., 2014) and on air pollution exposure while walking and cycling, compared to other modes of transport (de Nazelle et al., 2017). Furthermore, scientific publications include the initial methodological approach (Rutter et al., 2013), HEAT for cycling applications (Kahlmeier et al., 2010), a discussion paper on the approach to deriving road fatality rates for cycling and walking (Castro et al., 2018) and the latest methodological update of HEAT version 4.0 (Götschi et al., in press).

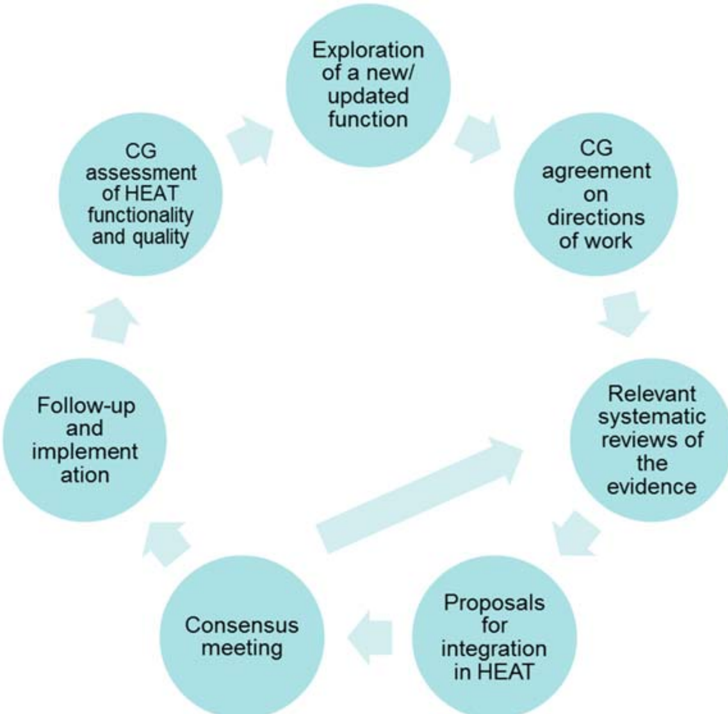


**Figure 15.1** Development process of the HEAT. *CG*, Core group; *HEAT*, health economic assessment tool. *Courtesy of WHO Regional Office for Europe. Kahlmeier, S., Götschi, T., Cavill, N., Castro, A., Brand, C., Rojas Rueda, D., et al., 2017. Health Economic Assessment Tool (HEAT) for Walking and for Cycling. Methods and User Guide on Physical Activity, Air Pollution, Injuries and CarbonImpact Assessments. WHO Regional Office for Europe, Copenhagen.*

## Overview of the tool

HEAT answers the following main question:

*If x people walk/cycle an amount of y on most days, what is the economic value of the health benefits that occur as a result of the reduction in mortality due to their physical activity?*

In addition to the benefits of physical activity, HEAT can now also consider how much road crashes and air pollution affect these results, and what the effects on carbon emissions are.

The tool can be used for several types of assessment, for example,

- assessing current (or past) levels of cycling or walking, such as showing the value of cycling or walking in a city or country;
- assessing changes over time, such as comparing before-and-after situations or scenario A versus scenario B (such as with or without measures taken); and
- evaluating new or existing projects, including calculating benefit−cost ratios.

Users can access HEAT at www.heatwalkingcycling.org. An assessment comprises five steps that are shown in Fig. 15.2 and described next. More details can be found on the HEAT website (www.euro.who.int/HEAT) and in the latest methodology and user guide (Kahlmeier et al., 2017).

In step 1, HEAT users define their assessment by selecting the active travel mode (cycling, walking, or both) and geographical scale (national, city, or subcity level) of interest, and whether data are available on a comparison case (e.g., in a before-and-after assessment) or not (in which case the entered values are compared with a hypothetical case of no walking or cycling). They also select which impacts they want to consider in their assessment (physical activity, air pollution, crashes—currently in cyclists only—or carbon emissions through trips shifted from motorized modes to walking or cycling).

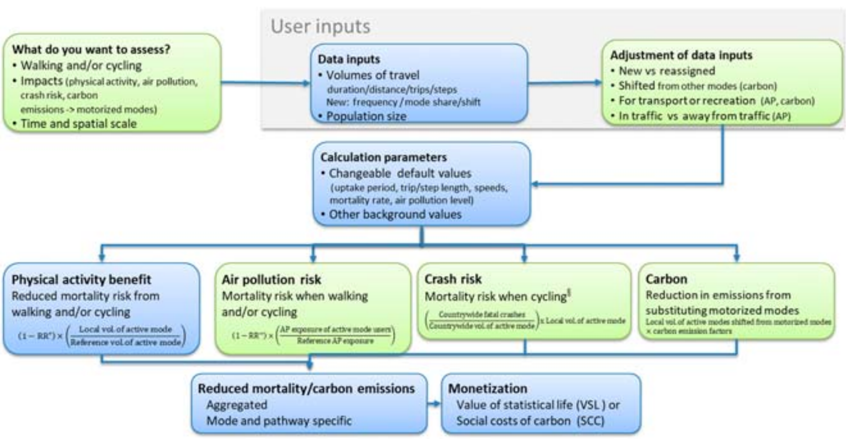


**Figure 15.2** Basic functioning of the HEAT for walking and cycling (dark grey, assessment steps of previous HEAT versions; light grey, additional assessment steps of HEAT 4.0). *HEAT*, Health economic assessment tool.

Based on these entries, HEAT selects default values for all-cause mortality, for parameters related to carbon emissions, air pollution levels and road fatality rates, and the economic valuation, as appropriate. For the economic valuation, HEAT uses the value of a statistical life (VSL) method for the mortality impacts, which estimates the overall economic value to society of reduced premature mortality based on the willingness-to-pay approach. For carbon emissions the social cost of carbon approach is used for the economic quantification, which can be defined as the monetized value of the worldwide damage caused by the incremental impact of an additional tonne of carbon dioxide equivalent (CO2e) emitted at a specific point in time.

In step 2 the two main parameters are entered: the amount of walking and/or cycling and the number of people in the assessed population. Travel volume data can be entered as duration (minutes or hours), distance (kilometers or miles), trips, steps, modal share, frequency, or location-based counts. By selecting the type of data source from which the walking and/or cycling data were derived, different entry options appear. For example, data could come from a national travel survey or from local roadside counts. This selection is important for correctly interpreting the entered volumes of walking and cycling. Next, users can define if the data apply to an average-aged population (i.e., for HEAT calculations 20–74 years for walking and 20–64 years for cycling) or if younger or older adults predominantly carry out the walking or cycling assessed. As HEAT has been designed to assess long-term average walking or cycling behavior, risk reduction available from the HEAT physical activity module is capped at 45% for cycling and 30% for walking to avoid inflated values (Kahlmeier et al., 2017).

In step 3, users are asked to provide additional information on the mode(s) being assessed to adjust the data for the selected calculations of impact. This includes, for example, temporal and spatial adjustment of walking or cycling data entered to consider any under- or overestimation from such factors as seasonal or spatial variation, the proportion of reassigned trips that merely follow a different route to now take place on a new infrastructure and are thus not considered in the assessment, or the proportion of active travel carried out in traffic versus away from major roads, in parks etc. to correctly assign air pollution exposures. For each possible adjustment, a default value is provided, based on literature, recommendations of the consensus meeting and/or expert knowledge.

In step 4, HEAT users are shown an overview table of all default and background values and data entries to review and to change, as appropriate. While the "default" values may be changed if more suitable local data are available (such as the mortality rate, the cycling speed or the VSL), the "background" values have been set by the expert advisory group according to the best information currently available and thus cannot be changed. These include, for example, the relative mortality reductions from cycling or walking (adjusted for other forms of physical activity) and the increased risk from air pollution exposure.

In the last step the HEAT results are shown, summing up the positive and negative health impacts across all selected pathways as well as effects on carbon emissions, and as detailed results by mode and pathway. Outputs include the number of premature deaths prevented, the sum of the economic value of effects on mortality (using the VSL), tonnes of emissions of CO equivalents avoided, and the related economic value (using social costs of carbon). Discounted values are also shown, as well as a cost—benefit ratio, if cost figures for a specific intervention have been inputted.

## Health economic assessment tool applications: overview and practical examples

Since its launch as an online tool in May 2011, the HEAT website has been visited about 85,000 times by over 55,000 visitors. The average session duration is over 5 minutes, which allows for the completion of a simple assessment. About 25% of visitors were from the United Kingdom, followed by the United States (14%) and France (7%).

A survey carried out in 2015 (Cavill and Kahlmeier, 2016) revealed 92 documented applications of HEAT, including

- 51 reports,
- 28 academic papers and abstracts,
- 14 government papers/guidance reports, and
- 7 websites.

In 2016 a systematic review of economic analyses of active transport interventions that included physical activity benefits found that over 50% of studies published after its inception had used HEAT

(Brown et al., 2016). HEAT has also been included in official national guidance in England, the United Kingdom and Sweden. It is promoted by national governments in Austria, Finland, and France.

Next, three practical applications of HEAT in different settings are presented to illustrate possible uses and ways of disseminating the results.

## Toledo, Spain: health economic assessment tool assessment supported the building of a bike path

Toledo, a Spanish city of around 83,000 citizens aimed to build a new cycle path from the city center to an adjacent neighborhood, linking it to the train station, the biggest commercial center in Toledo, a new hospital and other social locations. It was estimated to cost about €400,000. As part of an EU project, the health benefits of the path were quantified with HEAT, assuming different levels of usage (Cavill et al., 2017). Data were taken from a travel survey carried out in 2010 on trips between the old town and the Santa Mª de Benquerencia neighborhood. It was assumed that cyclists would ride on average on 124 days/year (as recommended in HEAT when using short-term data) and that 90% of people would make a return journey.

The results were as follows:

- Achieving a 5% shift of trips made by public transport or private car to bicycle from the city center to the Santa Mª de Benquerencia neighborhood would lead to a reduction in mortality valued at €222,000 per year. This resulted in a benefit−cost ratio of over 5:1.
- Achieving a 10% shift would lead to a reduction in mortality valued at €444,000 per year. This results in a benefit−cost ratio of over 11:1.
- Achieving a 20% shift would lead to a reduction in mortality valued at €888,000 per year. This results in a benefit−cost ratio of over 22:1.

While the value of the reduced mortality appeared to be relatively low, the benefit−cost ratios are persuasive because they are calculated over 10 years. While the cost of building the path is a one-time expenditure, the mortality benefits recur every year as people continue using the path.

After observing these results the project leader remarked, “These HEAT estimations have allowed the Castilla-La Mancha regional government to reinforce the arguments for the promotion of active mobility projects. The HEAT health message can be added to the environmental messages that cycling helps reduce energy consumption, improves air quality, reduces noise, and improves well-being."

The building of the bike path was approved in 2018.

## Using health economic assessment tool to explore health and spatial equity implications of the New York City bike-share system

While HEAT has been developed for the European context, supplying default values for the 53 countries of the WHO European region, it is possible to use particularly the physical activity, air pollution, and cycling crash modules outside the European context by replacing the most important values, including particularly the mortality rate and the VSL. This is also demonstrated by the relatively high usage in the United States, as discussed earlier.

In this application, HEAT was used to quantify the benefit of cycling associated with annual bike-share system members (Babagoli et al., 2019). At the launch in May 2013 the Citi Bike system in New York City included 335 bike share stations and approximately 5400 bicycles, which were concentrated around the central business districts of Lower Manhattan and adjacent parts of Brooklyn. In 2015 the system was expanded to adjoining neighborhoods, with an additional 176 stations installed. In August 2015 there were approximately 7300 bicycles available. As HEAT was designed for habitual cycling behavior, only membership and trip data for annual Citi Bike members were included into the calculation, using averages of real-world data for annual members for each of 12-month time periods.

Annual Citi Bike members took an average of almost 21,000 trips per day during 2013, and over 30,000 trips per day during 2015, a 43% increase. The average trip duration increased by 1.24 minute between the two time periods, with trips in 2015 averaging 14 minutes. The number of annual Citi Bike members increased by 1% (about 95,000 vs 96,000). HEAT estimated an annual effect of two premature deaths prevented in 2013, increasing to three premature deaths prevented in 2015 (taking into account the negative effects of air pollution and cyclist crash fatalities, using locally derived data). Using a US standard value for the VSL of $9.2 million, the economic value of the level of cycling in 2013 amounted to approximately $18.8 million per year, raising to $28.3 per year with the 2015 usage figures.

The authors also compared the Citi Bike station distribution by census tract poverty to assess spatial equity implications. They found that in both in 2013 and 2015, respectively, the highest proportion of bike stations were located in low-poverty census tracks (41% in each phase). In 2015 only 16% were in very high–poverty census tracks, a statistically nonsignificant change from 12% in 2013. To assess the effect if Citi Bike reached residents from higher poverty neighborhoods, the calculation was repeated with the usage figures of 2015 and the higher death rates of the high- or very high–poverty census tracks. Now, five-to-six premature deaths would be prevented, leading to an annual economic value of $45.5–$58.5 million per year, respectively, and thus significantly greater than the effect of the increased usage of the Citi Bike system between 2013 and 2015.

Authors concluded that the results "underscored the mortality benefit effect of such active transportation infrastructure" (Babagoli et al., 2019). The results also demonstrated the importance of examining spatial equity in the planning and expansion of bike-share systems.

### Sweden integrates core aspects of health economic assessment tool into the country's own assessment tool

The Swedish Transport Administration (STA) has been involved in the development of WHO/Europe's health economic assessment tool (HEAT) since the first HEAT consensus meeting in 2007. Since 2008 the STA has also recommended the use of HEAT in its own national transport impact assessment tool GC-kalk (Swedish Transport Authority, n.d.). This tool gives guidance for the economic assessment of pedestrian and cycling infrastructure investments and promotion.

GC-kalk contains the core aspects of HEAT. The current 2015 version uses the updated figures from the latest version of HEAT. In addition, the STA has made one interesting modification to the HEAT methods: when computing future benefits, the STA takes into consideration the annual growth rate of cycle traffic. The STA also uses a VSL with an annual increase equivalent to the annual increase of real income.

## Conclusion and future developments

HEAT is a widely used, practical tool that has fostered the recognition of the importance of taking into account health effects when planning transport infrastructure interventions (Brown et al., 2016). Its clear, continous development process, and evidence-based approach, has supported its acceptance, along with the ambition to provide a user-friendly tool requiring minimal data input. However, assuming wide-spread use of HEAT from the available web statistics, it is most often applied without informing the HEAT core team or any publicly available written report, limiting documented impact on policy decisions. Further improving usability, simplifying language used, clarifying guidance on data entry, and adding further background information and instructions remain a continuous task for the maintenance of HEAT.

Provided project funds become available, HEAT is continuously further developed. Supported by the World Health Organization Headquarters and the European Region Office, currently the accommodation of North American and other non-European use cases (with less default values provided) is underway. In another project the inclusion of bike-sharing data is being developed with the support of the WHO Regional Office for the Americas (Pan American Health Organization).

Possible future developments include the discussion of ways to include morbidities without unduly increasing the level of complexity of applying the tool. Further possible expansions include injuries from road crashes or more refined handling of age and population data.

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## Disclaimer

The authors alone are responsible for the views expressed in this chapter, and they do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated.

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CHAPTER SIXTEEN

# Incorporating health impacts in transportation project decision-making in the United States

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## Contents



## Introduction

Transportation can enhance exposure to air pollution and noise, increase traffic injuries, and contribute to physical activity, all of which can impact health. In addition to these direct impacts, transportation has been suggested as one of the 10 social determinants of health according to the World Health Organization (WHO) (Wilkinson and Marmot, 2003). This is not surprising as transportation planning and design can significantly influence accessibility to opportunities (i.e., jobs, education,

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recreation, and even health care), social interactions, and level of equity in a community in addition to the direct pathways mentioned earlier. Overall, the connection between transportation and health is well-known and has led to significant global efforts that document best practices and provide recommendations for community design and transportation policies that improve health.

The Organization for Economic Cooperation and Development (2012) has emphasized the need for compact city development that has positive impacts on accessibility, air quality, equity, and physical activity, and consequently health and has documented compact development strategies and policies as implemented around the world. In addition, the WHO has been a primary force behind efforts for healthy transportation options.

The World Health Organization/Europe (2019) has developed methods and tools, including the health economic assessment tool, which can be used to assess health impacts of increased active transportation and motivated its members to consider the impact of policies on health and sustainability. Additional efforts in Europe have materialized through the Transport, Health, and Environment Pan-European Programme, which is the outcome of a collaboration between WHO/Europe and the United Nations Economic Commission for Europe. This program is targeted at motivating governments to craft policy that improves transportation sustainability. In 2009 European governments signed the Amsterdam Declaration (World Health Organization/Europe, 2009) making an explicit commitment to address health and safety in transportation in addition to improving sustainability.

In the United States (US), several programs and grant opportunities exist that are targeted at improving health, some of which are related to transportation [e.g., the Center for Disease Control (CDC) State Physical Activity and Nutrition and the Racial and Ethnic Approaches to Community Health programs]. Health has also been considered in recent transportation bills [i.e., Fixing America's Surface Transportation Act (FAST Act) (United States Department of Transportation, 2016), Moving Ahead for Progress in the 21st Century Act (MAP-21) (Federal Highway Administration, 2012), Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (Federal Highway Administration, 2005)] through language referring to environmental protection, funding targeted at transit, bicycle, and walking-related projects as well as research funding on health effects, and programs addressing safety concerns often of vulnerable users (e.g., Safe Routes to School) (United States Department of Transportation, 2015).

At the same time, planning requirements at the federal level dictate that state departments of transportation (DOTs) prepare 20-year statewide long-range transportation plans. The two most recent transportation bills, MAP-21 (Federal Highway Administration, 2012) and FAST Act (United States Department of Transportation, 2016) require that plans are performance-based, utilizing performance measures and specific targets for those measures when prioritizing projects and making funding decisions. This has motivated multiple efforts at the state and regional levels to develop score-based decision-making frameworks over the past 10 years. Unfortunately, performance-based assessment of transportation projects as related to many determinants of public health is often missing or is indirectly accounted for (e.g., congestion reduction or air quality—related criteria).

One of the first attempts to ensure a health focus in decision-making at the state level in the US was the Healthy Transportation Compact of the 2009 Transportation Reform Bill. This was an interagency agreement between Massachusetts Departments of Transportation and Public Health, Executive Office of Health and Human Services, and Executive Office of Energy and Environmental Affairs that includes the incorporation of health in planning decisions among other objectives (Commonwealth of Massachusetts, 2009). This legislation also produced a directive that mandates the development of methods to assess transportation project impacts on health with the use of health impact assessments (HIAs). The follow-up Healthy Transportation Directive in 2013 has contributed toward the goals of incorporating health in transportation decision-making by requiring consideration of healthy transportation modes (i.e., walking, bicycling, and taking transit) in all Massachusetts DOT projects while accounting for the health aspects of the communities these projects serve, including environmental justice (EJ) (Massachusetts Department of Transportation, 2013).

The Virginia DOT introduced new legislation in 2014, the Virginia House Bill 2, which enabled them to develop a project prioritization process, currently referred to as System Management and Allocation of Resources for Transportation: Safety, Congestion, Accessibility, Land Use, Economic Development and Environment (SMART SCALE) (Virginia Department of Transportation, 2018). Even though not initially developed to directly address health disparities, many of the project scoring criteria do address health outcomes, for example, accessibility and safety.

At the regional level the Nashville Area Metropolitan Planning Organization (MPO) was one of the first MPOs in the US to recognize the connection between transportation and health and proceed with six actions targeted at addressing adverse health outcomes through transportation. One of those has been updates on their project scoring criteria to incorporate quantitative assessment of health impacts (Meehan and Whitfield, 2017).

Globally, there is an understanding of the interconnections between built environment, transportation, and health and the need to address health disparities through better design. As a result, public health and transportation agencies have performed HIAs and are continuously updating their decision-making frameworks to incorporate criteria related to health outcomes. This chapter first discusses the limited applications of HIAs for actual decision-making in the US and then focuses on project scoring and prioritization frameworks adopted by state DOTs and MPOs in the US as well as the level of health impacts they currently incorporate. Project scoring and prioritization frameworks for capacity expansion or enhancement, mainly for highways is emphasized, although some frameworks developed specifically for active transportation projects are also discussed. The chapter concludes with challenges and future research needs associated with incorporating health in transportation decision-making.

## Health impact assessment as a decision-making tool

HIAs assess the health impacts of policies, plans, and projects related to transportation, energy, housing, and other economic sectors through stakeholder input as well as various tools and models (World Health Organization, 2019; McAndrews and Deakin, 2018). HIAs have been systematically implemented worldwide in an effort to influence decision-making by informing stakeholders on anticipated health-related impacts of projects and policies under consideration, and encouraging public participation to ensure inclusion of relevant health issues in the assessment.

HIAs have been conducted for transportation-related projects to understand the source and full extent of health outcomes related to policy, plans, and projects, incorporating numerous overlapping direct and indirect mechanisms. These HIAs use health (e.g., mortality, morbidity, disability-adjusted life years, qualitative quality of life descriptions) or economic (e.g., income, availability of goods) metrics to measure health outcomes, allowing for the true costs and benefits of a project to be more readily assessed. HIAs often make use of specialized models and tools such as those related to transportation planning, air pollution, noise, accessibility, and health impacts as well as qualitative research reviews for outcomes of local concern (e.g., public safety). HIAs are advantageous compared to transportation health impact models, such as the Health Economic Assessment Tool, because they are capable of considering a greater and more flexible variety of exposure pathways and parameters (National Research Council, 2011).

## Health impact assessments in the international scene

Australia has been implementing HIAs since the early 1990s and has been leading efforts in the inclusion of equity as part of such assessments (Harris and Spickett, 2011). The European Union has long recognized the utility of HIAs. In 2004, the European Commission contracted the WHO and the national health departments of several member nations to produce the European Policy Health Impact Assessment, a document summarizing guidelines for effectively performing HIAs of EU policies (Abrahams et al., 2004). Notably, HIAs have been incorporated in Europe's Health in All Policies initiative, improving its visibility as an effective tool for assessing health outcomes and emphasizing the need for institutionalizing such efforts (Koivusalo, 2010). At the same time, many European countries have established regulations, policies, or other types of endorsement to support HIAs (World Health Organization, 2007). In some countries such as Australia, Canada, New Zealand, and Thailand, HIAs have been incorporated in Environmental Impact Assessment legislation (Dannenberg et al., 2006). In the developing world, motorization-related health impacts have been recognized as a public health crisis, spurring interest and support for the use of HIAs (Mahendra et al., 2014).

Many HIAs that have been conducted have been transportation focused; a review of 88 HIAs in Europe, Asia, and Africa revealed that 18% of those were transportation related (Davenport et al., 2006). The main objective of HIAs is to influence decision-making; however, a common thread among HIA performance assessments worldwide is the limited documentation of actual impacts on decision-making often due to the lack of a comprehensive documented process for monitoring such impacts (Davenport et al., 2006). Studies have found that between 37% and 48%

of HIAs performed in the US, New Zealand, Australia, and Europe have led to changes in decisions (Dannenberg, 2016), but not all of those are related to transportation projects, plans, or policies.

## Health impact assessments in the United States

In the US, transportation HIAs are primarily voluntary efforts (McAndrews and Deakin, 2018), but in some cases they have also been performed to support Environmental Impact Assessment processes or other processes required by laws or regulations; however, being mandated by law is a rare occurrence (Dannenberg et al., 2014). Transportation HIAs have more commonly been completed for projects than for plans or policies (Cole et al., 2019). The first law-mandated HIA was the Seattle SR-520 Bridge Replacement (Dannenberg et al., 2014). Since then, only Massachusetts has signed legislature (i.e., Healthy Transportation Compact) to institute HIAs as part of transportation decision-making (Dannenberg et al., 2014), which led to the Grounding McGrath Highway HIA (Massachusetts Department of Public Health, 2013). The CDC has long encouraged and supported HIAs through their programs by providing funding and supporting integration of health outcomes in transportation decision-making (Center for Disease Control and Prevention, 2016). In addition to the CDC, strong funding support for HIAs has been provided by foundations such as the Robert Wood Johnson Foundation and the Pew Charitable Trusts (Dannenberg et al., 2014).

Similar with HIAs conducted at international locations, the intention of US-based transportation HIAs has been to influence decision-making. HIAs in the US in general have been found to influence decision-making in many cases (Bourcier et al., 2015). However, recent findings from a comprehensive review of 59 transportation HIAs in the US has revealed that this is not the case for HIAs related to transportation projects, plans, and policies (McAndrews and Deakin, 2018). Instead, transportation HIAs have been primarily successful and have most commonly been used for initiating conversations and collaboration between the public health and transportation communities, providing information on certain issues of interest, and seeking and communicating community support (McAndrews and Deakin, 2018; Dannenberg et al., 2014). Another characteristic of transportation HIAs in the US is that they are often initiated and funded by public health agencies, rarely by transportation and planning agencies or grassroots efforts (i.e., the public) (McAndrews and Deakin, 2018).

Despite the high percentages of HIAs influencing decision-making worldwide, the level of influence varies from tangible changes in decisions to generally improving awareness of health issues and collaborations between stakeholders from different sectors; in some cases, HIA impacts are ignored (Dannenberg, 2016). In the US there are only a few HIAs that have successfully achieved direct impacts on plan development and decision-making in transportation. Such examples include the Atlanta BeltLine Transit, Parks, and Redevelopment Project and the Clark County Bicycle and Pedestrian Master Plan HIAs.

### The Atlanta BeltLine health impact assessment

The Atlanta BeltLine Transit, Parks, and Redevelopment Project is a multi-billion dollar project targeting redevelopment as well as transit and parks improvements along a 22-mi railway segment (Ross et al., 2012). An HIA was performed for this project over a period of 2 years (2005–07). Despite the fact that there was no mandate for an HIA for this project or for the adoption of its recommendations, reported outcomes included the adoption of most priority recommendations to address health inequities and the addition of a public health professional in the project's advisory committee. The HIA also motivated additional funding of $7 million for brownfield cleanup and greenspace development. Examples of HIA recommendations that were adopted are the inclusion of connectivity (i.e., accessibility) criteria in the federal Environmental Impact Statement and Georgia Environmental Impact Reports, the prioritization of greenspace projects as the very first construction activity of the bigger project, and the development of an affordable housing policy for the project using information from the HIA. The success of this HIA in influencing decision-making can be at least partially attributed to its timing, which occurred when only the redevelopment plan and some preliminary planning had taken place. The availability of resources and a comprehensive dissemination plan, as well as collaboration between decision-making stakeholders and public health professionals also contributed to its success.

### The Clark County Bicycle and Pedestrian Master Plan health impact assessment

Clark County conducted a rapid HIA on their Bicycle and Pedestrian Master Plan in May of 2010 (Clark County Public Health, 2011). Rapid

HIAs are quick HIAs (i.e., 3–6 months) that rely heavily on already existing data and stakeholder engagement (e.g., through workshops) to assess health outcomes of proposed projects, plans, or policies. Due to the limited timeframe, Rapid HIAs often focus on a limited group of potential outcomes (Pourshaban et al., 2016). The Clark County Bicycle HIA can be considered one of the most successful Rapid HIAs in terms of influencing decision-making as it resulted in 8 out of 11 recommendations being fully adopted and the other 3 being partially adopted (Dannenberg, 2016). Example recommendations that were adopted in the Master Plan are creation of policies to improve bicycle and pedestrian accessibility to nutritious food and design for inexperienced cyclists, inclusion of equity- and health-related project scoring criteria, prioritization of projects that improve walkability, and demand management strategies that reduce automobile traffic among others. This HIA also recommended a specific geographic area as the one to be prioritized and the reported outcomes show that the majority of the prioritized bicycle projects and all of the sidewalk projects were located in the recommended area.

## Limitations of health impact assessments

The failure of HIAs to substantially influence transportation decision-making can be attributed to multiple factors. Supporting these studies often relies on one-time grants, making ongoing monitoring of health impacts difficult. Some of these projects can also take many years to complete further limiting the ability to capture the actual outcomes or even compare them with estimated impacts produced by HIAs. While HIAs can vary as of the depth of analysis from simple checklists to comprehensive studies (Dannenberg, 2016) transportation HIAs often fall in the second category. As a result, they can be time-consuming and resource-intensive (Ross et al., 2012), requiring the use of multiple models and tools, as well as extensive data collection efforts (often at very high resolutions) and tools or supplemental information needed to assess certain health outcomes (e.g., income level or perceived public safety). For example, the Grounding McGrath Highway HIA in Massachusetts utilized a travel demand model, the Federal Highway Administration Traffic Noise Model, a line source dispersion model, and implemented a pedestrian and bicycle environmental quality index survey (Massachusetts Department of Public Health, 2013).

HIAs can also be expensive with costs ranging an estimated \$100,000–\$200,000 (Cole and Fielding, 2007), further limiting their applicability for project scoring and prioritization of multiple projects, plans, or policies that are competing for the same funding. HIAs usually focus on a single local project and evaluate several design options. In limited instances, they are tied to specific programs or legislature, part of which is to perform these HIAs as pilots. The lack of institutionalized procedures requiring HIAs (McAndrews and Deakin, 2018) is a potential factor limiting their use. The lack of standardized methods as well as limited funding and availability of personnel have also been raised as key obstacles in performing HIAs (Davenport et al., 2006). Finally, given that HIA outcome evaluation and documentation are not common (Dannenberg et al., 2006), it is possible that the actual influence of many HIAs on decision-making is lost.

Institutionalization, stakeholder involvement, consistent methodologies, documentation of health impact assessment (HIA) outcomes, and adequacy of resources are critical for success in terms of influencing decision-making HIAs.

In addition to addressing these challenges engagement of stakeholders and timing of HIAs can also be critical for allowing HIAs to influence decisions. Engagement of transportation and political staff (i.e., decision-makers) and processes that are consistent with the political and administrative environment and goals have been positively associated with the likelihood of an HIA to affect decision-making (Dannenberg et al., 2014, Davenport et al., 2006). HIAs that are performed early in the decision-making are also expected to be influential in shaping project outcomes (Dannenberg et al., 2006).

## Project scoring and prioritization frameworks in the United States

### Motivation

The main motivating factor that has led many state and regional transportation stakeholders to develop project scoring and prioritization frameworks has been the need for transparency in funding allocation and decision-making, which in turn can facilitate communication of funding decisions to the public. In particular, strong interests for data-driven capital investment decisions and performance-based planning, motivated by federal regulations [e.g., FAST Act and MAP-21 (Federal Highway Administration, 2019; United States Department of Transportation, 2016)], have been key driving forces in developing project prioritization criteria at the state and regional levels in the US. These frameworks are also seen as a way to explicitly consider multiple objectives for the common good (i.e., avoid making decisions by asset type) and facilitate achieving strategic goals [e.g., California DOT (Turner, 2017)]. An interest in assessing return on investment has also been reported for states such as Massachusetts, Maryland, and Minnesota, some of which have explicitly incorporated return-on-investment criteria in their decision-making frameworks (Minnesota Department of Transportation, 2019b; Maryland Department of Transportation, 2018). Many states and regional governments utilize these frameworks specifically for prioritizing projects as part of their Transportation Improvement Program. In addition to project prioritization processes developed by state DOTs and MPOs, federally funded prioritization tools have also been developed, such as the ActiveTrans Priority Tool, which can be used to prioritize bicycle and pedestrian improvements (Lagerwey et al., 2015). This tool has been used for example for curb ramp improvement prioritization by Massachusetts DOT (Massachusetts Department of Transportation, 2017).

Transparency in decision-making has motivated the development of project scoring and prioritization frameworks.

While many of the criteria included in these decision-making frameworks can relate to health outcomes, there are certain agencies, which have been proactive in accounting for health outcomes through their project prioritization process and scoring criteria. For example, health-related project scoring criteria have been considered by the Nashville MPO for the past decade. Nashville has recently also updated their point allocation that resulted in criteria related to public health, safety, or social equity receiving 80% of the points. This was part of an effort to promote projects that maximize public health benefits (Meehan and Whitfield, 2017). In 2018 the Massachusetts DOT started updating their highway project scoring framework to explicitly incorporate health-related scoring criteria.

## Health-related project scoring

Scoring processes have been developed separately for projects based on the transportation facility or mode of interest (e.g., highway, active transportation, transit, rail, and multimodal), specific corridors of interest [e.g., Minnesota DOT's Corridors of Commerce (Minnesota Department of Transportation, 2019b), type of project (e.g., capacity expansion, modernization), impact area of project [e.g., statewide, regional, or local as in North Carolina DOT's framework (North Carolina Department of Transportation, 2018), or area within a state as is the case of Virginia DOT's SMART SCALE (Virginia Department of Transportation, 2018)].

In addition to these processes, US states have also developed project prioritization frameworks to assist with funding decisions for specific federal programs such as the State of Good Repair (Federal Transit Administration, 2016) and the Highway Safety Improvement programs (United States Department of Transportation, 2019), state programs such as Minnesota DOT’s Transportation Economic Development Program (Minnesota Department of Transportation, 2019a), or regional programs such as the Sacramento Area Council of Governments (SACOG) (2019) Active Transportation Program. These frameworks often include benefit—cost or risk analyses as for Virginia DOT’s Highway Safety Improvement Program (Virginia Department of Transportation, 2015b) or incorporate numerically scored criteria developed specifically for that program as in the case of the Minnesota DOT's Corridors of Commerce framework (Minnesota Department of Transportation, 2019b).

Criteria categories are often the same for different types of projects but the specific criteria within each category can vary. In some cases, the weighting factors or points assigned to each criterion or category vary between different types of project scoring frameworks within the same agency; for example, North Carolina DOT (North Carolina Department of Transportation, 2018) has different weights for safety for the statewide mobility, regional impacts, and division needs frameworks. There are also project scoring categories and criteria that vary significantly between project scoring frameworks focused on different types of projects within the same agency. For example, North Carolina DOT’s highway, bicycle—pedestrian, and rail scoring frameworks include some criteria categories that are consistent across all three, for example, safety, but also include many other criteria types that do not overlap.

## Project scoring frameworks

Several scoring and prioritization processes have been used for transportation project decision-making, which are data-driven and use a variety of tools to assess included criteria. Others use a blend of quantitative and qualitative criteria; for example, the Transportation Alternatives and Revenue Sharing Programs of the Virginia DOT (Virginia Department of Transportation, 2015a). Scores are assigned to selected criteria in three ways: (1) using the numerical value of the performance measure to assess a certain criterion, for example, the number of fatal and severe injuries in a year or percent change of a measure, (2) using a lookup table that assigns scores based on certain attributes, for example, complete street features included in a proposed project, or (3) using numbers within a range, for example, 0−3, or −1 to 3 based on an assessment of existing conditions (e.g., a project located within or in proximity to an EJ area), proposed improvements (e.g., positive impacts on that area, negative or no impact on that area) or a combination of these two. Various combinations of the three ways to assess criteria are also included in some frameworks. Some of the scorings (are decided after comparison of numerical values with regional or national averages (or averages for similar types of facilities), similar areas or adjacent communities, for example, SACOG's Active Transportation Program (Sacramento Area Council of Governments, 2019), and North Carolina DOT (North Carolina Department of Transportation, 2018) rail scoring framework.

Criteria scores are weighted within each category (e.g., air quality, equity) and each category is weighted to produce the overall score. The California DOT has utilized a multicriteria decision-making method called Analytic Hierarchy Process in their State Highway Operation and Protection Program Project Prioritization Pilot Program (California Department of Transportation, 2016). Some frameworks have introduced area-specific weights for different regions or divisions (e.g., North Carolina DOT and Virginia DOT's SMART SCALE). When scores are based on absolute numerical values of measures, normalization is introduced to eliminate biases that could arise from differences in measure magnitudes. Normalization can be performed in various ways, for example, by assigning a certain number of points based on deciles or quantiles (e.g., Minnesota DOT's Corridors of Commerce) or relative to the highest value by comparing against other projects being scored (e.g., North Carolina and Virginia DOTs). Project size differences are accounted for by normalizing measures by mileage, or people/acreage affected by the project (e.g., Virginia DOT's SMART SCALE), or by multiplying criteria points by the project cost or project area to account for the magnitude of the benefit (e.g., Maryland DOT). In order to assess the feasibility of projects and facilitate comparison with other projects or alternatives, benefit—cost ratios are utilized by some DOTs and are usually calculated by dividing the final score with the project cost (e.g., California DOT, Maryland DOT, and Virginia DOT's SMART SCALE).

The scoring process also varies from framework to framework depending on whether criteria are assessed based on existing conditions within the project area to identify the projects located in areas most in need, for example, Ohio DOT's Transportation Review Advisory Council (Ohio Department of Transportation, 2015) and Tennessee DOT's Multimodal Suitability Index (Tennessee Department of Transportation, 2018), or on changes anticipated due to proposed project alternatives (e.g., Virginia DOT's SMART SCALE). As mentioned earlier, in some cases, both types of criteria are included in the same framework (e.g., Massachusetts DOT, Minnesota DOT's Corridors of Commerce, North Carolina DOT, and Nashville MPO). Ranking of projects resulting from implementation of such frameworks is often not definite, in the sense that local scorings and other often qualitative factors come into play in the final selection process. In the case of North Carolina DOT's regional impacts and division needs scoring processes (North Carolina Department of Transportation, 2018), local rankings influence the final decision-making, while for Massachusetts DOT, project readiness, types of funding, as well as regional and asset/mode distribution of projects are also considered following the project scoring process. Minnesota DOT's Corridors of Commerce program incorporates qualitative information related to low-income and minority populations along with information on the geographical distribution of high scoring projects in an effort to improve transportation equity. In the case of Virginia DOT's SMART SCALE, the rankings and scorings are not binding but in the case of any modification to the rankings, justification and approval from the Commonwealth Transportation Board need to be sought (Virginia Department of Transportation, 2018).

Finally, it is common to establish an advisory board, usually consisting of state and MPO representatives, that reviews project scorings and provides recommendations on changes to be made to achieve established goals. This is commonly performed on an annual basis. Public and local input is also sought for some of the programs such as in the case of the

Maryland DOT project scoring framework (Maryland Department of Transportation, 2018).

## Health-related project scoring criteria and measures

While the majority of project scoring and prioritization frameworks in the US have not been developed with a health focus, many of them include factors that can impact health such as accessibility, air quality, equity, physical activity, and safety. This section focuses on these health-related criteria and performance measures that have been introduced into DOT, MPO, and other federally funded project scoring and prioritization frameworks in the US to capture health-related impacts of transportation projects. Table 16.1 summarizes the criteria categories that have been included in decision-making frameworks, but only if the included criteria directly assess each of these six categories. These six criteria categories were chosen because they capture a wide range of pathways through which transportation affects health, such as exposure to air pollutants and traffic injuries, access to opportunities and physical activity, while accounting for health disparities that also affect health outcomes. As seen in

**Table 16.1** Health-related criteria categories considered in project scoring and prioritization frameworks in the United States.

| | Accessibility | Air quality | Equity | Noise | Physical activity | Safety |
|---|---|---|---|---|---|---|
| **Department of transportation** | | | | | | |
| California | • | • | | | • | • |
| Minnesota | • | | • | | • | • |
| Massachusetts | • | • | • | | • | • |
| Maryland | • | • | • | | • | • |
| North Carolina | • | | | | • | • |
| Ohio | • | • | | | | • |
| Tennessee | • | | • | | • | • |
| Virginia | • | • | • | | | • |
| **Metropolitan planning organization** | | | | | | |
| Nashville | • | • | • | | • | • |
| Sacramento Area Council of Governments | | • | • | | • | • |
| **Federally Funded** | | | | | | |
| ActiveTrans Priority Tool | • | • | • | | • | • |

Table 16.1, noise is not included in any of the frameworks and therefore it has been excluded from further discussion.

### *Accessibility*

Accessibility along with safety are the most commonly assessed health-related criteria in project prioritization frameworks. Accessibility is very often indirectly assessed via mobility-based measures such as changes in travel time (e.g., North Carolina DOT) or increases in speed, often focused on commute trips (e.g., Massachusetts DOT). However, such mobility-based criteria do not directly capture the impact of projects on accessing opportunities as they do not consider the types of modes that are available to certain communities. As a result, they have been excluded from Table 16.1. In general, there are three types of accessibility criteria included in existing decision-making frameworks that are assessed based on (1) the number of opportunities that can be reached within a certain time budget or distance, (2) the presence of mode-specific infrastructure, and (3) connectivity or the presence of new connections or facilities that are expected to improve accessibility.

Accessibility is most commonly assessed specifically for jobs and in some cases for other points of interest, such as schools and businesses that can be reached within a certain time travel budget or travel distance. For example, Virginia DOT's SMART SCALE assesses job accessibility as the number of jobs that can be reached within 45 minutes for highway and 60 minutes for transit projects. This criterion is assessed separately for the whole population and disadvantaged populations. Criteria like this indicate that accessibility and equity targets often overlap.

The presence of mode-specific infrastructure is used to assess accessibility related to active transportation, for example, points for projects that introduce pedestrian- and bicycle-specific infrastructure treatments, such as sidewalks and bikeways (e.g., ActiveTrans Priority Tool). Access to multimodal facilities is also commonly used as a qualitative criterion often based on certain project features that are expected to improve accessibility, for example, transit system improvements, park-and-ride improvements, and bicycle or pedestrian facilities (e.g., Virginia DOT's SMART SCALE, Maryland DOT, and Nashville MPO) or more quantitatively based on proximity to system access points such as transit stations and airports (e.g., North Carolina DOT).

Connectivity has been assessed qualitatively based on the presence of new links to areas with job densities higher than two jobs per acre, introduction of a new pedestrian or bicycle link (ActiveTrans Priority Tool), or introduction of links to transit stops, transit-oriented districts and other points of interest such as businesses and education (e.g., Massachusetts DOT). Connectivity has also been assessed quantitatively through measures such as intersection and roadway density (e.g., ActiveTrans Priority Tool), employment density (e.g., North Carolina DOT and Tennessee DOT), and sidewalk coverage (e.g., ActiveTrans Priority Tool). Other connectivity criteria include the quality of service index, which is based on the number and degree of connections to similar projects or active transportation facilities to be generated (e.g., North Carolina DOT). Criteria that incorporate information on the proximity to a certain center along with the types of centers that are connected have also been included for active transportation projects. (e.g., North Carolina DOT's Bicycle and Pedestrian scoring).

Other qualitative accessibility criteria include whether access to certain types of facilities or more generally points of interest is anticipated to improve after the implementation of a project alternative. It is common for frameworks to incorporate multiple accessibility criteria under different criteria categories such as "Mobility," "Social Equity," and "Economic Impacts" for Massachusetts DOT and "Economy" for California DOT. Virginia DOT's SMART SCALE and North Carolina DOT are the only frameworks reviewed that explicitly include an accessibility category with multiple related criteria.

### *Air quality*

Air pollutant emissions can be evaluated with respect to their impact on climate change (i.e., greenhouse gas emissions) or influence on local air quality at the ground-level. While climate change—related air quality affects health, the impact may not be direct. In contrast, there is strong evidence demonstrating that degradation of local air quality by vehicle tailpipe emissions (nitrogen oxides, ozone, particulate matter) is associated with adverse health outcomes (e.g., respiratory diseases and cardiovascular disease). Most existing project scoring and prioritization frameworks include a greenhouse gas-related criterion (63% of the ones reviewed); however, only two of the reviewed frameworks included criteria for pollutants affecting local air quality. While climate change—related air quality criteria could potentially be used as proxies for local air quality issues, they are only assessed qualitatively and not through state-of-practice emission modeling estimates or real-world data. Only in limited cases, more involved processes have been utilized to assess project life cycle carbon emissions (e.g., California DOT). Other qualitative criteria for air quality include whether a project is assisting the state with reaching its environmental goals (e.g., Maryland DOT).

Efforts to assess impacts on local air quality have been attempted via general mobility or active transportation-related criteria, as well as via scoring criteria related to alternative vehicle technologies (e.g., electric and hybrid). Reduction in vehicle-miles traveled, changes in mode share (e.g., SACOG), increase in the number of features that motivate active transportation (e.g., California DOT health score), improvements in public transportation, or infrastructure specific for alternative vehicle types (e.g., Virginia DOT's SMART SCALE Air Quality and Energy Environmental Effect score) are examples of ways to indirectly assess air quality. Quantitative assessment of vehicle tailpipe emissions that can adversely impact health is rare in these frameworks. Fine particulate matter and ozone concentrations are part of the health score in the California DOT framework, but they are only assessed based on poor, fair, or good level threshold ranges. Recent updates in the Massachusetts DOT framework are also incorporating criteria that are directly linked with air quality—related health outcomes. In particular, projects are scored more highly if they are located in areas with elevated levels of nitrogen dioxide and fine particulate matter concentrations (i.e., greater than the state average) and include project elements that are expected to reduce emissions (Massachusetts Department of Transportation, 2019).

### Equity

Equity has been addressed by the majority of project scoring frameworks often through multiple criteria within the same framework that are usually quantitative. In a few cases, there is an explicit criteria category designated to equity, for example, Massachusetts DOT includes a "Social Equity" scoring category consisting of five different criteria, including criteria related to EJ, title VI, utilization of housing choice grants or access to housing, air quality, and connectivity. Equity assessment tends to be a direct one, that is, explicitly measuring the change in an equity-related performance measure.

As mentioned earlier, equity criteria often overlap with economic performance and accessibility criteria, for example, accessibility to jobs within a certain travel time for disadvantaged populations. In addition to accessibility measures specifically targeted at disadvantaged populations, equity is measured by considering demographic characteristics in the area of interest and whether improvements will benefit those populations. Examples of such characteristics include low income, minority, zero car households, unemployment rate, EJ or title VI populations, disability, age, and university enrollment. Scores are assigned based on the prevalence of such demographic characteristics assessed either as density (e.g., number of K-12 and university enrollment by net acre; see SACOG), or comparative to adjacent communities or state averages (e.g., census blocks that have a higher rate than the average in unemployment or older than 65 years old; e.g., Nashville MPO and Ohio DOT).

Other equity measures that have been used are based on changes in accessibility to multimodal options, capturing the potential of a project to provide alternative transportation choices for underserved groups (e.g., Nashville MPO). Criteria related to community revitalization (e.g., Maryland DOT) and economic improvements (e.g., Ohio DOT) can also be considered as proxies for equity outcomes. In some cases, equity is captured through assessment of existing conditions, specifically for project areas that are currently not compliant with the American with Disabilities Act or are designated as health priority areas (e.g., Nashville MPO). Health priority areas are defined based on income, employment, age, and car ownership in the case of Nashville MPO's framework. Certain frameworks have considered regional equity in how funds are allocated and projects are scored based on whether the proposed projects are located in areas where federal funds have already been allocated. Finally, engagement of impacted jurisdictions via the submission of support letters for a specific project can be considered as an equity criterion (e.g., Minnesota DOT's Corridors of Commerce), as it allows the immediately affected populations to be able to influence decision-making.

### Physical activity

Physical activity criteria have been directly or indirectly included in most project scoring and prioritization frameworks within various criteria categories, varying from "System Preservation" to "Mobility" (Massachusetts DOT), "Policy Objectives" (Minnesota DOT's Corridors of Commerce), and "Community Vitality" (Maryland DOT). Criteria included in mobility-related categories tend to directly assess physical activity, while those in other categories usually capture the impact of a project element on physical activity in a less direct way. An example of an indirect physical activity criterion is one assessing improvements in transit mobility, for example by introducing transit preferential treatments such as buses-on-shoulders; see North Carolina DOT. Such transit-related improvements can also indirectly influence physical activity; they are often included under mobility-related criteria categories. Finally, criteria related to access to multimodal choices can also be considered as a proxy for assessing the impact of transportation projects on physical activity, for example, Virginia DOT's SMART SCALE and Maryland DOT.

Physical activity can also be assessed in more direct ways via criteria related to improvements for bicyclists and pedestrians such as through complete street features (e.g., Maryland and California DOTs), bike and pedestrian-specific infrastructure (e.g., Massachusetts, California, and Maryland DOTs), or simply by assessing whether the proposed project is expected to increase bike, pedestrian, and transit demand (e.g., California DOT). However, these criteria are rarely quantitative as there is a general lack of models connecting the built environment and specifically bicycle and pedestrian infrastructure with mode changes and active transportation demand. A composite criterion, named health score has been introduced in California DOT's framework and is assessed based on a combination of air quality levels and existence of active transportation attributes.

Quantitative measures that have been used to assess physical activity include intersection density, bike land and path mileage over total road mileage, and transit stop density (e.g., SACOG). Other quantitative measures have also appeared but are indirect as they relate to mobility-based criteria such as reductions in vehicle-miles traveled, which could be resulting in changes in mode share and increases in physical activity, (e.g., SACOG).

### Safety

Multiple safety criteria are included in all reviewed project scoring and prioritization frameworks often grouped in their own safety category. This is not surprising as safety and mobility are the primary reasons for any transportation project and therefore are an important determinant of project prioritization. Safety criteria most often capture motorized vehicle safety but in some cases, they also consider bicycle and pedestrian safety (e.g., Massachusetts DOT). As with other criteria categories, e.g., air quality and equity, some safety criteria include comparisons with adjacent communities, statewide averages, or areas/segments falling under the same federal classification (e.g., Massachusetts DOT).

Safety criteria are highly quantitative including number of crashes (e.g., Minnesota DOT Corridors of Commerce) and predicted crashes using crash modification factors (e.g., Massachusetts DOT), crash rates (usually per million of vehicle miles traveled) (e.g., Ohio and Massachusetts DOTs), crash density (per mile) (e.g., North Carolina DOT), crash severity (e.g., Maryland DOT), and crash severity index (e.g., North Carolina DOT). Existence of safety improvements targeted at different types of users (i.e., vehicles, bicyclist, and pedestrians) (e.g., Massachusetts DOT) and the percent of collisions that involves nonmotorized users (e.g., SACOG) have also been incorporated. Project eligibility for the Highway Safety Improvement Program is another safety-related criterion found in the Massachusetts DOT highway project scoring framework. Virginia DOT's SMART SCALE utilizes the Equivalent Property Damage index to allow for a monetary assessment of crashes and utilizes crash modification factors to assess the anticipated safety impacts of projects. A novel safety criterion that has been introduced by the California DOT incorporates elements of worker safety and safety improvements for users and workers.

## Health outcomes

Few states have documented the long-term impacts of incorporating health outcomes in their decision-making processes. This lack of documented impacts can be attributed to the relative recent introduction and implementation of these health-focused frameworks, for example, Massachusetts DOT updated highway scoring framework and Tennessee DOT’s multimodal suitability index (Tennessee Department of Transportation, 2018).

### *Virginia DOT's SMART SCALE*

A review of the projects recommended for funding during Rounds 1–3 [Fiscal Year (FY) 2017, FY 2018, and FY 2020] of Virginia DOT's SMART SCALE implementation revealed that a higher percentage of low-cost projects (<$5 million) were funded during the last two rounds compared to Virginia DOT’s Six-Year Improvement Plan (FY 2006–11) funding allocation. The review also concluded that the number of projects focusing on active transportation (i.e., bicycle and pedestrian projects) as well as transit increased over the years of SMART SCALE implementation resulting in 30% funded projects for active transportation and 7% for bus transit projects during Round 3 of its implementation (Virginia Department of Transportation, 2019).

### *Nashville metropolitan planning organization*

Use of the Nashville MPO's updated scoring and prioritization process has resulted in a larger portion of the MPO's long-term transportation budget dedicated to improving walk and bike conditions. In particular, 18 walking and/or biking projects have been funded so far, which improve accessibility to schools, downtown areas, jobs, public transit stops, and other opportunities (Transportation for America, 2016). Other reported outcomes include 67% (2035 plan) and 77% (2040 plan) of funded projects containing health-oriented transportation and planning elements versus 2% before the implementation of this scoring process (Meehan and Whitfield, 2017). In addition, a 15% increase in miles of sidewalks and 74% in miles of bicycle facilities was observed between 2009 and 2014 due to the implementation of this scoring process (Transportation for America, 2016). Overall, the updated process allowed for active transportation projects to be part of mainstream transportation decisions.

## Guidelines for scoring criteria

The selection of scoring criteria, performance measures to assess criteria, and weights associated with the criteria categories are critical for successfully incorporating health impacts in transportation decision-making. First of all, the magnitude of the measure used to assess certain criteria can significantly affect the overall scoring in benefiting one type of projects over others (e.g., projects benefiting one mode or big-budget projects). This can be resolved with the use of normalized values relative to the project with the highest value for that criterion, or relative percentile scores. In addition, scoring criteria need to account for the size of the projects being scored and in particular, the number of people being affected. In order for such criteria to allow for a fair comparison of projects of different sizes without eliminating small projects, a normalized monetary evaluation (e.g., benefit/cost ratio) could be implemented. Monetization of benefits and negative impacts is perceived as a fair way to compare projects (Virginia Department of Transportation, 2018), while there is also a need to incorporate life cycle cost analysis and risk assessment in project prioritization.

Caution should also be exercised when assigning weights to individual criteria or criteria categories (e.g., Mobility) to avoid overrepresentation of certain criteria categories and ensure that health-related criteria receive sufficient weighting to allow them to be influential in the decision-making. Stakeholders should consider adjusting weighting factors for different areas (e.g., urban vs rural), districts, and potentially areas with different socioeconomic characteristics or needs to avoid disproportional impacts of criteria weights on the total score. In addition, adjustments on both criteria and weights can be done to reflect specific priorities and issues of importance for the community of interest, for example to achieve increases in bicycling and walking, criteria that improve nonmotorized user safety and mobility could be weighted more highly. When such adjustments are coupled with a transparent and easily communicated scoring process, they can result in high public acceptance of upcoming projects or policies. For example, Nashville MPO found that emphasizing quality of life and economic benefits facilitated communication and engagement of the community and elected officials (Transportation for America, 2016). Finally, overlapping of criteria should be minimized (Virginia Department of Transportation, 2018).

## Conclusion

Transportation is highly correlated with health outcomes, both direct (e.g., respiratory and cardiovascular diseases from vehicle emissions) and indirect, that is, social determinants of health (e.g., equity issues from lack of access to multimodal choices for car-less populations). In the US, efforts to incorporate health into transportation decision-making have been attempted by implementing HIAs and updating project prioritization and scoring criteria that are part of decision-making frameworks.

Changing project scoring criteria is a cost-effective way to incorporate health in transportation decision-making (Whitfield et al., 2017).

As HIAs have not been institutionalized in the US, they are rarely used for assessing health impacts of transportation and influencing decisions. Comprehensive reviews of transportation HIAs list several factors that can contribute to the utilization and success of HIAs in influencing decisions, which include (1) engagement of public health professionals in transportation decision-making; (2) good documentation of successful HIA methods and outcomes; and (3) and resource availability. On the other hand, project scoring and prioritization frameworks seem to be the primary means for project prioritization and funding allocation in the transportation sector. As a result, changing project scoring criteria is seen as a cost-effective way to incorporate health in transportation decision-making (Whitfield et al., 2017).

Despite recent efforts from some public agencies to incorporate health into transportation decision-making, there are still many challenges that limit a comprehensive assessment and inclusion of all transportation-related health impacts. Many of these challenges are related to the lack of representative data especially for nonmotorized users and emerging micro-mobility options such as e-scooters. There is also a pressing need for a quantitative assessment of the connection between built environment and user behavior (e.g., models to estimate increases in physical activity from the introduction of a bike lane) (Ross et al., 2012). In addition, the introduction of new technologies such as automated vehicles is expected to bring changes in how people travel and behave that are not captured in existing literature or transportation models.

A bigger and potentially harder to address challenge is related to the apportionment of health impacts to transportation versus other industries. For example, air pollution could be attributed to both transportation and other industrial activities in a region. Another major issue with connecting transportation and typical health data is the mismatch in the resolution of data that are available. Transportation and demographic data can often be obtained at the census block level, while health data tend to be more aggregated mainly due to the need for privacy protection. Finally, staff availability, especially with expertise in epidemiology, and in general limited resources are often cited as barriers in assessing the health impacts of transportation and incorporating them in decision-making.

Overall, there is a growing interest in understanding the connection between transportation and health as indicated by recent publications. Several challenges and research gaps associated with health-related performance measures for arterials as well as other issues related to health-oriented design, planning, and operation of arterial roads have been documented in a Transportation Research Board E-circular (Christopher et al., 2018). A recent research roadmap also summarizes current research needs and identifies a prioritized list of research gaps in transportation and health that need to be addressed (National Academies of Sciences, Engineering, and Medicine, 2019). The roadmap emphasizes the need for a synthesis of best practices for incorporating health in transportation project prioritization.

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CHAPTER SEVENTEEN

# Community design, street networks, and public health

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## Contents



## Introduction

There is no shortage of research connecting transportation and the built environment to public health outcomes (Ding and Gebel, 2012; Feng et al., 2010; Renalds et al., 2010). Skeptics will say that little of the research is causal (Mokhtarian and Cao, 2008). They will also say that even if the research was causal, that most studies point to vague factors such as "sprawl" or "walkability" (McCormack and Shiell, 2011). This combination of skepticism and ambiguity often pushes public health to the back burner of transportation planning outcomes. Even when we do acknowledge health, we rarely do much more than budget a little extra money for sidewalks or bike lanes.

What can we make of these criticisms? When it comes to built environment concerns, such as asbestos or lead paint, causality is often readily

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apparent. When the outcomes become diabetes, asthma, or heart disease, however, causality is less clear due to issues such as self-selection (McCormack and Shiell, 2011). Self-selection references the idea of people that are already more likely to be physically active (and healthy) prefer to live in neighborhoods that support such physical activity. In other words, it may not be the transportation system or built environment that is prompting more physical activity and better health; rather, it could just be that certain places attract the sort of person that would be more physically active (and healthier) no matter wherever they live. In terms of the research that controls for self-selection—such as via longitudinal studies or focusing on children that cannot self-select—the results are much more mixed (McCormack and Shiell, 2011; Mokhtarian and Cao, 2008). However, in their review paper of studies that accounted for self-selection, McCormack and Shiell (2011) find that neighborhood type, walkability indices, and land use mix have all proven to be important and that this association "likely exists independent of residential location choices." We also have clear causal links between physical activity and health outcomes such as obesity, diabetes, cardiovascular disease, respiratory disease, and mental health (Fraser and Lock, 2011).

Of course, it would be nice to have more research establishing such causality, but even without these causal links, the fact remains that we have systematically designed much of our built environment so that active transportation is not a viable option. Saying that walking and bicycling are not viable options probably puts it too kindly in many cases. Physical activity is less likely to be built into our daily lives, so acquiring minimum recommended levels can mean driving somewhere to do so, as implied by the infamous gym in Fig. 17.1. Unsurprisingly, most of the population is not sufficiently active (Gebel et al., 2007). Ding et al. (2016) estimated the international health-care costs of physical inactivity and found that they top $50B each year (Iravani and Rao, 2019). The World Health Organization finds that physical inactivity contributes to more than 3.2M premature deaths each year across the globe (McCormack and Shiell, 2011).

Since diet plays a major role, it is easy to think that such health outcomes are simply a matter of personal choice. Yet, our current built environment takes that choice away from many people. The Surgeon General's obesity call to action report states that "individual behavioral change can occur only in a supportive environment with accessible and healthy food choices and opportunities for physical activity"


**Figure 17.1** Gym escalator.

(Burdette and Whitaker, 2004; US Department of Health and Human Services, 2001). In addition, more than one-third of Americans do not drive. Whether that is due to age, disability, income, or choice, the idea that of needing to drive somewhere in order to find a safe place to walk or cycle does not comport with a significant percentage of the population. These populations might be most impacted. While the childhood obesity rates continue their unprecedented climb, even in what has long been considered the healthiest states such as Colorado, it is also worth pointing out the shift in diabetes terminology. Type 1 diabetes used to be called juvenile diabetes, and Type 2 diabetes used to only be seen in adults and was called adult-onset diabetes. Once we reached a point where almost half of kids with diabetes had what was previously considered the adult version, we changed the name to Type 2 (Jackson and Sinclair, 2011).

The question is how do we build a supportive environment with opportunities for physical activity? More specifically, how do we build a healthy community? With much of the research focusing on imprecise descriptors such as "sprawl" or "walkability," we often do not have a clear path for doing so. Perhaps, it is as easy as providing a little extra funding for sidewalks and bike lanes. At a smaller scale, there is the "build it and they will come" literature suggesting increased walking and bicycling after the installation of infrastructure such as recreational trails or bicycling-specific facilities (Fitzhugh et al., 2010; Macbeth, 1999). Thus, one approach that has received a lot of attention is the Complete Streets movement. The term "Complete Streets" originated in 2003 with the America Bikes organization (Zehngebot and Peiser, 2014). Soon thereafter, Smart Growth America founded the National Complete Streets Coalition in 2004, which has been instrumental in helping pass more than 1400 Complete Streets policies across the United States. The underlying goal of a Complete Streets policy is typically "to enable safe access and travel for all users," and while road safety is in itself a public health outcome, they more broadly claim improved public health as an additional benefit (Smith et al., 2010). In theory, these benefits are to be achieved by compelling planning for all modes in all transportation projects; in reality, the more commonly held impression is that completing the street means adding design elements such as sidewalks, bike lanes, and raised medians to almost every major street. Given the term "Complete Streets," this line of thinking is not surprising. Unfortunately, these same major roads are still likely to remain as barriers to active transportation and comprise the high-injury networks of most cities. Moreover, walking and bicycling on side streets have shown to be associated with significantly less air pollution risk than on major roads (Carrington, 2017).

Focusing too much on Complete Streets and disconnected recreational trails has left us with too many incomplete cities. The research we highlight in this chapter suggests that street-level design elements matter, but not as much as overall street network and community design differences when it comes to travel behavior, public health, and road safety outcomes. The results provide design guidance for transportation planners looking to prioritize public health outcomes. We then highlight a related strand of research that uses deep learning, a subfield of machine learning, on satellite imagery to estimate public health outcomes.

## Background

Despite the relatively recent focus on the link between transportation and the built environment with public health outcomes in the literature, there is a long history of it in the planning discipline. In the mid-1800s, a German doctor named Rudolf Virchow established a link between the built environment and common diseases such as cholera, tuberculosis, malaria, and typhoid fever (Corburn, 2013). During the Civil War, Frederick Law Olmsted—who somewhat surprisingly was the founding director of the US Sanitary Commission—focused on similar health-related issues when designing military camps (Fisher, 2010). With innovations such as sanitary sewers and indoor plumbing, the focus shifted toward industrial pollution issues during the early 1900s (Rosen, 2003). Then, the need for this sort of thinking seemed to dissipate over the course of the 20th century as the medical field pushed into a more epidemiological direction.

Growing prevalence of obesity and obesity-related diseases rekindled interest and the need for research on this link between the built environment and public health in the late 1990s and early 2000s. Prior to the turn of the century, there was not much academic research about the built environment and health outcomes. Now, that research strand is simply staggering and has grown to include built environment for health-related topics such as physical activity, air pollution, noise pollution, mental health, social exclusion, and road safety.

But what even is the built environment? World Health Organization (2009) defines it as "the building and transportation design of a city, including factors such as open green spaces, bike ways/sidewalks, shopping centers, business complexes, and residential accommodation." For most people, this includes just about everything they see on a day-to-day basis. For example, urban residents looking to access nature by going to a park still usually go to a place dreamed up and built entirely by humans (Zapata-Diomedi and Veerman, 2016). The built environment also includes our street networks and the way that we lay out our communities.

While interest in urban air pollution was almost immediately preceded by the industrial revolution, the drastic shift in how we built our cities and transportation infrastructure evolved much more gradually. As a result, it took quite a while longer before we connected the way that we were building our cities to public health outcomes. Over the course of the 1900s, we initially shifted from traditional gridded street layouts toward more curvilinear and tree-like networks. Toward the latter half of the century, networks became ever sparser and more disconnected. Fig. 17.2 highlights this evolution.

Now what is interesting is that these changes were a departure from how we have been building cities for the past few thousand years. As early as 2500 BCE, the city of Mohenjo-daro, New Delhi, exhibited what


**Figure 17.2** Evolution of the built environment over the 20th century.

could be described as a gridded street pattern (Stanislawski, 1946). Over the centuries, these built environments transitioned from the orthogonal grids of the Greeks and Romans to the more organic gridded networks of medieval Europe, and then back to the orthogonally based cities built during the Renaissance. Both typologies made their way to the New World, starting with the organic gridded networks found in cities such as Boston and Lower Manhattan before then giving way to the orthogonal, rectilinear networks of cities such as New Haven, Philadelphia, and New York City. This trend continued into the suburbs, particularly those supported by streetcars, and across America straight through the early 1900s.

It is easy to point to the automobile as the primary factor behind the eventual shift, but the story is a bit more complicated than that. It was not until 1929 and Radburn, New Jersey, when the United States saw its first example of a hierarchical, cul-de-sac-based design. Charles Stein, one of the Radburn designers, declared "the gridiron pattern, which had formed the framework for urban real estate for over a century, as obsolete as a fortified town wall" (Southworth and Ben-Joseph, 2003). Before transportation planners had their say, the Federal Housing Administration (FHA) published two documents in the late 1930s that formally recommended hierarchical street layouts with cul-de-sacs. FHA called gridded layouts inefficient, monotonous, and unsafe. They even showed numerous comparative images of seemingly similar neighborhoods. They labeled the more traditional, gridded layout as "BAD" and the hierarchical, cul-de-sac designs as "GOOD." Even though FHA would have seemingly little authority as to implementation, they based their mortgage and mortgage insurance recommendations upon these standards and played a role in over 22M properties prior to 1960 (Southworth and Ben-Joseph, 2003).

Engineers did not really get involved until the 1950s when the Institute of Transportation Engineers (ITE) sponsored a study by Harold Marks that compared the road safety outcomes of gridded neighborhoods to cul-de-sac style designs in residential Los Angeles. Marks found 8 times more crashes on gridded streets and 14 times more crashes at four-way intersections than at T-intersections (Marks, 1957). Of course, the study did not account for crash severity or the likely increase in crashes along with collectors and arterials in a hierarchical network. By the mid-1960s, ITE (1965) began publishing their "Recommended Practice for Subdivision Streets" that encouraged replacing gridded networks with disconnected, curvilinear designs featuring T-intersections and cul-de-sacs. Eventually, the American Association of State Highway and Transportation Officials essentially codified hierarchal street network designs with the functional classification system. Intended to help engineers determine design criteria, the functional classification system categorizes roadways by two factors: facility type (highways, arterials, collectors, and local roads) and land use (urban and rural). This combination is supposed to help facilitate consistent street design by establishing the level of mobility or accessibility one should expect on the road. Instead, it encourages the channelization of vehicle trips from highways to arterials to collectors and then finally to local roads, which in turn, tends to produce tree-like street network designs.

Such community designs are not illogical. In fact, many people specifically choose to live on a cul-de-sac because it is protected from vehicle traffic and thus seems like a safer and healthier place to live. How well does this perception hold up? The research strand described in the next section digs into this question.

## Research overview

This chapter draws upon an extensive data set collected from 24 medium-sized cities in California, United States, with populations ranging from 30,000 residents to just over 100,000 (Marshall and Garrick, 2010a,b, 2011a,b, 2012; Marshall et al., 2015). The selected cities were all from a single US state because we wanted to ensure that the data, especially with respect to health outcomes, were collected on a consistent basis.

We selected these cities from over 150 California cities to best represent a geographically diverse collection of 12 medium-sized cities with good road safety records and 12 with poor road safety records:

| **Safer cities** | **Less safe cities** |
|---|---|
| • Alameda | • Antioch |
| • Berkeley | • Apple Valley |
| • Chico | • Carlsbad |
| • Cupertino | • Madera |
| • Danville | • Morgan Hill |
| • Davis | • Perris |
| • La Habra | • Redding |
| • Palo Alto | • Rialto |
| • San Luis Obispo | • Temecula |
| • San Mateo | • Turlock |
| • Santa Barbara | • Victorville |
| • Santa Cruz | • West Sacramento |

We collected street design characteristics for every major road—including the presence of sidewalks, bike lanes, landscaped medians, as well as the number of lanes—along with street network measures—including street network density, street connectivity, and street patterns. We also collected travel behavior and socioeconomic data from the Census and National Household Travel Survey, health outcome data from the California Health Interview Survey, traffic flow information, and over 230,000 individual crash records from 11 years of crash data. This information was geocoded into a geographic information systems (GIS) database and, even though we will not delve too deeply into the statistics, analyzed for the following outcomes at the Census block group level of analysis using the following methods:

- total road crashes, severe injury crashes, and fatal crashes via a negative binomial regression model;
- mode choice using multinomial logistic regression; and
- for rates of obesity, diabetes, high blood pressure, heart disease, and asthma using a multilevel, hierarchical regression model.

Since getting maimed or killed on the roads is objectively bad for your health, we begin by highlighting our findings with respect to road safety. Before we do that, it is worth describing our built environment measures and the logic underpinning our selections. The original study evolved from some back-of-the-envelope calculations suggesting that older cities were seeing fewer road fatalities than newer cities that were developed in the era of our modern engineering standards that should, in theory, be safer. Initially, we developed methods to estimate the approximate year of development for different neighborhoods across our cities. Seeing the differences in how these neighborhoods were built, however, led us to focus more on creating a straightforward set of street network measures across three "C" street network categories:

- compactness,
- connectivity, and
- configuration.

How do we measure these factors? While there has long been the field of graph theory to draw upon, we found that such measures never caught on in transportation due to their complexity and difficulty for people to visualize. As a result, we settled on more fundamental measures. For street network compactness, we selected intersection density that sums the total number or intersections, including dead ends, and divides it by the area (i.e., square miles). Street network connectivity is then measured by the link to node ratio, which divides the total number of links (i.e., road segments between intersections) by the total number of nodes (i.e., intersections) (Ewing, 1996; Handy et al., 2003; Litman, 2005). Interestingly, it was not uncommon for some researchers to focus their discussion on street connectivity but then use intersection density to measure it. It is very possible, however, for a street network to be highly connected but not at all compact. Take, for example, the cities of Portland, Oregon, and Salt Lake City, Utah. Both are fully connected, gridded networks with similar link to node ratios. Portland is quite compact at 550 intersections per square mile while Salt Lake City is quite sparse with only about 45 intersections per square mile. Thus if we try to use intersection density to measure connectivity, we may miss our target.

Compactness and connectivity are useful, but they do not always give us enough to work with when it comes to understanding configuration. Adapted from Stephen Marshall's book, Streets and Patterns, we applied his conceptualization of macro- and micronetworks (Marshall, 2005). For our purposes, we differentiated between what we call the citywide street network and the neighborhood street network as shown in Fig. 17.3.

To some extent, this approach overlaps with the functional classification system. The difference is that we are more focused on network structure. In other words, functional classification types will generally differ in

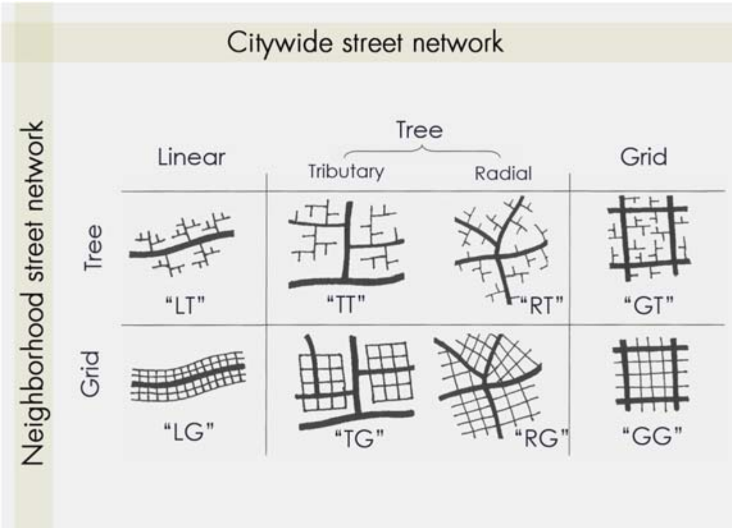


**Figure 17.3** Street network configuration. *Adapted from Marshall, S., 2005. Streets and Patterns. Spon Press, New York.*

terms of cross-sectional elements such as the number of lanes, lane widths, and the presence of medians or bike lanes. We measure those street-level variables separately and instead use this categorical configuration variable to help convey some of the complexities that distinguish street networks and communities in general. Take for comparison the fully gridded network configuration type (type "GG" at the bottom right of Fig. 17.3) to the tree-like tributary citywide network/gridded neighborhood type (type "TG" in the bottom row, second column of Fig. 17.3). While these two network types might see similar values with respect to intersection density and the link to node ratio, they function much differently in the real world. Understanding network configuration helps us characterize these distinctions.

In terms of the street-level data, we collected cross-sectional data for every citywide street via Google Earth and Street View. This data includes the number of vehicle lanes, whether there was median or not and if so, the type of median, as well as data regarding on-street parking, bicycle facilities, and sidewalks. We also collected health data from the California Health Interview Survey, Census sociodemographic/socioeconomic data, Census journey-to-work data as well as data from the National Household Travel Survey, vehicle volumes, and land use data. Overall, the intent was to control for as many possible confounding factors as possible.

With the land use data, for instance, we were interested in controlling for the food environment via relative accessibility to healthy or unhealthy food options.

## Street network design and road safety

While people that live on a cul-de-sac may experience better road safety outcomes when they are on that cul-de-sac, our results suggest that the types of big roads built to support such networks lead to significantly worse safety outcomes. In other words, those living in sparser and more tree-like networks are about three times more likely to be involved in a fatal crash (Marshall and Garrick, 2010, 2011a). More specifically in terms of street network design, high levels of street network compactness turned out to have the strongest association with fewer crashes across all severity levels. Holding all other variables at their mean value for our data set, increasing compactness from an average value of 144 intersections per square mile to 324 intersections per square mile was associated with an expected 40% reduction in severe injury crashes and more than a 70% drop in fatal crashes. Because network compactness is more important when it comes to higher severity crashes, this suggests that high compactness, and the associated unmeasured factors, may encourage lower speeds.

With respect to street network connectivity, our results saw a slight increase in crashes associated with higher levels of connectivity across all severity levels, holding all other factors equal. This negative association may be due to increased traffic conflicts associated with more connectivity. At the same time, it is worth pointing out that our highly connected street networks also tended to have complementary design features that were found to be associated with better road safety outcomes such as fewer lanes on the major roads and lower levels of vehicle exposure. This is a key point because fewer travel lanes on the citywide roads were associated with far better crash outcomes. Holding all variables at their mean value, an increase in the average number of lanes on the citywide streets was associated with a 34% increase in both severe injury and fatal crashes.

## Street network design and active transportation

One of the things that the existing literature is clear about is that people in certain built environments tend to participate in higher levels of physical activity. This turned out to be the case in our study as well. Controlling for a wide range of factors, including vehicle volumes, land use, income levels, and proximity to limited access highways or the downtown area, we found that both increased street network compactness and connectivity were associated with higher levels of utilitarian walking and bicycling mode shares. Due to a relatively high number of significant interaction variables, the results are a little harder to interpret, but in general, we found that the most compact and connected neighborhoods were associated with about four times more walking and bicycling than the average neighborhood.

One of the more interesting results turned out to be considering compactness with respect to configuration. For example, higher levels of compactness were associated with a much higher increase in active transportation rates in the fully gridded network types (see "GG" and "RG" in Fig. 17.3) as compared to a more tree-like citywide network (see "TT" or "TG" types in Fig. 17.3). This suggests that it is much more difficult to achieve high levels of physical activity in hierarchical, dendritic street networks regardless of compactness.

## Street network design and public health outcomes

The existing health literature continually highlights the need for clear and consistent built environment measures. Focusing the three C street network variables—compactness, connectivity, and configuration—helped us do just that. Controlling for land use, the food environment, and a range of sociodemographic/socioeconomic status variables, our results suggest that more compact and connected street networks with fewer lanes on the major roads are significantly associated with reduced rates of obesity, diabetes, high blood pressure, and heart disease among residents. Though we did not measure air pollution, our asthma results turned out to be nonsignificant.

The multilevel nature of this model presented us with the opportunity to compare the relative impact of neighborhood-level factors to citywide ones. Citywide street network compactness, for example, seemed to be associated with a much bigger difference in health outcomes than what was taking place at the block group level. In other words, those living in the most compact cities tended to be associated with the lowest rates of obesity, diabetes, high blood pressure, and heart disease, holding all other variables at their mean.

Configuration only really made a difference when we combined it with the three primary built environment measures—intersection density, the link to node ratio, and the number of lanes on the citywide roads—in an attempt to measure overall differences with respect to how these network configurations tend to be built in practice. Comparing the two most prevalent types in our data, the fully gridded street network ("GG" in Fig. 17.3) to the fully tree-like street network ("TT" in Fig. 17.3) suggests that those living in the fully gridded network type tended to have lower levels of obesity, high blood pressure, and heart disease.

It is certainly possible that people can lead a healthy lifestyle in almost any type of street network design; however, these results strongly suggest that those living in more compact cities tended to have much better health outcomes. Given the cross-sectional nature of our study, it is hard to tell whether the built environment is causal or if a healthier subset of the population is simply self-selecting into these places. But it is worth considering these results in concurrence with the active transportation results because these same places also tend to be seeing much higher levels of active transportation. It is also possible that sparse and disconnected street networks with higher numbers of lanes on their major roads may be deterring active transportation, even for people with a proclivity for it.

## A deep learning approach to estimating health outcomes with satellite images

One of the difficulties with health-related research is the acquisition of health outcome data. Historically, this data has been collected through surveys every 5—10 years. This approach is costly, and the data it provides is only an intermittent snapshot of a dynamic system. For governments and health agencies, data is critical for care but often cost prohibitive. This budding research strand addresses this problem through the development of an estimation model that uses deep learning and satellite imagery to estimate health outcome rates.

Deep learning is a subfield of machine learning that uses layers of artificial neural networks as a universal function approximator. Convolutional neural networks are a deep learning architecture developed specifically for working with images. Specifically, they take in raw images and progressively extract more and more abstracted features that allow for a compressed representation of image data that can be used for classification, regression, or generative tasks. Combining aerial, satellite, and Google Street View images of urban or rural landscapes, deep learning has demonstrated the ability to be used for a variety of estimation and prediction tasks (Jean et al., 2016; Suel et al., 2019). Research in this area is limited, however, in terms of the deep learning approaches used, the geographic regions explored, and their use in estimating specific health outcomes.

In order to address these issues, we used data from the California Health Interview Survey to train a convolutional neural network to estimate rates of diabetes, high blood pressure, and overweight residents in selected California census tracts based on satellite imagery of those same census tracts. Although this research is still in its early stages, the results thus far demonstrate the ability to estimate diabetes, high blood pressure, and overweight rates within confidence intervals of 11.1%, 31.6%, and 21%, respectively. The neural layers of the trained network were also visualized, which allows us to gain insight into specific visual built environment features in the satellite images.

While this research considered census tract level satellite images, future research will look at both smaller and larger scale images. As we found with our previous health outcome results, city-level compactness had a stronger association with public health outcomes as compared to the block group level factors. Thus a more holistic view of a city, perhaps combining several census tracts, could assist the deep learning model in identifying factors critical to health outcomes. In addition, using multiple data streams (e.g., Google Street View imagery, social media posts, and mobile phone data) could help improve the models even more. This last point illustrates the flexibility that deep learning models afford, in terms of their ability to integrate multiple data types (e.g., images, numeric data, and text) into a singular model.

Deep learning has the potential to provide powerful modeling capabilities for urban analysis, prediction, classification, and even generation tasks, but there are several challenges in working with these approaches that are worthy of a brief discussion. Deep learning requires large data sets. For example, data sets with millions of data points are typical for training state-of-the-art convolutional neural network architectures for image recognition tasks. There is a spectrum of techniques (e.g., transfer learning, data augmentation), however, that can be used to get around this issue, which means that it is possible to train these models on thousands of data points instead of millions. Another challenge is that the design of optimal deep learning architectures is still poorly understood. Researchers, therefore, cross-validate between several different models in order to improve results. Lastly, trained models can often provide accurate results but be difficult to understand in terms of how the model is able to produce these results. Despite these challenges, the capabilities and flexibility of deep learning approaches are numerous, and their application in built environment and health outcome research and planning remain unrealized.

## Conclusion

Our health-care systems are often overly consumed with caring for those that are already sick instead of preventing sickness in the first place. Adapting our built environments and our street networks for higher levels of compactness and connectivity, along with improved configurations, has the potential to be an impactful and proactive approach toward reducing the number of people that are getting injured on our roads, increasing their physical activity, and improving health outcomes. Given this, the basic job description of transportation planners and engineers needs to include explicitly considering public health outcomes in scenario planning exercises. As is, we have left too many people without a choice in the matter when it comes not being able to use active transportation.

Isn't it too late to develop differently? The current US population is approximately 327 million, but it projects to be more than 438 million by 2050 (Passel and Cohn, 2008). With this population growth, researchers estimate that we will build 89 million homes and 190 billion square feet of nonresidential space by 2050 (Ewing et al., 2007; Nelson, 2006). Assuming we are still here in 2050, we would be able to say that two-thirds of everything in the United States was built in just the last 40 years; this number does not even include all the cities that may need to be rebuilt due to natural disasters. It is not too late to make a significant difference.

While our street networks represent the bones of our communities, it is worth keeping land use in mind as well. Other than finding that a diversity of land use tends to be beneficial, our results do not speak as specifically to land use as they do streets and street network. In part, this is due to the fact that land use—particularly mixed environments—is difficult to quantify (Leck, 2006). If everything is zoned as single use, it is unlikely that people will have many places to walk or bicycle to. If we built communities that integrate restaurants and civic uses and clinics and libraries and schools, we can fundamentally change how people need and use the transportation system. Historically, transportation professionals have been overly concerned about mobility and moving lots of cars quickly. However, a successful transportation system is really more about getting people where they need to go. If land use changes facilitate people being able to access destinations without needing to go very far—and to perhaps do so via an active mode—such changes should be considered a successful transportation intervention.

It will take more than simply reconfiguring our land uses. Half of all trips made in the United States are 3 mi or less, and 72% of those trips are by motor vehicle (National Household Travel Survey, 2009). 40% of all US trips are 2 mi or less with 68% driving mode share; and trips that are 1 mi or less represent 28% of all trips with 60% driving mode share (National Household Travel Survey, 2009). These trends notwithstanding, a recent national survey found that 73% of Americans feel that they have no choice but to drive as much as they currently do, while 66% of respondents want more transportation mode options (Weigel and Metz, 2010). These statistics suggest a need for improving street designs as well as our street network. Yet, our results also suggest that if we focus on street design elements without broader consideration of overall network design, we will fail to realize the multitude of benefits that come with more active travel behaviors and better health and road safety outcomes.

So, why have we been getting so much wrong for so long? One problem is that transportation professionals tend to direct their efforts at fixing individual intersections or road segments. Communities also tend to focus their interventions on trying to fix known trouble spots. Both groups tend to abstain from the planning and design of street networks. In doing so, they miss the bigger picture and the fact that street network design is what ties these individual elements together to help improve road safety, physical activity, as well as health outcomes. The Surgeon General's obesity call to action report says, "governments can create and promote policies that promote an environment in which healthy dietary and physical activity options are readily accessible" (US Department of Health and Human Services, 2001). Doing so will mean understanding the importance of the three C street network variables—compactness, connectivity, and configuration—in what should be considered standard design practice.

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PART V

# Policy education and workforce

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CHAPTER EIGHTEEN

# Barriers and enablers to change in transport and health

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## Contents



Since the mid-20th century, noncommunicable diseases (NCDs) have been taking over as the leading causes of mortality, morbidity, and rapidly rising health-care costs. First affecting wealthy nations globally, and today, increasingly impacting low- and middle-income countries also, NCDs are now leading burdens of illness that must be addressed. The United Nations (UN) has recognized this global need and the urgent crisis before our world today through three general assembly meetings focused on the high and increasing rates of NCDs. The first of such meetings occurred in 2011, the second in 2014, and the third and most recent in 2018 (World Health Organization, 2018).

Today, 41 million deaths, or 71% of all deaths, annually around the world result from NCDs, including cardiovascular diseases, chronic respiratory diseases, cancers, diabetes, and mental health conditions. Five main risk factors are key drivers of the burdens of illness from such conditions, namely, tobacco use, harmful use of alcohol, unhealthy diets, air pollution, and physical inactivity (World Health Organization, 2018). The third and most recent UN meeting has called for the advancement of universal health coverage, implementation of policies, and engagement of the public on NCDs. Among the policies to be implemented and the issues to engage the public on, "create healthy cities and environments" is on the list.

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## Barriers

Challenges cited in the UN report from its third meeting on NCDs include lack of political will and commitment; lack of policies and plans for NCDs; difficulty in priority setting; impact of economic, commercial, and market factors; insufficient technical and operational capacity; insufficient (domestic and international) financing to scale up national NCD responses; and lack of accountability (World Health Organization, 2018). This chapter will further explore these barriers as well as potential solutions to them.

One key area for creating healthy cities and environments is related to transportation systems and health. Research on transportation and its impacts on health have been growing over the past few decades. According to the World Health Organization, "urban transport systems that fail to facilitate public transport, walking and cycling, contribute to air pollution and road traffic injuries, and to physical inactivity" (World Health Organization, 2016). A lack of access to affordable transportation options may also be a barrier to access to food retail premises that may carry affordable healthier options, to health-care services, and to opportunities for social connection, all of which can also impact today's priority health outcomes.

The US Department of Health and Human Services' Community Preventive Services Task Force (US DHHS CPSTF) (2016) now recommends the following to improve health-protective factors, such as physical activity, based on a systematic review yielding sufficient scientific evidence for such interventions: "interventions to improve pedestrian or bicycle transportation systems with one or more land use and environmental design interventions." Transportation system interventions in the US DHHS Task Force recommendations include both policies and practices that can be undertaken to improve the infrastructure for and connections to amenities of streets, sidewalks, trails, bicycling, and public transit (US Department of Health and Human Services Community Preventive Services Task Force, 2016).

Just as the infrastructure of cities and municipalities globally has been crucial in impacting previous burdens of disease and ill health, namely, infectious diseases, through improvements such as sanitation, safe water and food systems, and ventilation in buildings, the time has also come for the much needed *implementation* of evidence-based infrastructure interventions, including transport-related policies and practices, in our cities and municipalities to address today's NCD epidemics. Although evidence has been growing and is now considered sufficient for action, one of the key challenges today has been the as-yet nonroutine development and implementation of wide-scale city and municipal infrastructure improvements to create healthier cities and environments needed for decreasing air pollution and improving physical activity, and also increasing access to healthier foods, health-care services, and social connection opportunities.

The issue of knowledge translation of available research evidence into actions in policies and practices to enact real-world improvements can be a key challenge in any sector. Those conducting the research are usually not the practitioners and the policymakers who enact the policies and practices in communities, states/provinces, or nationally. The process of policymaking also has many actors that can include both those working as practitioners in their particular sector and those who do not. Considerations of budgets and available resources for a particular sector's implementation initiatives are not just driven by those in that sector but also by decision-makers not bound to that sector who are prioritizing allocation of resources among multiple sectors. If these decision-makers are politicians, considerations such as public awareness and engagement on particular issues may be important drivers for decision-making.

In the realm of transport and health, challenges can be compounded further by the need for intersectoral action by multiple sectors. These sectors include not just health and transport but also urban and regional planning, as well as the housing, affordable housing, and commercial development sectors. Often, these sectors have not worked together and are siloed from one another. Over the last century the health sector, for example, has spent much of its efforts in the health-care arena, delivering care within health-care settings. When community-level interventions to improve our environments have occurred in areas such as public health, they have largely focused on the prevention and control of infectious diseases, such as municipal sanitation, food, and water safety systems. Sometimes, acute toxic hazards (e.g., chemical spill) may also be addressed. Chronic daily unhealthy condition exposures, such as urban sprawl and automobile dependency, however, have largely been unaddressed by health and health-care practitioners. In the area of the growing burdens of NCDs, health workers have primarily focused on primary, secondary, and tertiary prevention measures from within health-care settings, rather than looking outside health-care settings for upstream environmental solutions that would create more supportive conditions for physical activity, reduction of air pollution, and access to healthier foods and beverages. Primary prevention has often focused on giving patients individual advice to eat more healthily and to get more physical activity. Secondary prevention focuses on screening for diseases early within health-care visits. Tertiary prevention tries to prevent further complications of disease through medical or surgical treatments once diseases are diagnosed. On the other hand, the work of the transportation, planning, housing, and commercial development sectors has not traditionally focused on health outcomes outside of already regulated safety and infectious disease control factors enacted to address past rather than current burdens of health concerns.

## Enablers

Exceptions have occurred in areas such as tobacco control and alcohol control, however. There have also been some jurisdictions globally that have begun policy and practice knowledge translation work in the area of transport and health. There are lessons to be learned from these examples.

It is well recognized today that a key part of tobacco control and the reduction of tobacco-related burdens of disease is a need to focus on smoke-free municipal environments (US Department of Health and Human Services Community Preventive Services Task Force, 2014). Smoke-free legislation and regulations have taken root in many cities around the world, particularly in high-income countries (although it is recognized that work is still needed in many jurisdictions in medium- and low-income countries). A key component for the creation of such smoke-free environments in many cities globally has been the scientific evidence base that had accumulated over previous years on the links between exposure to second-hand environmental tobacco smoke and health risks among nonsmokers as well as workers inadvertently exposed in their occupational settings. Of the 14 factors known to affect public perception of risks, perceived control, or more accurately the lack thereof, is one key factor that can elevate risk concerns (Harvard University, 2011). Risks perceived as personally "uncontrollable" can elevate the perceptions of those risks and may assist in mobilizing public concern over such risks and the factors influencing such risks. Within tobacco control the evidence for the health risks associated with environmental tobacco smoke, not controlled by one's own choice to smoke, has helped to set the arguments for the need for protection against such involuntary exposure to second-hand smoke and has played a key role in the passage and enactment of smoke-free policies within both occupational settings (including restaurants and bars where waiters and bartenders have to work) as well as public settings. Additional factors that can increase the perceptions of risks include hazards and environments that affect children, and public awareness of the specific risks. The efforts to raise awareness about the research on the risks of environmental tobacco smoke, including for children exposed, have also assisted in the support among the public for policies that could mitigate such risks and exposures.

The evidence base that has been growing around the built environment—the human-made environment consisting of our neighborhoods, streets, buildings, and their amenities—and physical activity and air pollution, presents us an opportunity similar to the generation of evidence around environmental tobacco smoke used to help one to enact smoke-free places policies that have now occurred in many municipalities around the world. In particular, unlike interventions that counsel people individually to increase their physical activity (interventions that tend to emphasize people's control over a key risk factor), the scientific evidence on the links between community environmental factors, such as available transportation options and the design of neighborhoods and streets for safety, accessibility and affordability of such options, has the opportunity to highlight the more "uncontrollable" risks related to air pollution and physical inactivity that many people may face as a result of the environments in which they and their children live, work, go to school, and play. Efforts need to be made to continue to increase awareness of the public on the existence and growth of such evidence over the last few decades.

There are also lessons to be learned on knowledge translation progress that can be and has been made on transport and health policies and practices from jurisdictions that have worked on these issues directly in recent years. One such jurisdiction is New York City in the work that the City began during the Bloomberg administration. Such lessons have also been explored in other publications (Lee, 2020; Galeo et al., 2019; Lee, 2019; Kelly et al., 2016; Designed to Move, 2015; World Health Organization and Metropolis, 2014; Rube et al., 2014).

In New York City, under Mayor Bloomberg's administration, concerted efforts were made by the City to focus on addressing today's NCD epidemics through a comprehensive environmental and policy approach. The goal was to create a healthier city environment for supporting tobacco cessation and prevention of initiation (through efforts that included smoke-free spaces legislation and increased tobacco taxation) as well as improving dietary behaviors and physical activity, to address the three most important risk factors for the NCD epidemics in New York City. For food environments the New York City Department of Health and Mental Hygiene, the public health department with jurisdiction over New York City's five boroughs of Manhattan, the Bronx, Queens, Brooklyn, and Staten Island had begun their work focusing on the environments over which their own inspectors had jurisdictional powers for licensing and/or inspection: daycares and restaurants. Public hospitals were also targeted.

For the broader community environments that needed to be shaped by the Departments of Transportation, Planning, Housing, School Construction, Parks and Recreation, and Administrative Services/Facilities Management, partnerships and processes to develop and sustain cross-sector partnerships were key strategies. While many organizations pay lip service to the need for partnerships across sectors, very frequently, these intentions are not accompanied by resources needed to develop and maintain those partnerships and partnership processes. In New York City, in 2006, the Department of Health and Mental Hygiene invested resources into creating a dedicated Directoral position for the Built Environment and Health, along with two Masters level staff initially to support the needed partnership work. (This eventually grew to 12 staff and additional consultants with the successful procurement of multiple sources of grant funding.) The new Director was given accountability for the formation and development of partnerships with the departments and organizations that could shape the City's environments across different settings. These included the Departments of Transportation, City Planning, Housing Development, particularly, Affordable Housing Development and Preservation, School Construction, Parks and Recreation, Administrative Services/Facilities Management and other public, private, and nonprofit sector organizations who could be mobilized to develop and implement policies and practices for the built environment that could improve physical activity and healthy food and beverage access. Four focal areas emerged from this work, including the development and implementation of improved policies and practices for active transportation, active recreation, active and healthy buildings, and healthy food and beverage access. Through its concerted comprehensive environmental and policy approaches to NCD prevention and control, New York City has been one of the few jurisdictions globally to achieve early reversals in childhood obesity trends and to increase life expectancy through improvements in chronic disease outcomes, all within less than one decade of its environmental and policy-focused efforts (Sekhobo et al., 2013; Li et al., 2016). The New York City's levels of transportation-related physical activity and overall physical activity, measured with the implementation of the initiatives, have also been shown to far exceed US levels (Bartley et al., 2019).

Once a position of accountability had been created through a funded Director of Built Environment and Health position, the challenge initially was for the Director to create processes to break down silos among the different City departments and organizations from different sectors. The decision was made to partner with a built environment organization, the American Institute of Architects New York Chapter that had membership from both building architects and urban designers, to cohost a conference that would bring the different sectors effectively and efficiently together for dialog. The first annual Fit City conference occurred in New York in 2006 (American Institute of Architects New York Chapter (AIANY), 2006). The Fit City public conference had speakers from both the health and nonhealth sectors, with health speakers focused on sharing information about the current burdens of disease and the available evidence on environmental factors, including transportation factors, that could assist in addressing these health burdens. Nonhealth speakers shared previous initiatives in New York City that had started to address such environmental factors, demonstrating feasibility of such interventions within the local context. A meeting was also held after the public conference focusing on City of New York departments and their leadership and staff to discuss cross-departmental ideas for potential interventions that might be feasible and timely in the local context. Fit City conferences have now been held in multiple cities in both the United States and more globally, including Miami, Boston, London in the United Kingdom, New South Wales in Australia and Sao Paolo, Brazil, and have been used similarly to effectively and efficiently catalyze multiple sector discussions about the built environment and health, including transport and health issues (Miami Dade College Forum, 2014).

One key lesson from New York City's cross-sectoral partnership work and successes has been the important role that other sectors outside of health play in helping to determine—not just implement but also to identify and develop—key nonhealth policy and practice interventions that can be used to address health challenges within a local context. In New York the Inaugural Built Environment and Health Director relied greatly on the technical and operational knowledge, expertise, and capacities of the leadership and staff from the other sectors, including those in transportation and planning, to identify possible policies and plans within their sectors that could be feasibly implemented to improve NCD risk factors. In so doing, these cross-sectoral partners assisted the Built Environment and Health Director and staff to prioritize key feasible initiatives within their sectors in the City's particular context. Initiatives were identified by the partners who also addressed additional priorities for their sectors, such as environmental sustainability goals and/or economic development goals for specific neighborhoods that could align with the health-improvement goals. These cobenefits were frequently important components of framing proposed initiatives for political will and commitment.

Another key lesson from New York City's work lies in the different levels of policy change that could be leveraged or targeted. Very often, opportunities for policy change may be viewed primarily through legislative or regulatory spheres. From the third UN General Assembly Meeting on NCDs, on the list of policies to be implemented and the issues to engage the public on is "tighten laws and regulations." Although improved legislation and regulations can ultimately be the strongest measures for ensuring permanent changes to our environments, such policy measures can sometimes be the most difficult to change. As such, they may be better as longer term solutions, while other solutions may be better suited for the short-term wins needed for solidifying early partnerships. Many feasible early wins may lie instead in policy measures that may not require city council votes for the passage of new laws.

Smaller but important early wins may lie in the opportunities found within the administrative policies of different departments that do not require political votes but may be changed through the partnerships between the civil servants from health and nonhealth departments working together. Examples of such administrative policies include mayoral orders and directions, integration of health priorities into the goals and objectives outlined in the work and documents of different departments, and guidelines and criteria used in requests for proposals (RFPs) on development projects (City of New York, 2013). The inclusion of explicit goals and objectives for health outcomes and their risk or protective factors, for example, can be integrated into a City's Overall Master Plan, or smaller Area or Neighborhood Plans through partnerships between health departments and organizations, and urban and regional planning departments and organizations working directly on such plans or plan updates. RFPs that cities and municipalities may put out to bid for developers and design and construction firms on housing or commercial development projects, transportation projects and other infrastructure projects may be able to integrate health-promoting and health-protecting criteria, along with other criteria, on which submitted proposals are judged. In New York City, version 2 of *PlaNYC 2030* released in 2011 integrated in Public Health explicitly through a dedicated chapter. Philadelphia's Master Plan *Philadelphia 2035* similarly integrated in health goals and objectives. In New York City, affordable housing development RFPs in the later years of the Bloomberg administration included criteria for demonstrated use of health-promoting guidelines such as the Active Design Guidelines that had been developed jointly by 12 City departments, coled by the Departments of Health, Design and Construction, Planning and Transportation (City of New York, 2010).

In New York, another key component of achieving early wins in healthier built environment improvements, including transportation-related improvements, was the use of pilot initiatives to create rapid interventions that could be grounded in real-world experience by both members of the public and key stakeholder groups. Among the most famous of the pilot interventions undertaken was the pedestrianization of Times Square. Despite large numbers of pedestrians, the previous Times Square neighborhood had very limited space for them. Since a key priority for New York City Department of Transportation transitioned during the Bloomberg years from moving vehicles to improving mobility for people, initiatives began to take shape that focused on improving the public realm for pedestrians, cyclists, and transit users. With its extreme sidewalk overcrowding and the pedestrian and vehicle conflicts in the neighborhood, Times Square became a case study of what could be done—and how to do it. The City was keen to improve the pedestrian conditions in Times Square but business owners were extremely concerned that a closure of some streets to cars would negatively affect their business. In order to allay their concerns, a temporary pilot was proposed with evaluations to be undertaken for various health, safety, and business outcomes. Rather than starting with the expense and time that would be required to make a permanent pedestrian plaza in Times Square, the City proposed instead to trial out the creation of a temporary pedestrian plaza using quick, inexpensive materials. Paint was used to demarcate newly closed streets, along with plant potters to act as barriers. Temporary street furniture such as patio tables and chairs were brought onto the streets. The street closures were enacted rapidly and the various outcomes of interests were evaluated.

Evaluation results showed that pedestrian volumes further increased. Air pollution measured in the area dropped. Injuries to pedestrians—and drivers—plummeted. Retail sales soared so much so that Times Square skyrocketed to become one of the top 10 retail areas internationally after pedestrianization. Opposition waned and construction was only then begun to make these changes permanent.

Rapid and inexpensive interventions, including rapid and inexpensive pilot initiatives, are key strategies for creating momentum for change. Such interventions, often starting only with paint and other removable materials such as plant potters, can make the task of improvement seem less daunting. Paint can be laid down quickly—and if needed, removed quickly. Temporary barriers such as plant potters can both improve the aesthetics and pedestrian friendliness of our streets but are also easy to put down and remove. The lack of permanence may provide assurance for doubters and skeptics, while evaluation of health and other outcomes of concern to stakeholders can be used during temporary pilots to provide facts about the real impacts, facts that may be needed to allay the initial fears and perceptions of potential negative consequences from change. In New York City, such evaluations have now been conducted on multiple transportation-related improvement initiatives piloted throughout the five boroughs and have consistently demonstrated the outcomes seen in Times Square (City of New York, 2012) (Fig. 18.1).

Such interventions that are rapid and inexpensive also need not only be temporary pilots. In many jurisdictions the debate over transit expansion or creation, particularly rail transit infrastructure such as subway systems, can be prolonged and extensive. Digging underground and creating rail tracks can take time and can be very expensive, and heated debates over such infrastructures can occur. Either during such debates, or should needed funding for rail transit systems not be successful, a rapid method of expansion of public transit can be learned from Latin American countries and cities that have implemented Bus Rapid Transit systems. One

**Figure 18.1** Rapid and inexpensive pedestrian plaza and bike lane creation with paint and plant potters, New York, NY, United States.

example of a very successful system is the TransMilenio bus rapid transit system in Bogota, Columbia, but many other Latin American examples also exist. Such rapid bus systems are created to complement existing rail transit and local bus systems by creating networks of dedicated bus lanes on existing roads inexpensively and quickly through the use of paint. In addition, unlike most local bus systems where riders purchase tickets from the bus driver upon entry onto the bus, slowing the process of boarding the bus, bus rapid transit systems frequently provide ticket-purchasing machines at their bus stops. There are also increased distances between stops, allowing for less frequent stops. Such infrastructure can thus assist in increasing physical activity from bus rapid transit use compared with use of local buses, among able-bodied working adults and students who tend to be targets of bus rapid transit systems (Day et al., 2014) (Fig. 18.2).


**Figure 18.2** Bus only lanes to facilitate more rapid bus transportation options, New York, NY, United States.

Local buses remain important when such rapid bus systems are created in order to continue to serve those who may need more frequent stops, such as elderly populations who may rely on transit once they can no longer drive.

Finally, another key strategy is the need for public awareness and engagement. This is highlighted in both the report resulting from the third UN General Assembly Meeting on NCDs as well as the principles about the factors that impact risk perception (World Health Organization, 2018; Harvard University, 2011). Public awareness and engagement is often necessary to mobilize political will and commitment on topics of interest, and issues related to transport and health are expected to be no exception. Public awareness and engagement is also needed to increase consumer demand that industry will respond to. Without such demand by community residents and citizens, there would be little reason for many private-sector housing developers and developers of commercial and retail developments to respond in-kind and change their routine practices that can improve their developments to include healthier transportation opportunities. It is important to note that public awareness and engagement can potentially be enhanced by initiatives that focus on experiential engagement. For example, long-standing initiatives such as weekend ciclovias in many Latin American cities and more recent open streets events in North American cities provide safe and often new ways for people to experience their city streets with activities other than driving. Walking, cycling, rollerblading, and even group exercise and other social activities on streets that are temporarily closed to cars on dedicated days and times can be used to both create new experiences and public engagement on active transportation opportunities as well as provide additional opportunities for increased physical activity. Evaluations of such initiatives, such as the Summer Streets events in New York City, have shown positive impacts, including the promotion of active transportation and physical activity (Wolf et al., 2015).

Key components of New York City's successful cross-sectoral work are now being used in other jurisdictions also (Figs. 18.3 and 18.4). For example, the City of Edmonton in Alberta, Canada is updating its Master Plan. City of Edmonton's new City Plan now integrates a "Healthy City" as one of its key pillars. In Alberta, Canada, a new Housing for Health initiative funded by the Public Health Agency of Canada is working to recreate the five processes deemed essential success factors in New York City's initiatives to improve active transportation, access to active recreation, healthy food and beverage access, and more active and healthy

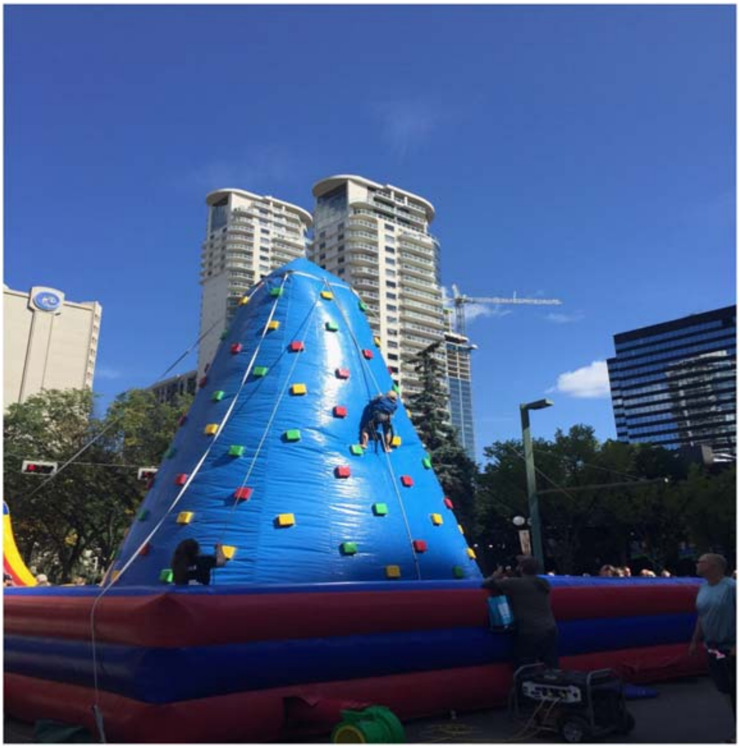

**Figure 18.3** Children's climbing structure at open streets event, Edmonton, AB, Canada.

**Figure 18.4** Experiencing active transportation modes to and at open streets event, Edmonton, AB, Canada.

buildings. In Alberta, this initiative is working to improve the planning and design of housing developments and their surrounding neighborhoods to better support physical activity, healthy food and beverage access, and social connections. The five key processes being implemented to achieve improvements to the built environment for health are (1) cross-sector partnerships among health and multiple nonhealth sectors; (2) pilot initiatives; (3) evaluation of health and other outcomes in pilots; (4) community engagement; and (5) dissemination efforts for lessons learned.

Process and content strategies such as previous have now been documented in several publications. These publications can provide additional details to the discussions found in this chapter (Lee, 2020; Galeo et al., 2019; Lee, 2019; Kelly et al., 2016; Designed to Move, 2015; World Health Organization and Metropolis, 2014; Rube et al., 2014).

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CHAPTER NINETEEN

# Moving to health transport: the drivers of transformational change - a view from Scotland

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## Contents



## Introduction

At the core of the struggle to make sustainable transport[1] the dominant and normative modes of everyday travel for the majority of populations, and which by default are health promoting, are the political leadership and organizational and cultural transformative capability. This can sweep aside the current entrenched normative travel behavior centered on the car. The urgency of the task is driven by the need for a major energy descent in order to help stabilize global average temperature rises to no more than 1.5 degrees above pre-industrial levels, as agreed at

[1] Environmentally sustainable transport by definition is a transport system which will meet the needs of future generations as well as current, drawing on the Bruntland Report's (1987) definition of sustainable development.

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the 2015 Paris Agreement on Climate Change. According to reports of the Intergovernmental Panel on Climate Change, the Lancet Commission on Health and Climate Change and many more, today's substantial global health gains are being undermined by climate change. In the United Kingdom, transport sector emissions have increased over recent decades, in contrast to other areas of public policy such as industry. So, the key driver for a move to healthy transport, this chapter suggests, is the need for rapid decarbonization of the transport sector in achieving transformational change. Transformational change is the emergence of an entirely new state prompted by a shift in what is considered possible or necessary which results in a profoundly different structure, culture, or level of performance.[2]

This decarbonization endeavor involves two major and opposing options in the road transport sector: versions of supply and demand. For the supply side, it is either the continuation of road space provision for private motor vehicles within the current dominant paradigm of predict and provide, or halting that approach through demand management. Demand, for the purposes of this chapter, is to stimulate and release suppressed and latent demand for sustainable transport. This can be achieved by increasing the supply for sustainable transport infrastructure (walking, cycling, and public transport) through road space reallocation and building new space, supported by behavior change (encouragement and social norm work). Technological advances can be applied within either supply or the demand options, for example, electric bicycles and cars, smart ticketing. Demand management also requires control of road space, including through provision, both for parked and moving vehicles, and including the use of pricing mechanisms such as workplace parking and road pricing itself.

To examine the most effective route to sustainable transport normativity, incorporating both travel behavior change (the demand) and technological advances which bring transport energy savings, Brand et al. (2018) explored four contrasting futures for Scotland that compare transport-related "lifestyle" changes and sociocultural factors. This was set against a transition pathway focussing on transport electrification and the phasing out of conventionally fuelled vehicles using a socio-technical approach (Brand et al., 2018). What they found was that the most significant impact of

[2] The definition of transformational change is taken from the Kings Fund (London, UK): https://www.kingsfund.org.uk/publications/transformational-change-health-care (accessed 14.10.19.).

lifestyle change on the transport energy system is due to reductions in the overall demand for transport energy, particularly for fossil fuels. Lower transport energy demands bring benefits for energy system costs, carbon emissions, and energy import requirements. Lifestyle change alone has a similar effect on total transport energy demand to a transition to electric vehicles with no lifestyle change. This reminds us that transport is a derived demand. It does not exist for its own sake. This has important implications for climate mitigation policy. A scenario that involves lifestyle change will place much less pressure on policy to require rapid (and potentially disruptive) technical change, including technologies at the point of use. The researchers conclude that given the many uncertainties involved in decarbonizing the transport sector, there are strong arguments for pursuing both demand and supply side solutions in order to make the path to deep decarbonization more sustainable and potentially more certain. As they conclude, "we cannot just wait for the 'technology fix.'" We might add that this applies, at the least, to all high-income countries (HICs). So, their message is—let us use all the tools available to help one to achieve the goal of energy descent in the transport sector, and this can start now with road space reallocation and behavior change to the sustainable travel modes, and an unknown contribution from technology over time.

The urgency to achieve energy descent in the transport sector perhaps perversely provides the strongest rationale for a move to healthy transport and transformative change in the transport sector. Unfortunately, environmental and economic arguments, while important, are not moving climate change policies quickly enough. Caring about our own health, however, tends to supersede all other priorities. Therefore focusing on the problems of and solutions to climate change through a health lens compliments not only the environmental and economic efforts but also, most importantly, a health framing can bring more focus and resolve to the global climate crisis. Or so Patz (2016) argues. While it might seem like a paradox, the actions taken to confront climate change today represents possibly the largest public health opportunity in more than a century. His thesis is that there is no better time to focus on health as central in the negotiations; and in so doing, we may move faster and further with effective actions on climate change and the subsequent health benefits that will arise from a low-carbon society. This thesis makes an attractive and potentially powerful case. Patz notes that the interdependence of current rates of chronic disease and the global climate crisis affords an enormous opportunity to solve both simultaneously.

## Barriers to healthy transport

So, the case may be strong that a focus on the steep carbon energy reduction required to meet even minimum thresholds of relative safety from global temperature rises is the way to go in also generating large health benefits to populations. This is to be achieved by switching to routine healthy modes of transport for the majority of the population. Yet the barriers to achieving this remain even if we can surmount the challenge from climate change deniers in charge of powerful nations.[3] This is overcoming the hegemony of the car and road building and road network expansions in UK policy-making that erects barriers to progress toward health and environmentally sustainable transport. First, providing the UK case as largely indicative of HICs, around 90% of road transport funding gets spent on highways measures to support car use, including the current £20B program of new roads and widening of major roads, launched by the Department for Transport in 2015 for England (Department for Transport, 2015). By contrast, in the United Kingdom sustainable transport receives, at best, some hundreds of £millons spread across a decade as stop—start small-scale programs, at the mercy of the favorable disposition of particular junior politicians remaining in post to defend this spend. Second, the predict and provide approach (predict motor traffic growth and then try to build sufficient road space to meet "demand") further suppresses the use of sustainable travel modes, starved of funds it locks in carbon-based private motorized transport lifestyles and erodes the efforts of the small-scale sustainable transport programs (Davis and Tapp, 2017). "Predict and provide" policies favoring private motorized traffic growth occur similarly across many other European countries. It is important to note, however, that there were exceptions, such as in The Netherlands, significantly affected by the 1972—73 oil crisis and its consequent actions to reduce transport energy use. In Denmark the Town Planning Institute in the 1940s noted the US mass motorization model of transport planning and purposefully chose not to copy it.

The result of car hegemony has at least three further major deleterious aspects on human health:

[3] For example, within the UK Government as of October 2019, Conservative Members of Parliament (MPs) were five times as likely as other MPs to vote against bills to tackle the climate crisis. Source: The Guardian newspaper, October 12, 2019. pp. 18—19.

1. Locking people into habitual car use with subsequent damage to their own physical and mental health and well-being as well as those who using sustainable travel modes are at increased traffic danger from habitual car use. This then creates a spiral of worsening environmental conditions, declining perceived safety and retreat to routine car use for those with the option.
2. In the process, health inequalities widen as the weakest (cognitively and physically impaired and children) find accessing schools, work, and routinely accessed facilities more difficult with increasingly fractured land use patterns, limited public transport services, and limited or nonexistent safe routes for active travel.
3. Further distortions in land use planning favoring dispersed activities such as edge of town retail and some health care, where distance between locations can often only be shrunk by car use.

## Disrupters of transport policy

Do we have any examples of transformational change in transport to guide us? We have examples of when the oil supplies within HICs were severely disrupted by strikes, for example, the UK fuel protest of September 2000, and a war with a subsequent oil embargo on a country. Can we learn from these enough to gauge what level of change can be achieved in altered scenarios not driven by strikes or war? The one leading to transformational change was the oil embargo. In the early 1970s, the Yom Kippur War led to an oil embargo on The Netherlands. The Prime Minister, Joop den Uyl, went on television to say that the Dutch would have to change their behaviors and be less dependent on energy but that this was possible without a decrease in the quality of life. Policies that particularly supported cycling fitted with the situation. There was already an environmental backdrop of concerns from the 1960s, including about rising car ownership, pollution, child road safety, and the destruction of housing, to make way for new roads.

In 1972 an early response to the crisis from the Dutch Government came with the publication of the Environmental Urgency Report. The report set in train the development of pollution monitoring and research, the extension of the use of levies on items harmful to the environment such as pesticides, and the encouragement of energy conservation. This led, in turn, to other new approaches so that by the late 1970s provincial governments were convinced of the need to control the growth of settlements, not least because of the rise in car use with dispersed settlements (VROM, 1983).

Part of this more integrated approach in The Netherlands involved ensuring that all new housing developments were located within cycling distance of existing facilities and that the same should apply when designing for new work and recreational facilities. This came at the same time as municipal authorities were given money to redesign streets from 1976 with segregated cycle facilities on all but residential roads following a successful national cycling demonstration project. Another factor is that The Netherlands was the most densely populated country in Europe. So, a major fault line was the oil embargo that required an immediate and substantive Government response and a set of national and local circumstances that supported change and helped transition The Netherlands' population to a less car-intensive lifestyle.

## Evidence and its uses

### Evidence at the margins

Politics is arguably the key determinant of transport policy. Attempts at evidence-based transport policy are often thwarted by ideological stances at odds with environmental sustainability and focused on road building rather than on access for all. Policy-making takes place in the context of uncertain conditions and increasingly complex policy problems. At the same time, there is an often stated desire among some policy makers to formulate policies based on the best available evidence. But the evidence has to align with what Kingdon (1995) called "the political stream". This is the standpoint of politicians, composed of such things as "public mood," pressure group campaigns, election results, and which party holds power in government. Even where evidence exists and has been presented to governments by their own agencies, they can choose to ignore it or simply select from it what they want to suit their purposes (Hunter and Visram, 2016). Davis (2016) has portrayed this relationship within national and municipal government as a bounded reality triad where evidence is a much smaller constituent part of a triad as shown in Fig. 19.1. Power and influence lies not with the evidence providers but with politicians and

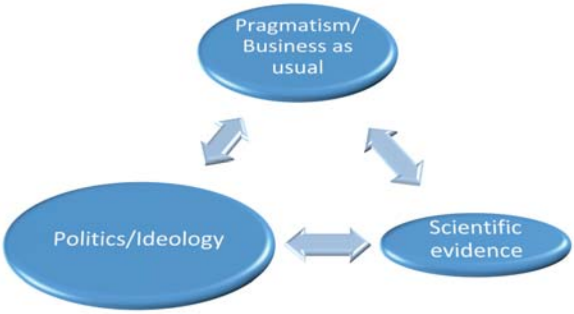


**Figure 19.1** The bounded reality triad of government work (Davis, 2016).

their ideological beliefs, tempered by incrementalism, a business as usual approach. What transpires is often evidence at the margins of policy development. In the detail, this also reflects some no go areas for politicians—including changes to funding streams largely devoted to road building.

This is, of course, a problem with human behavior at the political level, replicated across the world. Researchers in Australia report on the development of transport policy in Australian cities in recent decades and that it has been combined with land use planning and embedded within metropolitan-wide strategic plans (Legacy et al., 2017). The last 15 years have seen a rise in consensus-based processes designed around deliberation and inclusive public dialog to support these plan-making processes and the development of key policy priorities. These plans inscribe an understanding into the planning landscape that investing in urban public transport is both desired and critical; particularly, in the face of climate change or higher rates of urbanization. This is strongly coupled with an understanding that integrating land use and public transport planning can offer residents and employees the benefits of improvements to their accessibility—the ease with which they can reach the daily activities they need access to.

Yet, by 2013 there was a discernible "turn" in transport planning (echoing the United Kingdom) with the investment agenda shaped by large road infrastructure projects that rise to prominence from outside the discourse fostered by an open and evidence-based strategic planning process. Instead, the decision-making process is opaque and emerges from the political domain. The resulting proposals represent partisan policy agendas that are imposed on communities who, in turn, question the democratic and procedural legitimacy of these flagship projects. In what appears to be a continuation of a dominant policy of predict and provide in Australian cities there is now open antagonism between power wielded by elected officials and the strategic policy priorities negotiated between civil society groups and the planning bureaucracy.

The United Kingdom has witnessed a similar pathway. What was termed "multi-modalism" became accepted as the normative way of meeting transport needs from around 1998 to 2015. It involved road building and some behavior change and infrastructure projects to promote sustainable transport but largely without traffic restraint. Yet, from 2015, it had fallen back to the dominant norm where the overwhelming spend is focused on predict and provide with new road space, as it was prior to 1998 (Davis and Tapp, 2017).

## Evidence commissioned

The Dutch rebuilt their local highways infrastructure to a significant degree to make cycling perceivably and actually safe. What since then is the evidence for increasing cycling and walking levels that could be suitable across many other nations? An evidence review examined the current and potential contribution of active travel to physical activity levels and reviewed the effectiveness of active travel interventions at increasing walking, cycling, and physical activity (Sport England, 2019). The 84 studies meeting the inclusion criteria were then clustered by a series of intervention typologies:

- city- and town-wide interventions,
- building or improving routes or networks,
- social marketing, including marketing of infrastructure,
- workplace and other institution-based interventions,
- interpersonal interventions (e.g., personalized travel planning for individuals and families), and
- school-based interventions.

City- and town-wide interventions were distinguished from the other intervention typologies by virtue of their effectiveness at increasing active travel use and the fact of the approach applied being usually a combination of measures that likely provided a supporting and synergetic effect. These combinations typically included measures also in the other typological clusters. The other groups of identified typologies tend to be relatively more localized. Overall, the review concluded that there is strong evidence for the positive impact of interventions to increase active travel.

Each of the other intervention types reported some increases in walking and or cycling.

Part of the evidence-base for placing city- and town-wide interventions as the most impactful intervention type was drawn from the city-wide sustainable travel interventions in three English towns. The program (2004–09) led to increases in cycling and walking, sustained 5 years post project, while car use declined In 2004, Darlington, Peterborough, and Worcester jointly received £10 million funding from the Department for Transport for the implementation of large-scale "smarter choice" programs over a 5-year period, as part of the "Sustainable Travel Towns" (STT) demonstration project. All three towns put in place a range of initiatives aiming to encourage more use of noncar options—in particular, bus use, cycling, and walking—and to discourage single-occupancy car use. The strategies adopted by the three towns included the development of a strong brand identity, travel awareness campaigns, public transport promotion, cycling and walking promotion, school and workplace travel planning, and large-scale personal travel planning work.

An evaluation was conducted of the impacts of the STT project (Cairns and Jones, 2016). This included analysis of national data sets about local travel—in particular, Census data, National Road Traffic Estimates data, and DfT figures on bus use. As an indication of activity, the following programs took place:

- Darlington had a strong program of walking and cycling promotion, which was conducted in partnership with substantial infrastructure improvements as part of the Cycling Demonstration Town activity. Walking featured in general travel awareness, school and workplace activities, and specifically in active travel promotions run by the public health team, including the giveaway of 10,000 pedometers.
- Peterborough's Travelchoice team established enhanced working relationships with their planning colleagues. One legacy was that Development Control and Planning officers continued to stipulate robust requirements of developers in relation to sustainable travel.
- In Worcester, funding focused most on infrastructure upgrading walking/cycling links across the river, around the university, and local corridors.

The evaluation, unusually with post-project data to 2014, concluded that STT was successful in reducing travel by car and increasing the use of other modes, from a comparison with trends in other medium-sized urban areas. There was a 26%–30% increase in cycle trips per head. Overall, in the three towns, there was a reduction in total traffic levels in the order of 2%, together with a reduction of 7%—10% in the number of car driver trips per resident. A cost—benefit analysis, considering congestion benefits only, produced a benefit to cost ratio of 4.5:1 (over 4:1 is stated as "very high value for money" by the DfT).

A major question follows what was accepted as a successful intervention by the Department for Transport as funder and this is- "why was a version of the STT not funded across the rest of the country at least for towns at roughly the population scales of the three STTs?" Several authors commenting on aspects of UK politics help here. Carter and Clements (2015) note that the incoming Conservative Prime Minister in 2010, David Cameron, had largely lost an internal battle within the Conservative Party as to the importance of the environment given the significant numbers of climate change sceptics and strong links with fossil fuel industries, and with it his claim to the "greenest government ever" had failed. Melia (2018) reports on the particular role of the Secretary of State (and Deputy Prime Minister), George Osborne, in championing roads infrastructure, in particular, as a stimulus to the economy in the aftermath of the economic "crash" of 2008. In such an environment, city- and town-wide demand management was never considered as an option. Economic growth is embedded with the subliminal belief that effective interventions require major infrastructure programs, often roads. Evidence to the contrary such as noted in the Eddington Report that small-scale transport schemes can really deliver high value for money (The Eddington Transport Study, 2006) (which would include city- and town-wide demand management interventions) was heresy and taboo.

Regarding evidence on public transport effectiveness, increasing bus use can make a significant impact on carbon emissions and public health. Efforts to increase bus and train usage may not only decrease road congestion and air pollution but may also have the added health benefit of increasing the proportion of adults who obtain 30 minutes of daily physical activity. As many studies have concluded, more minutes walked per day or a greater uptake of public transport by inactive adults would likely lead to significantly greater increases in the adult population considered sufficiently active (Rissel et al., 2012; Chaix et al., 2014). The relationship between public transport and walking is important from a public health perspective because unlike the built environment, which may take a considerable amount of time and money to change, existing public transport services can be enhanced within a relatively short period of time

(Lachapelle and Norland, 2012). Rail too has an important role to play in achieving a healthier transport system not least through physical activity, most often for commuters travelling to and within urban areas.

Schemes that give buses priority, and marketing of the environmental and other benefits are important in achieving a switch from car to bus use. By way of example, a study of Bus Rapid Transit as a tool for mitigating transport-related $CO_2$ emissions along arterial routes in Dublin, Ireland, resulted in modal shift on this corridor (McDonnell et al., 2008). These results indicate that while $CO_2$ abatement was not a part of the policy rationale for implementing Quality Bus Corridors (QBC), in the absence of a QBC, $CO_2$ emissions would have been approximately 50% higher (McDonnell et al., 2008).

Across the United Kingdom, bus services outside London were privatized under the Transport Act 1985. Bus services across most local authorities were in decline before, due to rising car ownership, and have continued in decline since, but run for profit from 1986. While the advantages of bus regulation can be best summarized by the idea of the public interest, hence bus services are run in the public interest rather than on the basis of profit, this overlooks the fact that the basic underlying economics of bus operation will dictate whether such benefits can be realized. This can only be reversed through a combination of demand management measures that improve the attractiveness of the bus, that is, measures restricting car usage. Only then does regulation become effective in curbing excessive profitability and ensuring services are provided on the basis of supporting wider policy objectives.

## Scotland: climate emergencies, political leadership, and healthy transport

There are signs of transformation coming. Scotland, heralded as a world leader on climate change action,[4] has embarked on a remarkable program of Government to address climate change over and beyond existing programs.[5] The Climate Change (Scotland) Act 2019, an updating of the Climate Change (Scotland) Act 2009, saw cross-party agreement to

[4] https://www.globalcitizen.org/en/content/scotland-government-programme-climate-change/ (accessed 11.11.19.).

[5] https://www.gov.scot/policies/climate-change/ (accessed 11.11.19.).

increase the rate of reductions in emissions toward a net-zero emission target of 2045 with an interim target of a 75% cut by 2030 (up from 66%).[6]

In the detail of policy work in Scotland, in 2019, an independent review of progress on improving air quality in Scotland was requested by the senior politician (Cabinet Secretary) in charge of environment. The subsequent report to Government among its recommendations included ending road building. Arguably, such a report only 2 or 3 years earlier may well have been seen as unacceptable but this had changed in the wake of clear political commitments to a broader agenda of climate stability. The Review noted early on its concerns that road building is likely a policy at odds with a nation strongly committed to tackling climate change:

> *Managing down aspects of traditional supply is necessary, as it is strongly suspected that new road building signals the acceptability of, and provides the opportunities for, expanded use (p. 8).*[7]

More substantially, the Review Recommendations stated:

> *Additions to the existing Trunk Road and Motorway network should be significantly de-prioritised and ideally end within the next five or so years — other than for safety, maintenance and flow improvement reasons, and taking appropriate account of rural and remote needs. This is so that there is no further demand incentive offered, especially in urban areas, through the supply and expansion of these networks. Arguably, expansion at best does nothing to encourage behaviour change in supporting reduced emissions, and at worst increases emissions through actual and perceived continued infrastructure support, based on current travel behaviour. Given that analysis of the National Travel Survey shows that daily time spent travelling has remained constant over time, and vehicle km travelled have increased eight fold since 1952, it is safe to conclude that investments in new road infrastructure encourage people to travel further, and faster, by car, rather than cutting the amount of time that they spend travelling. This response to new road capacity is unhelpful from an air quality point of view (p. 46).*[8]

Such a clear statement by an independent review gives weight to Patz's thesis that framing from a health lens can bring more focus and resolve to the global climate crisis.

[6] https://www.bbc.co.uk/news/live/uk-scotland-scotland-politics-49795289 (accessed 11.11.19.).

[7] https://www.gov.scot/publications/cleaner-air-scotland-strategy-independent-review/pages/15/ (accessed 11.11.19.).

[8] The author notes his role as Chair of the Transport Working Group, although playing no role in the Steering Group and its selection of recommendations to the Scottish Government, including the abovementioned statement.

By way of response the draft National Transport Strategy appears to accept this recommendation. It says:

> *"We will not be building infrastructure to support forecast demand — we will reduce the need to travel by unsustainable modes" (Transport Scotland, 2019, p. 9).*

The Recommendation to end road building and the draft National Transport Strategy statement do not match up wholly so that Government could, it must be noted, defend road building but *not* be building infrastructure to support forecast demand. Attempts to meet only the letter of a policy but not the spirit will of course remain a challenge and sustainability advocates within and without of the Scottish Government will need to be vigilant.

Can we achieve transformational change in Scotland and what would it look like in the transport sector? The first minister has stated, in setting out their Government's work program for 2019/2020, that:

> *"The National Transport Strategy… will redefine investment priorities, putting sustainable transport at the heart of decision-making."* [9]

Looking back, Brand et al. (2018) noted that travel demand management strategies in Scotland (such as the Smarter Choices Smarter Places programme), while having a number of local successes, have failed to deliver widespread changes in mobility practices to date (Scottish Government, 2013). The emphasis has been on lifestyle changes and evolution that follows, without any lifestyle choice restrictions to date. The theory is as follows:

> *"changes in social norms and attitudes towards travel, cultural shifts away from motorisation/mobility to accessibility and an increased emphasis on resilience/less disruption. In turn, the changing attitudes and norms allow more radical policies to be implemented: for example, a ban on binge flying, a ('frequent flyer levy') and radical car restraint policies in urban areas."*

They stress that the supporting policy environment is based around soft measures, for example, smarter choices, smarter places, large scale and sustained awareness campaigns (so that people attribute their own behavior and transport choices to, say, climate disasters and high air pollution episodes), pricing incentives that favor localized trips and shorter distances, zone/access restrictions, regulation to "lock in" market transformation,

[9] https://www.gov.scot/publications/protecting-scotlands-future-governments-programme-scotland-2019-20/ (accessed 11.11.19.).

and so on. By contrast the progress for technological change is as yet unclear. A key question is whether changes in social norms and attitudes toward travel will be enough. This is very unlikely without demand management, including car parking management, as a fiscal lever. The Transport (Scotland) Act 2019 in has approved application of the Workplace Parking Levy by local highway authorities.

## Scotland at 38 degrees

If there is to be transformational change, we should no longer be including "sustainable economic growth" within the lexicon of transport strategies but rather making an important shift in language to "economic prosperity," which itself sends a powerful message of encouragement to others to think and act beyond "growth." A strategy proclaiming to be part of a zero carbon national ambition has to make the leap away from growth. Meadows et al. (1972) first showed the world that continued growth would lead to the type of ecological and societal catastrophe that the Scottish Government is committed to avoiding.

The Transport (Scotland) Act of 2019 offers "an ambitious new model for bus services." This is basically the option for local authorities to reregulate bus services in their respective areas to undo some of the damage to patronage wrought by the 1985 Transport Act that privatized most bus services across the United Kingdom. Where local highway authorities implement Workplace Parking Levy with funds ring-fenced for reinvestment in sustainable transport, the evidence from Nottingham (the only city to introduce it) is that it has enabled a step change in transport infrastructure, through levering in funding to more than double the size of the city's tram network through a £570m extension, a £60m redevelopment of the city's Railway Station and to support the city's electric Link bus network (Hallam and Gibbons, 2017).

There is a clear choice between pretending that sustainable transport is the priority yet also continuing to support motorized traffic growth and actually reversing major policy drivers set in place in the 1950s and 1960s. The alternative of a new low-carbon, health-promoting transport policy and delivery service that places walking and cycling at its core, supported by public transport, is culturally and financially new territory. The resources that need to be in place for sustainable transport in Scotland are not yet in place or agreed. This maneuver requires as much a culture change within Scotland's Government and transport delivery agencies (e.g., Transport Scotland, ScotRail) as a funding seismic shift.

Yet, every journey starts with a first step, and the Government has set out a bold challenge in the Draft National Transport Strategy and is gathering the necessary ingredients for a journey of transformative change. Driving all sustainable transport policy efforts now is the climate emergency that we can never "turn off." Patz may well be right that current rates of chronic disease and the climate crisis afford an enormous opportunity to solve both simultaneously. In the process, we may see more HIC cities across the globe reject car hegemony as unfit for purpose and national government likewise reject predict and provide and restructure their roles around facilitating and supporting demand management. It will be a gargantuan challenge for which there is no precedent. Let us revisit this issue in 2030 in seeking answers to the questions "How far did Scotland get on the road to sustainable transport as the norm?" and "How far has my country achieved transformative change to sustainable transport?".

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CHAPTER TWENTY

# The role of cross-disciplinary education, training, and workforce development at the intersection of transportation and health

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## Contents



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## Abbreviations

**CARTEEH** Center for Advancing Research in Transportation Emissions, Energy and Health
**HIA** Health impact assessment
**ISGlobal** Barcelona Institute for Global Health
**MPO** Metropolitan planning organization
**MSc** Master of Science
**NCST** National Center for Sustainable Transportation
**PEMS** Portable Emissions Measurement System
**$PM_{2.5}$** Particulate matter with a diameter less than 2.5 micrometers
**RIDOH** Rhode Island Department of Health
**TRAP** Traffic-related air pollution

## Introduction

This chapter covers education, training, and workforce development in the context of the transportation and health fields. In general, education is a process whereby individuals accumulate knowledge and enhance their intelligence (Ritchie and Tucker-Drob, 2018), training is a term that refers to building an individual's technical, interpersonal, leadership, and management skills (Toole and Martin, 2004), and workforce development is a process that improves an individual's performance in their present role and prepares them for greater responsibilities in the future (Armstrong, 2006). The relationship between education, training, and workforce development is interconnected as shown in Fig. 20.1. To elaborate, education may be used as a method to train employees so they develop their current skill set. Education may also facilitate an improved workforce by equipping employees with the necessary knowledge for their future roles and responsibilities. Furthermore, training may increase the number of employees who possess certain skills, which provides these employees with the ability to go back to the classroom and educate students using their newly acquired skills or open new horizons and curiosities for those professionals to go back to the classroom themselves. Training also translates into workforce development as it has the potential to develop workers with new skills that can be utilized in their workplace for increased responsibilities or higher roles that require the newly developed skills. Finally, workforce development improves worker performance and prepares them for increased responsibility in the future; the knowledge and experience

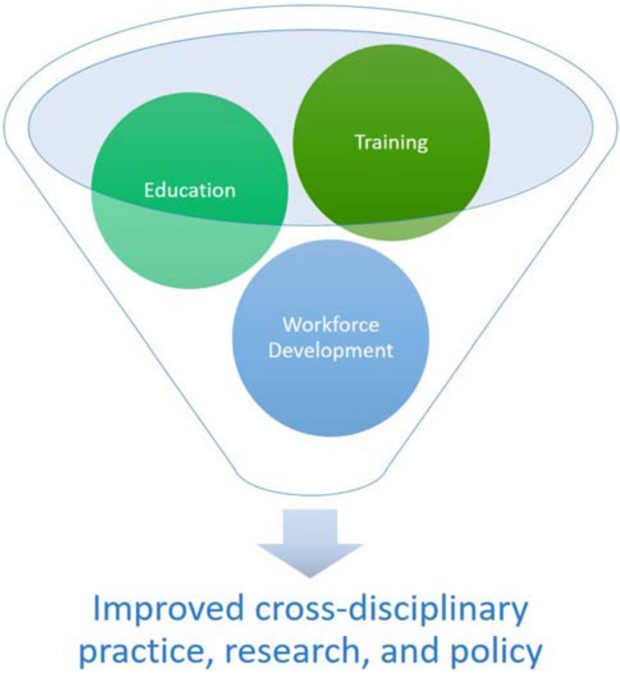


**Figure 20.1** The relationship between education, training, and workforce development.

gained from this process may be used by those workers to educate students or train their coworkers. All three elements—education, training, and workforce development—together can improve cross-disciplinary practice, research, and policy, if they themselves are cross-disciplinary in nature.

The transportation and health fields are two areas that have not traditionally worked together in the past. However, there is growing value in cross-disciplinary practice, research, and policy, and as such, new approaches are necessary for effective collaboration between these two distinct fields. In this chapter, we will discuss the current state of the transportation and health fields, education, training, workforce development, real-world perspectives, and future recommendations.

## Transportation and health

The interconnected relationship between transportation and health may not be obvious at first. After all, transportation facilitates the movement of people and goods (Khreis et al., 2019), whereas health is a state of complete physical, mental, and social well-being (World Health Organization, 1995). Nonetheless, these two fields have more connections than many realize. In fact, as many as 14 pathways have been identified linking transportation and health (Khreis et al., 2019). Fig. 20.2 displays "Transportation and Health: A Conceptual Model" which details the pathways between transportation and health. Some pathways are beneficial for health, while others are detrimental to health. For example, transportation has the potential to positively affect health through increased physical activity (e.g., biking or walking), mobility independence, green space, and aesthetics and provides access to opportunities for people to improve their health and well-being (e.g., ability to get to and from medical appointments) (Khreis et al., 2019). In contrast, transportation negatively affects health through a variety of pathways, including exposure to air pollution, noise, heat, greenhouse gas emissions and climate change, motor vehicle crashes, stress, social exclusion, contamination, electromagnetic fields, and community severance (Khreis et al., 2019). As noted in Khreis et al. (2016), cultural and economic dependence on motor vehicles as the primary mode of transport dominates urban transport design and planning, thus reducing opportunities for alternative, healthier transport modes in developed countries (Jeekel, 2013). Khreis et al. (2016) also note that although mass motorization started later in developing countries, it is growing rapidly and causing similar problems in many developing cities, too (Dargay et al., 2007). The increased use and dependence on motor vehicles has led to increased vehicle emissions and traffic-related air pollution (TRAP), which in turn adversely impact human health (Health Effects Institute, 2010; Zhang and Batterman, 2013). Such issues warrant increased cross-disciplinary expertise to solve transportation- and health-related problems with a holistic perspective. For example, engaging public health experts in environmental decision-making is necessary for reducing the risk of chronic diseases (e.g., asthma attributable to TRAP) (Burke et al., 1997). As transportation- and health-related issues become increasingly complex and intertwined, it is necessary for experts across different fields to work together to address them both adequately and comprehensively. Indeed, cross-disciplinary collaboration is necessary to promote healthy transport practices (Khreis et al., 2016), and holistic perspectives are needed to achieve healthier environments overall (Koehler et al., 2018).

As shown in Fig. 20.2, there are four interrelated transportation elements: land use and the built environment, transportation infrastructure,

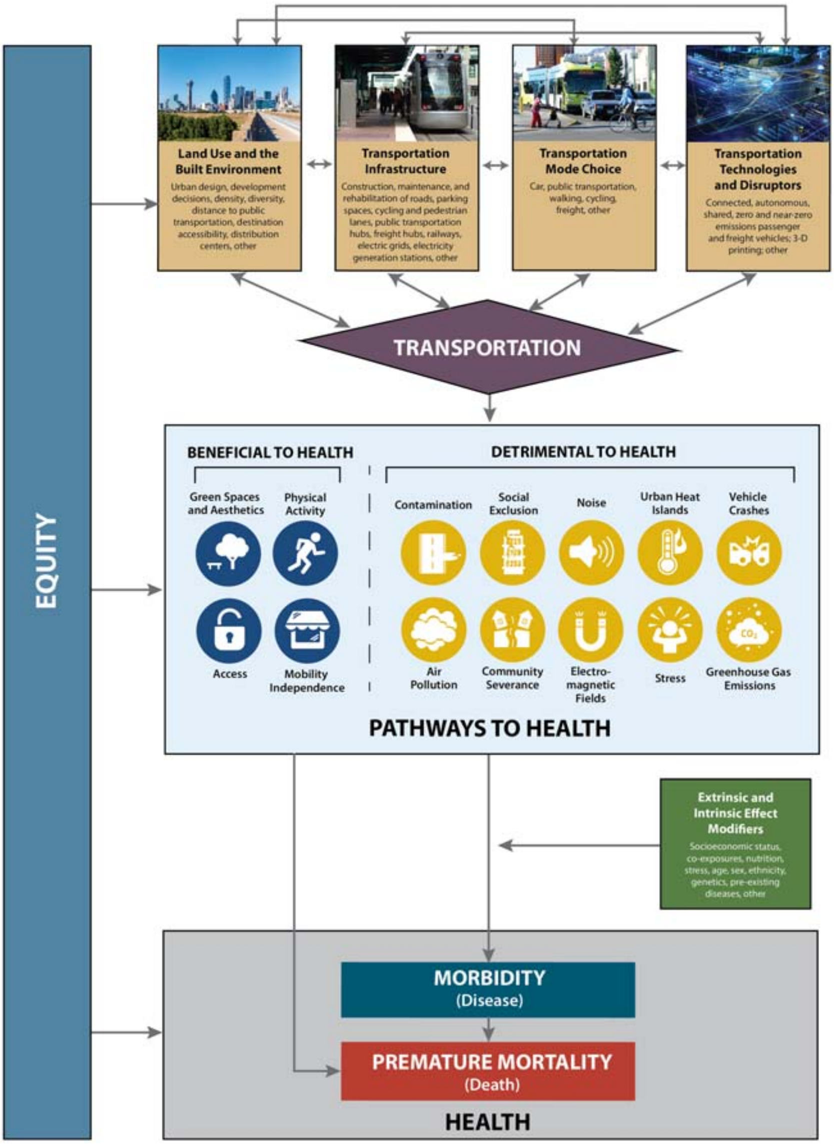


**Figure 20.2** Transportation and health: a conceptual model.

transportation mode choice, and transportation technologies and disruptors. Traditionally, the transportation field is concerned with these four elements and is limited in its ability to evaluate associated health implications. In contrast, the health field is traditionally concerned with a wide variety of individual and population health outcomes and lacks the transportation expertise on how to resolve transportation-related health effects and protect public health through the modification of upstream factors. Clearly, there is a gap in linking these two fields in practice, research, and policy, and there is a very limited number of professionals who are equipped with the necessary cross-disciplinary mind and skill set. Thus there is a great need for improved education, training, and workforce development at the intersection of transportation and health. This recommendation has also been made in a previous review, Khreis et al. (2016), that outlines specific issues that various stakeholders (e.g., transport engineers and planners, health practitioners, researchers, policy decision-makers, and public constituencies) need to address in order to better integrate health in the transportation field. For example, transport engineers and planners are recommended to consider improving health as an additional objective in their work, rather than a constraint, and to meet this goal, transport engineers and planners should be provided with easily accessible information on the relevance of considering health in their planning and design projects (Khreis et al., 2016). Furthermore, health practitioners are recommended to better understand the urban and transport planning agenda (Banister, 2002), partner with transport planners at the beginning of projects to ensure health is considered as an objective and support transport engineers and planners in conducting health impact assessments (HIAs) (Khreis et al., 2016). Finally, researchers are recommended to advocate cross-disciplinary work in becoming a central point in transport design and planning, and policymakers are encouraged to allocate funding to include health assessments in proposed transport projects (Khreis et al., 2016). The aforementioned recommendations are a small sample of a larger set of recommendations made by Khreis et al. (2016) to encourage cross-disciplinary practice, research, and policy. Unfortunately, cross-disciplinary collaboration in practice, research, and policy is lacking (Sallis et al., 2004), but a proactive approach and paradigm shift will prepare transportation and health students and workers alike for more integrated, collaborative environments. Ultimately, a more collaborative mindset and knowledge transfer across practice, research, and policy and will play a fundamental role in promoting healthy transport practices (Khreis et al., 2016).

It is also worth noting that with modern technology and resources, opportunities for collaboration are increasingly possible. Individuals are no longer limited by their geographic area or primary affiliations as their access to experts around the world is expanded with the help of online tools, such as Dropbox, Google Drive, teleconferencing applications, and cross-disciplinary data hubs, including the Center for Advancing Research in Transportation Emissions, Energy, and Health (CARTEEH) Data Hub and City Health Dashboard. Experts in one field may utilize these resources to reach out to and collaborate with experts in another field on a project requiring cross-disciplinary skill sets. For example, Khreis et al. (2016) were a collaborative paper involving transport engineering, urban planning, and research and health professionals. The work was developed over various meetings, and “full collaboration” was achieved with the use of Google Drive and emails to maintain dialogue across the authors (Khreis et al., 2016). Another notable resource is the CARTEEH Data Hub that hosts data on topics spanning the transportation, energy, emissions, air quality, exposure, health, and technology fields (Center for Advancing Research in Transportation Emissions Energy and Health, n.d.). The purpose of the data hub is to organize, share, and link data relevant to transportation emission and human health (Center for Advancing Research in Transportation Emissions Energy and Health, n.d.). Before, data barriers between transportation and health (e.g., heterogeneous methodologies) may have hindered collaboration between the two fields, but now the CARTEEH Data Hub provides an accessible platform that may be utilized to integrate data across the transportation and health disciplines. Furthermore, the City Health Dashboard houses data on 37 different measures across clinical care, health behaviors, social and economic factors, the physical environment, and health outcomes for the 500 largest cities in the United States (NYU Langone Health, 2019a). The database is a “one-stop resource for comprehensive, reliable data” that aids in painting a clear picture of community challenges and how to address them in order to improve health (NYU Langone Health, 2019a). Furthermore, a useful cross-disciplinary feature in the City Health Dashboard is the “Take Action” page, which compiles external resources related to the dashboard’s measures and promotes collaboration by listing various opportunities, such as finding partners and funding (NYU Langone Health, 2019b). The City Health Dashboard not only compiles data across different topics, but it also facilitates various connections, thus promoting collaborative efforts and opportunities. Ultimately, a variety of technological tools and resources have the power to promote increased collaboration between transportation and health students, professionals, researchers, and policymakers.

## Education

Education is the process whereby individuals accumulate knowledge and enhance their intelligence (Ritchie and Tucker-Drob, 2018). It is important because it is the gateway to information for many individuals. Education may supplement training and help create well-informed, knowledgeable employees for the workforce. However, the current structure of the education system is lacking in its cross-disciplinary nature. Traditionally, subjects are taught in an isolated manner. Consequently, students have limited opportunities to work with and learn from students in other disciplines. For example, transportation engineering students currently have limited to nonexistent health courses required in their degree plan, and public health students have limited to nonexistent transportation or urban planning courses required for their degree plan. Typically, most educational overlap between transportation and health students is found in the core courses (e.g., general introductory courses, such as English, and political science) as higher level courses are usually more specific to each major. Although there is some overlap, cross-disciplinary opportunities are still insufficient and depend a lot on instructors' experiences and interests. For real-world perspective, students from engineering, urban planning, and public health shared their educational experiences in the following sections.

### Engineering education

"I have a bachelor's degree in civil engineering, and my master's degree is in transportation engineering, which is one of the civil engineering areas of specialization. Generally speaking, civil engineers aim to plan, design, operate and construct infrastructure, houses, bridges, highways, harbors, airports, etc. Transportation engineers are trained to plan transportation within cities, design and construct transportation infrastructure (e.g. highways, intersections and pavements) and improve transportation safety. In both the bachelor and graduate programs in civil engineering, we had some cross-disciplinary courses, such as architectural design, urban planning, hydraulics, econometrics, etc. However, none of them overlapped with public health. Despite the proven impacts of transportation on public health, I cannot remember any discussion around the relationship between civil engineering or transportation and public health in our courses."

## Urban planning education

"In both my Bachelor and Master of Urban Planning programs I was housed within the larger College of Architecture. As a result, I was often in classes with architects, landscape architects, environmental scientists and urban designers. There were instances in which students from more distantly related disciplines, such as civil engineering and public policy, would also be in my classes. Several courses I took were composed of integrated material that spoke to a cross-disciplinary audience. These courses focused on topics pertaining to the creation of sustainable communities, the study of urban ecology and developing healthy communities. Urban planning as a practice is responsive to the needs and issues that are cultivated by urban environments, which inherently requires cross-disciplinary collaboration between a multitude of professional expertise. I believe that this dependency on cross-disciplinary collaboration was reflected in both the content of the courses I have taken and the demography of students." Notably, this student acknowledges the limited collaboration between urban planning and public health students. "There was one course called 'Healthy Communities' that was cross listed between Urban Planning and Public Health. That was the only class that I had with a considerable number of public health students. We mainly collaborated through class discussion, but I don't recall any specific assignment that required us to apply our distinct knowledge bases to address some cross-disciplinary issue. The Healthy Communities class was lecture-based, and our class meetings were spent listening to a lecture, rather than collaborating with peers."

## Public health education

"My college education was focused in the public health area. As a student, I took a variety of courses geared toward public health. Some courses I completed include: Biological Bases of Public Health, The Environment and Public Health, Public Health Communication and Writing, Data Management and Assessment, Epidemiology, Health Policy and Advocacy, Project Management and Emergency Management in Public Health. The topics covered spanned the environment, communication, data, policy and management. The diverse nature of public health courses allowed students to gain knowledge about different areas. However, it is important to note the courses were taught in the context of public health. Thus, public health students were limited to a more health-oriented perspective, rather than integrating other field perspectives into their studies. Course collaboration with other majors would benefit students by preparing them for cross-disciplinary roles involving other professionals. I would have appreciated more opportunities to learn with and from different majors to gain different perspectives of certain topics. Although public health is more cross-disciplinary in nature, major gaps still remain in linking health to other fields of study."

Unfortunately, the current segregated course format creates gaps between transportation engineering and planning and public health students, which typically carries over into the workplace. This gap is important to address because there is a growing value in cross-disciplinary skills. There is a limited but growing number of transportation-health job opportunities as seen by various job postings seeking professionals who have knowledge across these two distinct fields. In order to best prepare students for these types of positions and to think more holistically about connected issues, it is imperative to shift the current education system to include more collaborative, cross-disciplinary opportunities. Koehler et al. (2018) recommend that educational silos between disciplines be broken down and yield to cross-disciplinary skills and methods. In this way, students will have an increased capacity to promote a better world by expanding their narrow focus to account for more factors, such as health, in their future careers. MacKenzie et al. (2018) highlight, "More than ever before, it is important that students learn effective communications and... advocacy skills, leadership and negotiation skills and a systems approach for identifying sustainable public health solutions."

## Cross-disciplinary curriculum

One strategy to integrate different fields of study in an educational setting is developing and implementing cross-disciplinary curriculum. This would provide students at the undergraduate and/or graduate levels the opportunity to complete courses that provide more integrated approaches and cross-disciplinary perspectives. Koehler et al. (2018) highlight that there is a need for strengthened curricula and electives in environmental health programs that span across transportation, energy, planning, and health disciplines. It has also been recommended that interdisciplinary courses be developed to link the built environment (e.g., transportation) and public health (Koehler et al., 2018). Four examples of cross-disciplinary curricula are described next. These are only select examples based on our knowledge and are not meant to be an exhaustive or representative list. The first two originate from the University of Leeds, United Kingdom, which provides international examples, the second comes from The National Center for Sustainable Transportation (NCST) and Georgia Institute of Technology School of Civil and Environmental Engineering, and the third was developed by CARTEEH.

### *Healthy cities: transport and health*

At the University of Leeds, United Kingdom, "Healthy Cities: Transport and Health" is a cross-disciplinary course designed to provide students with knowledge about transport planning for healthy cities (Jopson, n.d.). The course aims to integrate transportation planning and health perspectives and bring awareness to the importance of decision-making through a variety of teaching methods, including traditional lectures, private study, and group learning. Course learning objectives include understanding the role of transportation in healthy cities, understanding the contribution of healthy cities to wider sustainability objectives, demonstrating critical awareness of a variety of options available to planners to promote health through appropriate transport choices, and understanding the importance of decision-making, demographic trends, and cultural differences in understanding and promoting healthy cities (Jopson, n.d.). The cross-disciplinary course topics paired with a variety of interactive teaching methods affords students the opportunity to learn more about the relationship between transportation and health from their instructor and fellow classmates. At the end of the course, students will be able to apply the cross-disciplinary knowledge they learned into other courses, research and work.

### *Master of Science in Sustainable Cities*

Also at the University of Leeds, United Kingdom, the Master of Science in Sustainable Cities graduate program aims to equip students with skills necessary for becoming an urban sustainability leader by taking a "systems approach" to teaching about sustainable cities (University of Leeds, 2019). This program integrates urbanism and sustainability concepts through applied, problem-based learning approaches. Participants learn about energy systems, transportation networks, housing provision, health impacts, and urban ecosystems; apply their problem-solving-based knowledge to different practical; cases and complete a research project, which allows them to apply their knowledge to a real-world issue.

Required modules for this program include Cities and Sustainability, Research and Skills for Urban Sustainability, City Systems: Energy, City Systems: Sustainable Housing, City Systems: Mobility, City Systems: Urban Ecosystems and Research Project and Leadership for Sustainability (University of Leeds, 2019). Sustainability is a central focus of the program; however, other disciplines, such as energy and mobility, are integrated into the curriculum as well. The cross-disciplinary nature of the program serves to create and develop urban sustainability leaders of the future who will work to solve "urban sustainability crises of climate change, ecosystem degradation, socio-economic exclusion and urban pollution" (University of Leeds, 2019). A key highlight of this program is in utilizing cross-disciplinary strengths across its faculty so that students are able to gain "a critical understanding of the concepts of sustainability and urban theory, a new [basket] of tools, techniques and methods to address urban problems using action research, deep systems knowledge on the potential for change in each system and new leadership and research skills" (University of Leeds, 2019).

### *Sustainable transportation curricula*

NCST along with Georgia Institute of Technology School of Civil and Environmental Engineering developed a comprehensive, cross-disciplinary curricula outline titled "Sustainable Transportation Curricula" (Cruz et al., 2015), which focused on integrating sustainability and transportation. The goal of the curricula was to develop sustainable transportation courses focused on teaching practical ways to analyze the impacts of transportation on the environment, economics, and social sustainability; as a result, it would help produce graduates or train practitioners that are knowledgeable, skilled, and well prepared for transportation sustainability practice (Cruz et al., 2015). NCST developed their materials with the aim to integrate traditionally isolated fields and help students understand the cross-disciplinary nature of transportation sustainability, rather than maintain educational silos. The potential course modules listed in the curricula outline include urban infrastructure systems and sustainability, environmental and social impact assessment, urban economics and resource economics, land use planning, transportation planning and sustainability, sustainable transportation policy, transportation system performance, asset management for sustainability analysis, transportation and energy, transportation and air quality, transportation impact assessment (environment, economic, and societal impacts), sustainability education, sustainable freight systems and goods movement, sustainability modeling tools, and case studies in transportation sustainability. The aim of the courses is to integrate sustainability principles (environment, economic, and social) across transportation-related activities (policy and planning, design and construction and operations, and maintenance and end-of-life) as well as integrate practical analytical frameworks and modeling tools (Cruz et al., 2015). A key recommendation from NCST is that there is a need to collaborate with different disciplines as it is a great challenge to help students think holistically about sustainability in transportation (Cruz et al., 2015). Integrated approaches will enable students to think more comprehensively, thus better preparing them for work in cross-disciplinary fields and problem-solving.

### *Traffic-related air pollution: emissions, human exposures, and health*

CARTEEH has set out to develop a unique, cross-disciplinary curriculum titled "Traffic-Related Air Pollution: Emissions, Human Exposures and Health" (Khreis, 2019) to bridge the gap between transportation and health in education. This curriculum is designed to integrate the engineering, urban planning, health, and policy fields in a graduate-level course. The objective of the course is to equip participants with the cutting-edge knowledge and skill sets required to understand, assess, and quantify road traffic, vehicle emissions, TRAP, human exposures, biological mechanisms, associated health effects, population-based impacts, and their societal cost in addition to exploring the role of environmental regulation, policymaking, and practice (Khreis, 2019). Three different tracks (health track, transportation track, and planning and policy track) will be offered for the course that will tailor to participants' existing knowledge. For example, the health track is targeted toward transportation, urban planning, and engineering students who have limited public health knowledge. The health track serves to fill health gaps in students with minimal knowledge in this area and will enrich their understanding on the relationship between transport and health. Lectures from this course may be used in its entirety or lectures may be mixed and matched to fit the needs of different student populations. A modified course based on the CARTEEH curriculum was piloted at Georgia Institute of Technology in Spring 2019 as a special topic titled "Transportation and Health." A description provided in the syllabus states the course: "Examines the linkage between transportation and human health in both a population and occupational sense. Explores the role in which public and private decision making and engineering design of transportation systems influences public health" (Rodgers, 2019). Dr. Michael Rodgers served as the primary instructor and was aided by Dr. Haobing Liu, Davide Ederer, Michael Garber, Dr. Sandra Willis and Mary Fox, who all have different expertise and skills spanning emissions and dispersion modeling and public health. Thirty-four students from seven different majors were represented in the course. Grading was determined by discussion participation, quizzes, assignments, and projects. Two projects were to be completed throughout the semester, one of which focused on mobile source emissions estimation, and the other focused on air pollution exposure and health assessment. Projects were weighted most heavily and involved small group collaboration, which provided students the opportunity to work with people from different majors to accomplish a common goal.

### *Possible topics for other transportation and health cross-disciplinary curricula*

Further topics that may be considered for inclusion in other transportation and health cross-disciplinary curricula developments are outlined in Table 20.1. This table does not represent an exhaustive list of relevant topics but rather provides a general overview of suggested topics for consideration.

Although cross-disciplinary curriculum development and implementation is a step in the right direction, there is still much progress to be made in integrating the transportation and health fields in an educational setting.

## Training and workforce development

Training refers to the process of building an individual's technical, interpersonal, and leadership and management skills (Toole and Martin, 2004). Training is important because it helps individuals expand their skill set, and they can use their skills to educate others or prepare for greater responsibilities and higher roles in the workplace. Training may be supplemented with educational elements, such as an informational module (e.g., slide set informing workers how to use a new software), and it has the potential to enhance workforce development by equipping workers with new skills that are needed for higher roles. Because training plays a valuable role, it is important that the right approach be taken, especially

**Table 20.1** Possible topics for other transportation and health cross-disciplinary curricula.

| | |
|---|---|
| Transportation | Active transportation |
| Traffic emissions | Transportation modes |
| Air quality | Traffic-related air pollution |
| Green spaces | Physical activity |
| Mobility independence | Access |
| Social exclusion | Contamination |
| Traffic noise | Community severance |
| Stress | Heat |
| Greenhouse gases | Motor vehicle crashes |
| Electromagnetic fields | Mental health |
| Human exposures | Animal exposures and biological mechanisms |
| Health impacts | Burden of disease |
| Occupational health | Strategies to mitigate health impacts |
| Policy and decision-making | Economic impacts |
| Sustainability | Urban and transportation planning |
| Urban design | Land use and the built environment |
| Transportation infrastructure | Connected, autonomous, shared and electric vehicles |
| Transportation in developing and developed countries | Alternative fuel technology |
| Community partnerships | Stakeholder engagement |
| Program evaluation | Research skills and methods |
| Equity and justice | Progressive urban planning |

in a transportation and health context. As mentioned previously, cross-disciplinary collaboration in practice, research, and policy is lacking (Sallis et al., 2004), and shifting toward a cross-disciplinary mindset will require the appropriate training. For example, decisions regarding whether cities should develop new transit systems or shift toward electric vehicles will require adequate tools and training if future workers (e.g., planners and engineers) are to accurately assess the economic costs, energy and emissions impacts of these changes (Cruz et al., 2015), and as importantly, the health impacts of such decisions. In addition, initiatives, such as Public Health 3.0 from the US Department of Health and Human Services, reiterate the need for cross-disciplinary collaboration in order to make impactful health improvements, which in turn has important implications for training students (DeSalvo et al., 2016; MacKenzie et al., 2018). Thus integrative training methods are necessary for developing well-rounded individuals. One way to promote this would be hosting cross-disciplinary, application-based seminars, webinars, or short courses in order to reach a broader audience and promote idea sharing across different disciplines and expertise. Previous cross-disciplinary seminars include "Perspectives on Transportation Emissions, Exposures, and Health" with Nieuwenhuijsen (2017), "Use and Applications of Low-Cost Air Quality Sensors" with Polidori (2018), "High-Performance Computing Solutions for Real-World Transportation Systems Understanding" with Macfarlane (2019), and "Traffic Pollution, Health and the Theory of Everything" with Sarnat (2019) hosted by CARTEEH. These seminars were livestreamed and available as a webinar so others could attend and participate online, too. In addition, the Barcelona Institute for Global Health hosted cross-disciplinary seminars on the following topics: "Home is Where the Health Is: Housing and inequities in the U.S." (Mehdipanah, 2019), "Wearable Cameras: Potential Applications in Environmental Exposure Assessment" (Tonne, 2019), "Socio-environmental Exposures and Neurodevelopmental Disorders" (Suades, 2018), and "Modelling the Health and Economic Impact of Built Environment Interventions" (Zapata-Diomedi, 2018) to name a few. Furthermore, cross-disciplinary short courses may also be valuable for training. The Oxford Leadership Program hosts "Global Challenges in Transport" that is composed of four short courses covering infrastructure, climate change, smart technologies, and health and well-being (Transport Studies Unit, 2019a). The courses serve to encourage participants to "share knowledge, think critically and generate ideas within the transport policy/planning arena to address the complex challenges of sustainable transport futures" (Transport Studies Unit, 2019a). In particular, the "Global Challenges in Transport: Health and Wellbeing" short course is a 4-day course that covers the "complex relationships between forms of transport and mobility, with health and wellbeing," through group teaching, critical thinking, and debate (Transport Studies Unit, 2019b). The interactive course format provides participants with cross-disciplinary perspectives on transport planning and health topics and affords them a certificate upon completion of the course. Ultimately, cross-disciplinary training is valuable because it provides opportunities for workers to develop skills beyond their traditional field.

Furthermore, workforce development is a process that improves individual performance in their present role and prepares them for greater responsibilities in the future (Armstrong, 2006). Workforce development is important because it increases worker quality and creates workers who can in turn educate students or train coworkers using the knowledge and experience they have gained. In a cross-disciplinary setting, workforce development provides an opportunity for workers to grow both professionally and personally by enabling them to learn and gain experience from a different field. For example, a transportation-based employer might fund one of their employees to obtain higher education in a health-related field or vice versa. Furthermore, employers may sponsor employees to attend a conference beyond their traditional field. For example, a public health employee might attend a transportation conference, or a transportation employee might attend an environmental health conference. In this way, workforce development would help facilitate a well-rounded employee who is knowledgeable across different disciplines, and therefore better prepared for higher responsibility and real-world cross-disciplinary issues and required solutions. Another method to improve workforce development might involve employers implementing internal programs that support worker development and advancement toward cross-disciplinary knowledge, skills, and mindsets. For example, a previous undergraduate public health intern at CARTEEH was given the opportunity to work full time with transportation experts as a research assistant upon graduation. The transition not only afforded the intern full-time job experience, but it also helped them to develop knowledge and skills in the transportation field they might not have developed otherwise. This opportunity developed the worker by enhancing their transportation mindset, allowing them to share their public health knowledge with other workers and providing them with firsthand experience in a transportation and health cross-disciplinary environment. Training and workforce development, along with education, have the ability to promote well-rounded students and workers that are prepared for cross-disciplinary environments.

## Real-world experiences in a cross-disciplinary setting

This section reviews real-world perspectives on the transportation and health cross-disciplinary experience. Firsthand thoughts and experiences are documented from CARTEEH senior staff members who have years of experience in the workforce, younger CARTEEH interns who are college undergraduate students, Johns Hopkins Bloomberg American Health Initiative staff who provide public health perspectives, and from other selected professionals we know who have experience in cross-disciplinary settings.

## Center for advancing research in transportation emissions, energy, and health senior staff experience

A group of senior staff at CARTEEH was interviewed to understand their perspectives and provide insight on cross-disciplinary work. They were asked to describe their education and work background, their experience working in a transportation and health cross-disciplinary environment and provide recommendations on how education, training, and workforce development can be improved to prepare students and employees for cross-disciplinary work.

Many CARTEEH senior staff agree that there is value in increasing cross-disciplinary opportunities. Dr. Ann Xu has background in transportation engineering, statistics, data, and energy, and she emphasizes the importance of broadening horizons through experiences. She recommends increasing opportunities for project-based experiences where individuals can apply their knowledge. In addition, Dr. Tara Ramani, whose background is in civil and transportation engineering and urban planning, states, "offering cross-disciplinary courses at university (for example, a health and transportation certificate program) or just having people from different disciplines work together on projects or to solve problems can go a long way. Any kind of dialogue or knowledge exchange is ultimately what ensures success of cross-disciplinary research." Further, Dr. Suriya Vallamsundar, whose background is also in engineering, specifically civil and environmental, recommends, "having guest lectures/seminars from different fields, collaborating with researchers from other departments, hiring students from different fields for research positions and partnering with the industry on projects and having students involved," to encourage more cross-disciplinary opportunities. In her opinion, "Although, there has been a lot of progress to move away from the 'silo' nature, still there is a lot of disconnect between the fields in terms of sharing of concepts, and data (including resolution matching). A possible reason could be due to the difficulty of collaboration or difficulty in learning from each other's fields."

While there is value in increasing cross-disciplinary opportunities, it is important to note the various challenges associated with cross-disciplinary settings. For example, Dr. Xu mentions, "cross-disciplinary collaboration is difficult to do" and highlights some limitations by explaining how work is usually done in a siloed fashion and that there are currently a limited amount of opportunities in cross-disciplinary settings in the first place; the bottom line is that we need more cross-disciplinary opportunities. Furthermore, Dr. Meitiv, who has varied work experience and educational background in physics, and Dr. Ramani point out the fact that people from different disciplines do not necessarily speak the same language. Jargon and different problem-solving styles from different fields are a barrier to cross-disciplinary collaboration and must be remedied for efficient collaboration between transportation and health disciplines.

Regardless of the various limitations in integrating the transportation and health fields, there are great strengths and possibilities in integrating the two fields. Dr. Vallamsundar elaborates on this point and states, "the only way we can address problems of climate change, expanding carbon footprint, urban sprawl and health impacts is to take a cross-disciplinary approach. An integrated approach between these different fields will help in the seamless flow of knowledge, data and skills thereby enabling to model the cause-and-effect chain between the source (people's activities) and effect (health and air quality)." It is imperative that continued effort be made in bridging the transportation and health fields and providing more opportunities for cross-disciplinary experiences.

## Center for advancing research in transportation emissions, energy, and health internship experience

Each year, CARTEEH selects a group of undergraduate students from engineering, urban planning, and health backgrounds to participate in a 10-week long internship program. Each intern completes a research project working with a mentor and gains experience working in a cross-disciplinary environment. In this section, we provide firsthand perspectives about the cross-disciplinary experience from the 2019 CARTEEH interns, Alexander Yu, Kathleen Weil, John Medeiros, and Jillian Barthelemy.

Alexander Yu is a mechanical engineering student at the University of California, Riverside in Riverside, California. Alexander had previous experience with a portable emissions measurement system testing and training before his CARTEEH internship. In addition, he was exposed to "advanced coursework which taught dispersion and the effects of particulate matter with a diameter less than 2.5 micrometers ($PM_{2.5}$)." Thus Alexander felt well prepared to work in a cross-disciplinary environment. He further states, "I think all students should take a course studying particulate matter and its health effects."

Kathleen Weil is an environmental engineering student at Georgia Institute of Technology in Atlanta, Georgia. Kathleen states she felt well prepared for the CARTEEH internship because of her "study abroad classes about sustainable transportation which provided a framework for cross-disciplinary problem solving... With students from five different countries with a variety of majors, our learning environment provided opportunities for well-rounded and cross-disciplinary discussion." Similar to Alexander, Kathleen felt prepared for a cross-disciplinary environment; however, her preparation stemmed from a study abroad experience rather than from working in an emissions lab. Although Kathleen felt prepared, she further expressed how her intern experience served to enhance her knowledge. She explains, "Before the internship, I was aware of a connection between particulate matter and lung health. Now, I have a much more comprehensive and nuanced understanding of the variety of health effects from all types of emissions... I also understand how these relationships are calculated and modeled, including specific model advantages and disadvantages and their appropriateness for certain contexts." Furthermore, she states, "I think training and education can be improved with more problem solving-based learning, in class and professional environments. Problem-solving is most effective with a diverse team, so this path would benefit from more collaboration and cross-disciplinary perspectives. I believe that having concrete applications improves understanding and having different perspectives throughout the process adds more nuance and balance to the discussion and final result." While Alexander and Kathleen's unique background prepared them for work in a cross-disciplinary environment, it is important to note that many undergraduate students do not have similar educational opportunities exposing them to the interconnected relationship between transportation and health.

John Medeiros is a civil and environmental engineering student at Texas A&M University in College Station, Texas. His perspective on cross-disciplinary environment strengths is as follows: "The greatest strength of a cross-disciplinary environment is the combination of diverse experiences and ... expertise of all the workers. This then allows for research and projects to be carried out in a more comprehensive manner [creating] better connection and analysis of the various aspects of transportation and health [and] their relation to each other, which is essential for addressing issues and devising solutions." During his experience, he recognized the value in collaborating with individuals beyond his area of expertise. Like Alexander, John believes, "training and education can be improved with greater course selection and flexibility... to obtain knowledge about a variety of subjects." Furthermore, he states, "higher level courses or electives could be designed to imitate the work... in a future [cross-disciplinary] career and help the students apply knowledge gained in previous course work, such as designing and following a project or product from start to finish while working with a team of [cross-disciplinary] students."

Jillian Barthelemy is also a student at Texas A&M University in College Station, Texas. Unlike the abovementioned engineering interns, she studies public health with a minor in sociology. Prior to her internship with CARTEEH, she had experience in an environmental health lab analyzing substances via mass spectrometry and gas chromatography. She explained her limited understanding of transportation and health links before her internship, "When I thought about transportation and health, the biggest things that came to mind were car crashes and air pollution. I did not have an in-depth understanding of the linkages between the two." She feels "there is a huge need for more collaboration opportunities between majors" and goes on to explain the "noticeable difference" between how she, a public health major, and other interns with an engineering background approached problems. Each intern's unique background provided them with a certain mindset that, when used in collaboration, was helpful in developing each of their work. Jillian states, "I think within a major, we all start to think similarly and approach problems the same way. It is important to have more cross-disciplinary courses in order to prevent a group think mentality." In addition, Jillian took note of the existing gaps between transportation and health opportunities in the classroom and beyond: "I did not feel like I had any experiences that had prepared me for the transportation-health intersections. Most public health classes will generally discuss how transportation pollutants negatively impact health, but none of them [give] an in-depth explanation for the link between the two." Furthermore, "There is a lack of companies and research that look into the transportation and health intersection. Hopefully with time, it becomes a more popular environment because there is potential for a lot of greatness."

In summary, each of the abovementioned interns came from diverse backgrounds and agrees that more cross-disciplinary opportunities are necessary for a holistic, enriching education. It is imperative we begin preparing today's students with the appropriate cross-disciplinary education and experience to set them up for success as tomorrow's leaders.

## Johns Hopkins Bloomberg American Health Initiative

The Johns Hopkins Bloomberg American Health Initiative strives to improve health by tackling five critical public health challenges in the United States through education, research, and practice (Sharfstein et al., 2018). The five areas of interest include addiction and overdose, adolescent health, obesity and the food system, violence, and environmental challenges (Johns Hopking Bloomberg School of Public Health, 2019). Emphasis is placed on the importance of collaborative efforts between the transportation, energy, planning and health fields for a systems approach in tackling environmental challenges. Dr. Mary Fox, assistant professor of health policy and management at Johns Hopkins Bloomberg School of Public Health, is involved in the initiative and elaborates on the importance of cross-disciplinary training: "People with cross-disciplinary training can be more effective in technical and research work because they are more likely to know where the most important data gaps are," and "an understanding of policy-making (beyond research/technical work) makes people more effective in field work." She further points out, "When resources are limited, cross-disciplinary training may help you build partnerships to get things done." Dr. Fox also notes strengths and challenges associated with cross-disciplinary training. Strengths include, "better communication skills and more information to communicate" and "potential for research collaboration." On the other hand, challenges include "building shared language and terminology" and "making the training interesting and engaging for multiple audiences."

## Other cross-disciplinary professional experience

In addition to the above groups, other professionals with cross-disciplinary experience related to transportation and health were contacted for their input. Their experiences and recommendations are described next.

Dr. Greg Griffin, assistant professor of urban and regional planning at the University of Texas at San Antonio, shared his perspective on "integrating health into transportation planning in professional practice with a metropolitan planning organization (MPO), in research on active transportation and in working with students to integrate our thinking across fields." He elaborates, "My health planning course, for instance, pulls in students from architecture, public administration, urban planning and other disciplines to survey the intersection of public health and planning. We delve into the roles of equity and location of health amenities, biophilic (nature-loving) design and healing, architecture, healthy aging, food systems and the role of emerging technologies. We also engage in practical exercises such as health impact analysis, evaluation of plans for health goals and actions and public communication of health planning needs via an op-ed or blogs. This perspective pulls thinkers and do-ers out of focusing in disciplinary silos—recognizing that each field has both immediate outputs (like bike lanes improving crash rates), but also broader impacts (like increased physical activity to mitigate leading causes of disease). Even though coursework, urban plans and government programs have silos, we find ways to build bridges for transdisciplinary health solutions."

Mr. Julian Drix is currently the Asthma Program Manager at the Rhode Island Department of Health (RIDOH) and was a Johns Hopkins Bloomberg American Health Initiative Fellow. As a Bloomberg Fellow focused on environmental challenges, Mr. Drix "had the opportunity to participate in classes and other learning opportunities that intentionally crossed-disciplined and focused on the underlying systems that need to be changed. For example, I took a class 'A Built Environment for a Healthy and Sustainable Future' that had lectures focused on transportation systems and health. At the Bloomberg American Health Initiative's symposium on environmental challenges, I was able to participate in a roundtable discussion on transportation and air quality." Mr. Drix highlights, "The intersection between academic learning and applied public health practice was enhanced by the Bloomberg American Health Initiative fellowship. My practicum and capstone research projects focused on the health, climate, and environmental justice impacts of freight systems and ports. This inherently required cross-sector engagement and learning to bring together health, environment, and transportation systems." Beyond the educational realm, Mr. Drix states, "some of the best opportunities for learning came through public health practice of working at a state health department that prioritizes upstream systems approaches to address the social determinants of health. Through my work as the Asthma Program Manager at the Rhode Island Department of Health, I have participated the Division of Statewide Planning's Freight Transportation Advisory Committee and collaborated with the Rhode Island Department of Environmental Management on an EPA-funded study of near-road air quality along interstate I-95. The location of the air quality monitors was selected based on highway proximity to asthma hot spots and sensitive receptors such as schools, homes, and health centers, and we helped disseminate results to community stakeholders." Finally, Mr. Drix highlights, "The challenge comes with implementation and ability to engage with decision-making processes in those other sectors, which often do not consider health impacts when making decisions and setting policies. In order to support the ability of public health professionals to influence these decisions, we need to go beyond a theoretical understanding of the issues. There is a need for education, training, and workforce development on the nature of how other sectors such as transportation operate, how decisions get made and how to use tools like Health Impact Assessments or tactics like community organizing to influence those decisions. To support these efforts, the RIDOH hosted a Health Impact Assessment training provided by Human Impact Partners, to provide our staff and partners with a practical tool that can be used to integrate public health into transportation-related decision-making. RIDOH has staff and leadership that participate in transportation planning processes at the state and local level. And finally, RIDOH supports community-led collaborative efforts such as Rhode Island's Health Equity Zones, some of which have engaged in policy and planning work around transportation such as through passing Complete Streets policies."

Finally, Dr. H. Oliver Gao is the director of systems engineering at Cornell University. Dr. Gao states that education and practice are problematic because there is much "disciplinary disconnect and sectorial siloes." For example, "engineers are trained for optimization and cost-analysis, not necessarily environmental aspects," so there needs to be a paradigm shift toward smart and healthy cities. "We need to cross boundaries to solve air quality and health problems," and this requires a systems approach. Dr. Gao emphasizes, "We need people from different expertise to come together to solve these problems to achieve smart and healthy cities, and this requires consistent integration and innovation."

## Future recommendations

This chapter reviewed education, training, and workforce development in the context of the transportation and health fields. The transportation and health fields have not traditionally worked together, but there is growing value in cross-disciplinary knowledge and skills. Together, education, training, and workforce development can improve cross-disciplinary practice, research, and policy to better understand, account for, and address health impacts of transportation. It is evident that although there is progress in integrating transportation and health, there is still much work to be done in bridging existing gaps and promoting collaborative and cross-disciplinary mindsets and practices. Education systems, training methods, and workplaces are encouraged to shift toward cross-disciplinary approaches and work to break down barriers hindering cross-disciplinary collaboration. Ways to promote transportation and health collaboration include but are not limited to

- developing and implementing cross-disciplinary curriculum;
- mentoring interns from different backgrounds and majors;
- sending employees or students to a conference in a different field;
- sponsoring an employee's higher education in a different discipline;
- implementing transportation and planning content in health training;
- implementing health content in transportation and planning training;
- hosting seminars, webinars or short courses on cross-disciplinary topics;
- partnering with professionals from other disciplines on a project or initiative;
- utilizing online tools and resources (e.g., Google Docs, Dropbox, teleconferencing, CARTEEH Data Hub, and City Health Dashboard) to facilitate collaboration and data integration among a broader population;
- encouraging a systems-based approach in practice, research, and policy;
- implementing HIA tools in transportation and urban planning; and
- incentivizing cross-disciplinary opportunities in education, training, and the workforce across practice, research, and policy settings.

It is imperative that continued effort be made in bridging the transportation and health fields and providing more opportunities for cross-disciplinary experiences because there is great potential in what might be accomplished when individuals from these different fields are able to work together more frequently and effectively. The transportation, planning, and health disciplines alike are highly encouraged to adopt a cross-disciplinary, systems-based mindset throughout education, training, and workforce development to develop individuals who possess a more holistic perspective in practice, research, and policymaking.

## Contributions

HK conceived the idea for this chapter. KS and HK designed and drafted this chapter. HK identified relevant contributors for quotes, examples, and curricula. All authors read, provided feedback, and approved the final chapter.

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PART VI

# Conclusions

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CHAPTER TWENTY ONE

# Transport and health; present and future

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## Contents



## Introduction

Transport is an essential component of economic and social activity and is often envisioned as a driver for urban development and a key contributor to economic returns. Transport also has direct negative, and potentially positive, impacts on the health of a population. Transport provides many jobs, which positively impacts the income of people and their health. However, there are also many negative health impacts of transport, particularly motorized transport in cities. These impacts occur through pathways such as motor vehicle crashes, high air pollution and noise levels, heat island effects, and lack of green space and physical activity (PA). It is now well recognized that there is a relationship between land use, transport, and health, and to change transport and health outcomes, one has to also alter land use (Figs. 21.1 and 21.2). In their chapter, Nieuwenhuijsen and Khreis (2020a) provided an introduction to the topic

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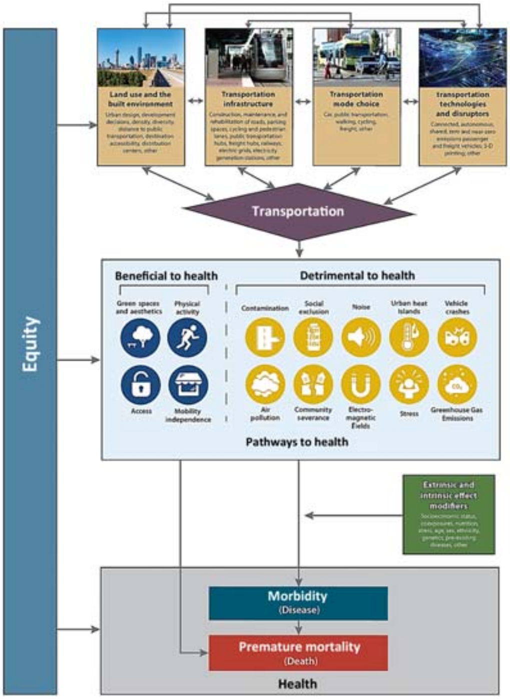


**Figure 21.1** Transportation and health conceptual model. *Khreis et al. (2019)*.

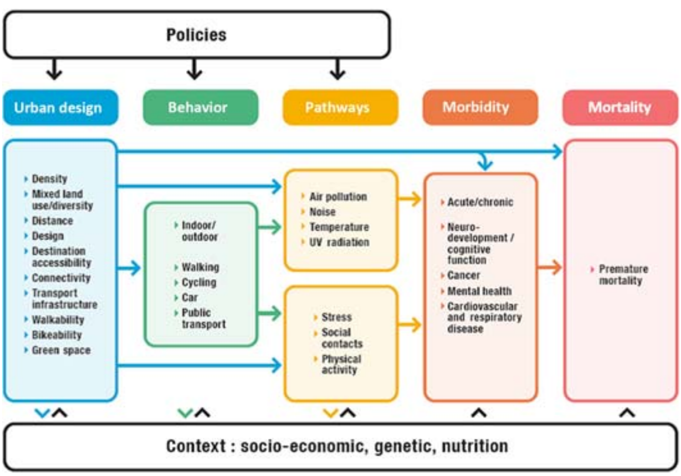


**Figure 21.2** The relationship between urban design, behavior, environmental pathways, and morbidity and mortality.

and make some suggestions on how to reduce the negative health impacts of transport. These suggestions included land use changes toward denser, more diverse and connected designs, a move from private motorized transport toward public and active transportation and changes in policy assessment. In the various subsequent book chapters, we learned what some of the main issues in transport and health are how they can be assessed and addressed and how we should move forward. Here follows a summary.

## Transport and effects on health

Wunderlich and Shipp (2020) pointed out that traffic fatalities still present a significant public health issue as one of the leading causes of preventable death in the world. In the United States, approximately one-quarter of all fatal injuries are due to traffic crashes. The frequency of traffic fatalities in the United States varies over time with notable differences by rural versus urban geography, single versus multivehicle crashes, mode type, and demographic characteristics of drivers and passengers. Continued population growth and expanded economic opportunity are likely to increase travel. Reducing the risk associated with that travel is critical to improving health outcomes. They also pointed out that there is no one approach that appears likely to solve the traffic crash issue, but increased emphasis on implementing infrastructure improvements, incentivizing safe behaviors, and sanctioning and discouraging high-risk behaviors, including advanced safety technology in vehicles, and adopting a safe system approach, can all make a difference in the quality and longevity of life throughout the world.

Khreis (2020) went on to describe that traffic-related air pollution (TRAP) is ubiquitous in today's cities and a major public health concern resulting in premature mortality and a wide spectrum of global diseases. The importance and relevance of TRAP continue to increase with increasing urbanization and rapid population growth that go hand in hand with increasing demand for travel, and in many regions, increasing motorized vehicles travel and roadway expansion. Furthermore, the list of adverse health outcomes associated with TRAP continues to rapidly grow and now includes cognitive decline, neurodegenerative diseases, and numerous metabolic conditions such as diabetes and obesity, all of which can cripple health-care services and severely affect quality of life, productivity, and ability of societies to leapfrog into the "knowledge economy." She provided a broad overview of TRAP in the context of public health by providing basic definitions, methods to assess TRAP and human exposure, a summary of well-established and emerging health effects, and air quality guidelines that establish limits for key air pollutants that pose health risks. She showed how health risks still occur below these air quality guidelines and briefly discussed the use of burden of disease and health impact assessments (HIAs) to quantify the health burden attributable to TRAP in cities. Khreis also summarized the quantified and potential air quality and health impacts of select emerging technologies, namely, electric and autonomous vehicles, and outlined best practices and their overlap with other agendas such as increasing PA and mitigating climate change. She concluded by discussing environmental justice issues surrounding TRAP exposures and health and finally summarized research gaps making recommendations for future studies.

Sørensen et al. (2020) suggested that noise is another health risk and stated that increasing noise from traffic also occurs in parallel with urbanization. Traffic noise may act as a stressor and disturb nighttime sleep, followed by an activation of the sympathetic and endocrine system, thereby increasing a number of biological risk factors. Transportation noise is classified as the second worst environmental risk factor in Europe, and the World Health Organization recently concluded that road traffic noise increases risk for ischemic heart disease and potentially other diseases and conditions. They gave an overview of the current mechanistic insights into the relationship between noise exposure and disease and summarized the epidemiological research on effects of transportation noise on annoyance, sleep, lifestyle habits, cardiometabolic disease, mental health, and cancer. Lastly, they described available strategies for noise mitigation.

On a more positive note, Woodward and Wild (2020) went on to describe the human body as the most sophisticated transport technology available. What is fundamental to its good use is understanding that the anatomy and physiology of the body are coded for movement. Deprived of the chance to be active, the body deteriorates. For most of our species existence, PA was obligatory and food was scarce. The tables have turned—for most people, machines do our work and food is on hand at all times. Active transport offers a rare opportunity to build activity into daily routines. And where there are attractive options for walking and cycling, it is clear that there are benefits for physical and mental health.

Those who cycle or walk to work or school are more likely to achieve minimum levels of healthy PA than those who commute by other modes. Active transport is associated with improved mood and feelings of well-being, lower body weight, and better heart health. Walking and cycling are linked also with better cognition and mental alertness. Clinical researchers have shown that the combination of arousal, sensory reward, and exercise is a powerful brain tonic and this mix of challenge, sensation, and exertion is familiar to city cyclists and pedestrians. PA has been called the best buy for public health because it is effective, cheap, and by large is risk-free. If city streets are designed for walking and cycling, and this means more people are more active more often, then this is an opportunity that should not be missed.

The transport sector's contribution to total energy-related $CO_2$ emissions globally has increased at a faster rate than other energy end-use sectors. Road vehicles constituted 80% of the transport emissions, especially from the emerging economies. Health cobenefits of climate mitigation can provide added justifications for governments to mainstream climate action into national policies. Kwan and Hashim (2020) went on to discuss that public transport is one of the key urban transport strategies to reduce emissions. They discussed how public transport can promote health cobenefits among population sustainably in their daily rhythmic commute. Results and assessment methods in recent empirical studies and scenario modeling on three health determinants (air pollution, traffic injuries, and PA) in relation to public transport were reviewed. In their last section the authors briefly discussed about modal shift and access of public transport services.

Mindell and Anciaes (2020) provided a state-of-the-art review on the relationship between transport and community severance and described potential health effects and impacts, with a particular focus on recent developments. They summarized ways to measure community severance and also provided suggestions on how to reduce severance, with examples of successful programs. Transport-related community severance is the "barrier effect" of transport infrastructure, or vehicles using that infrastructure, on the movement of pedestrians and cyclists, impeding access to the goods, services, and social networks necessary for a healthy and fulfilling life. Barriers from infrastructure include linear infrastructure such as motorways (or other roads with physical barriers preventing pedestrians and cyclists from crossing), railways, rivers, and canals. These barriers cause what is sometimes referred to as "static severance," to distinguish it from the "dynamic severance" caused by the number, characteristics, and speed of motor vehicles. Roads with high volumes of traffic tend to cause dynamic severance, especially when there is a high proportion of heavy goods vehicles in the traffic, or when traffic is moving at a fast speed.

Martens (2020) presented a justice perspective to transport and health. It is well understood that the health benefits and burdens related to transport are not distributed evenly over the population. This holds for exposure to transport-related air pollution, for traffic risks, for access to healthy foods, for opportunities for active travel, and so on. Empirical studies often equate disparities with inequalities and inequalities with inequities. These terms, however, have a distinct meaning. The terms differences, disparities, and inequalities are in its essence descriptive terms. The terms inequities and injustices, in turn, imply a normative judgment of these differences. Martens (2020) discussed three possible perspectives on justice in health. It is proposed that the just health framework developed by Norman Daniels is the most suitable perspective for a discussion on transport and health. Daniels argues that a health inequality "is unjust when it results from an unjust distribution of the socially controllable determinants of population health." This perspective clarifies, first, that virtually all transport and health literature focus on the social determinants of health and, second, that the analysis of the unjust disparities in these social determinants is an essential part of the literature on justice and health. Martens (2020) continues to explore what an "unjust distribution" may mean for three distinct social determinants of health: transport-related air pollution, traffic crashes risk, and opportunities for active travel. This exploration underscores that a justice approach to transport and health goes beyond the mere mapping of disparities and suggests that, in some cases, some level of disparity may well be in line with requirements of justice. He ends with a call on researchers of transport and health to more explicitly engage with notions of justice than is currently the case.

## Recent and future developments

Rojas-Rueda (2020) discussed that new transport technologies, such as electric, shared, autonomous vehicles, and micromobility, are major disruptive technologies producing drastic changes in the transport sector and the built environment. New transport technologies have been expanded rapidly in urban areas across the world. In cases of e-scooters, e-bikes, or services such as Uber or Lyft, urban mobility has been significantly impacted, changing travel behavior, and transport-related health determinants. He described the health determinants related to new transport technologies and how these technologies are affecting public health.

Nieuwenhuijsen and Rojas-Rueda (2020) went on to describe that the interest in urban cycling is increasing and the number of bike-sharing programs has grown rapidly over the last 10 years or so. Bike-sharing programs have existed for almost 50 years, but the recent change in the technology used and interest in more active and liveable cities has prompted a more widespread use of the programs. The benefits of bike sharing are flexible mobility, emission reductions, PA benefits, reduced congestion and fuel use, individual financial savings, and support for multimodal transport connections. Numerous studies have shown beneficial health impacts of bike-sharing systems that have led to considerable reduction in, for example, premature mortality. However, bike-sharing system users do not use helmets very often and they are not a representative sample of the general population. Bike-sharing systems are facing many challenges and opportunities, that should be tackled to improve their health benefits, such as provide more equally distributed bikes throughout the population, increase the use of helmets, and attract more users from private motorized modes such as cars or motorcycles. In general, bike-sharing systems should be seen as a tool for public health promotion and protection.

Sundfør et al. (2020) went on to discuss another new technology, the electric bike and its health impacts. It is well established that PA is health enhancing, and that active travel can increase total PA. The e-bike demands lower levels of intensity for the same pace and distance as a conventional bicycle (CB), due to the assistance of the electrical motor. Still, the e-bike provides PA of *at least* moderate intensity, for both inactive and active individuals. The net volume of PA from starting to use an e-bike depends almost entirely on the transport mode it replaces, and the changes in travel patterns and other PA. Overall, people tend to ride longer and more often when they switch from a CB to an e-bike. The impact of psychological health arising from riding an e-bike is still inconclusive. E-bikes represent the fastest growing segment of the transport system. Combining more bicycle friendly cities and rapid advances in technology has facilitated the rise of the e-bikes in recent years. In Europe sales, the numbers of e-bikes increased from 588,000 in 2010 to 1,667,000 in 2016. In general, e-bikes in European, North American, and

Australian context refer to bicycle-style e-bike design (i.e., the bicycle has functional pedals but is assisted with an electric motor) as opposed to scooter-style e-bike design (with no pedals). E-bikes following the regulations made by the European Union (EU) are formally known as electric pedal—assisted cycles but are also known as *pedelecs*. The EU regulations mean that the motor assistant is limited to 250 W, and that the motor stops assisting beyond 25 km/h. Pedelecs are in most countries legally classified as bicycle, as they require pedaling for the electrical assistance to be provided. A key-difference of the pedelecs compared to the CB is that they can maintain speed, with less physical effort due to the electric-motor support. Following this, pedelecs have been highlighted as an alternative method of active travel that could overcome some of the common barriers to cycle commuting.

Chillón and Mandic (2020) discuss another important and related topic: active transport to and from school. They started with an overview of definitions, international data on prevalence and trends, and correlates of active transport to and from school. A subsequent section discussed health effects of active transport to and from school focusing on PA, body weight, and cardiorespiratory fitness as well as other benefits. They then provided an overview of the key intervention studies that have been implemented to encourage active transport to and from school in children and adolescents. A discussion of the effectiveness and quality of those interventions was included. They concluded with recommendations for researchers, practitioners, and policy makers for designing and implementing future active transport to school interventions.

## Tools and design

Aldred (2020) critically discussed recent literature on built environment interventions and their impact on active travel. She assessed the current state of the research, including methodological and data availability issues affecting the quality of the evidence. She covered key challenges, the growing use of epidemiological methods, and the potential for new data sources (such as "Big Data") to increase knowledge. She ended by suggesting pathways for future research to improve the quality of future evidence.

Recently, we have seen a rise in intervention studies (such as longitudinal studies) and systematic reviews assessing these, helping to fill some gaps. In general, studies find the expected associations or no associations, although more and better studies are still needed, particularly for walking infrastructure. Studies have found active travel infrastructure to have a greater impact on people living in households without a car, although there are still knowledge gaps related to associations between demographic characteristics, infrastructure, and uptake. Preference studies find differences in the strength of preferences expressed for "good" improvements; for instance, cycling infrastructure separated from motor traffic is perceived as particularly important by women and those cycling with children. Walking research has similarly highlighted potential differences in perception in low-income areas, including related to microscale factors that may be related to (perceived) risk of crime. However, she went on to state that we still know relatively little about how these may (or may not) translate into differential uptake associated with different built environment interventions.

Nieuwenhuijsen et al. (2020) then described HIA as an important tool to integrate evidence in the decision-making process and introduce health in all policies. In transport planning, investment appraisals are generally conducted by estimating costs and benefits of a transportation scheme known as cost—benefit analyses. Often, these tools do not fully integrate health impacts of the scheme in question. HIAs could and should form a part of this appraisal to consider and account for the impacts on health. HIAs could answer various pressing questions such as what are the best and most feasible transport planning and policy measures to improve public health in cities? Also, the process on how to get the results is often as important as the actual output of the HIA, as the process may provide answers to important questions regarding how different disciplines can effectively work together and develop a common language, how to best incorporate citizens and stakeholders, how different modeling and measurement methods can be effectively integrated, and whether a public health approach could make positive changes in transport planning and policy.

Kahlmeier et al. (2020) went on to describe a fairly new HIA tool, the Health Economic Assessment Tool (HEAT) for walking and cycling that has been developed as a user-friendly yet robust tool for transport and urban planners allowing the inclusion of PA benefits in transport appraisals. The most recent version can now also consider how much road crashes and air pollution affect these results, and what the effects on carbon emissions are. The HEAT process adheres to an agreed set of key principles and a standardized, iterative process for updates. An assessment consists of five steps that were described. The HEAT has been used widely, and three practical applications in different settings were presented to illustrate possible uses and ways of disseminating the results.

As described previously, transportation can affect health through exposure to air pollution, noise, and traffic injuries, as well as influence PA levels by encouraging or discouraging active transportation. In addition, transportation can affect access to opportunities and mitigate or worsen equities related to all of these exposures. Christofa et al. (2020) therefore say that it is critical to recognize and assess health impacts of transportation project plans and policies, and develop prioritization frameworks in order to make transportation decisions that support healthy communities. Health impacts have been accounted for in transportation decision-making in the United States primarily through two approaches: (1) HIAs and (2) project scoring and prioritization frameworks. The authors described these two approaches, their applications, as well as the documented impact they have had on actual transportation decisions. While HIAs in transportation have not commonly been successful in influencing decision-making, they have initiated collaborations between the health and transportation sectors and improved the awareness of the transportation impacts on health. On the other hand, it is common for Departments of Transportation and Metropolitan Planning Organizations to develop project scoring criteria and prioritization frameworks to assist them in their decision-making. Still, with the exception of a few recent efforts, these frameworks lack a direct focus on health and generally have not documented the actual impacts of their scoring process on the types of projects and real-world health outcomes.

Marshall et al. (2020) argued that the job description of transportation planners and engineers needs to explicitly include consideration of public health outcomes. Actually, doing so has proven to be difficult, in part, due to health research often focusing on vague terms such as sprawl or walkability. Better guidance can only come from better research. They delved into the health-related impacts of street network and street-level measures based on a strand of recently published research papers focused on more than a decade's worth of data for 24 Californian cities. Their results suggested that adapting our built environments and street networks for higher levels of compactness and connectivity, along with improved configurations, has the potential to be an impactful and proactive approach toward: reducing the number of people who are getting injured on our roads; increasing their PA; and improving health outcomes such as obesity, diabetes, high blood pressure, and heart disease. Fewer lanes on the major roads were the primary street-level factor associated with better outcomes. However, instead of focusing on street-level efforts, as is customary, this research suggests the need for a network-level approach to planning for healthy communities.

## Policy, education, and workforce

Lee (2020) goes on to state that noncommunicable diseases (NCDs), such as cardiovascular diseases, chronic respiratory diseases, cancers, diabetes, and mental health conditions, are now the leading causes of mortality, morbidity, and rapidly rising health-care costs. Among policies the United Nations (UN) has called for to address this dire situation is the creation of healthy cities and environments. According to the World Health Organization, transport systems in cities unsupportive of walking, cycling, and public transport contribute to physical inactivity, air pollution, and road traffic injuries. The UN has identified challenges to the development and implementation of healthy city policies, and these challenges affect policies that can improve transportation infrastructure for health. To address these challenges, lessons can be learned from advancements already made in policies on other NCD risk factors, such as tobacco. There are also lessons on knowledge translation progress for transport and health policies and practices from jurisdictions that have worked on these issues directly in recent years. Such work has identified five key processes to achieve improvements in health promoting and protecting policies and practices in sectors outside of health, including (1) cross-sector partnerships among health and multiple nonhealth sectors, (2) pilot initiatives, (3) evaluation of health and other outcomes in pilots, (4) community engagement, and (5) dissemination efforts for lessons learned.

Davis (2020) stated that the need to stabilize global average temperature rises to no more than 1.5°C may be the driver for transformational change that will also deliver major improvements in public health. Barriers to change in the transport sector have long included political commitments to road capacity expansion irrespective of evidence of effectiveness. The climate crisis demands political leadership away from this approach and to draw on existing evidence of effective interventions to move sustainable transport toward being the normative modes of travel. He looked at Scotland (United Kingdom), a country with a reputation for leadership on climate change. He considered its trajectory toward ending its roads program, partly based on health impacts, and other intervention opportunities that could help sustainable transport become the normative travel behavior.

Sanchez and Khreis (2020) stated that the transportation and health fields are two areas that have not traditionally worked together and have been viewed as distinct and separate practice and research fields. However, transportation has huge, yet preventable adverse human health impacts. In fact, 14 pathways link transportation and health (Nieuwenhuijsen and Khreis 2020). There is growing value in cross-disciplinary practice, research, and policy to tackle multifaceted contemporary challenges. As such, new approaches are necessary for effective collaboration. The authors showed that currently, there are limited cross-disciplinary opportunities at the intersection of transportation and health, but the need for knowledge and skills spanning these different disciplines is increasing. More opportunities for collaboration across transportation and health are warranted in education, training, and workforce development as these elements may enhance cross-disciplinary practice, research and policy. Sanchez and Khreis discussed the current state of the transportation and health fields, education, cross-disciplinary curriculum, training, and workforce development. They also included real-world perspectives and future recommendations, including on topics to be considered in a joint transportation and health curricula.

## The future

This book has brought together international leaders on transport and health to provide state-of-the-art knowledge on the many linkages between transport and health, the available tools needed to estimate and evaluate the health impacts of transport, future technologies, the developments that can change the direction and magnitude of the health impacts, and the policy and education issues that can result in better practice and knowledge translation. The content, therefore, provides valuable information on how and why to take health into consideration in transport planning and policy, showing how to estimate the impacts of transport on health in planning and policymaking. As importantly, the book discussed the need for education, training, and workforce development to move toward cross-disciplinary approaches to prepare a future generation to better deal with the multitude of multifaceted issues cited through this book.

Transport is an essential component of economic and social progress and is a giant sector that continues to grow. Yet, transport has direct negative, and potentially positive, impacts on the health of a population. These impacts are modifiable. As shown throughout this book, there is robust evidence base which shows that transport still poses many negative environmental, climate, social, and health impacts that can and should be reduced. This is not easy and needs strategic and systemic approaches with long-term vision and commitment.

New technologies such as electrification and the integration of autonomous vehicles into the market can address some of these concerns. However, many profound changes are needed to make a larger impact, including land use, life style, and behavioral and social changes, some of which have been discussed in this book. Throughout the book the consensus was that we need more multidisciplinary and systemic approaches that address not only one aspect or one exposure but also tackle issues more holistically and avoid (unintended) negative consequences.

We can no longer leave transport only to transport professionals and health only to health professionals. These sectors need to better work together and also bring in other relevant sectors such as land use and city planning, sociology, economy, ecology, and technology. Although there are increasingly good examples of practice, we believe that we still work too much in our own silos.

What we need to address in transport is not only mobility issues but also environmental, climate, social, economic, and health issues, all at the same time. Only then we can really move toward more sustainable (low carbon), liveable, inclusive, and healthy living environments, which we desperately need.

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# ADVANCES IN TRANSPORTATION AND HEALTH

## TOOLS, TECHNOLOGIES, POLICIES, AND DEVELOPMENTS

EDITED BY **MARK J. NIEUWENHUIJSEN AND HANEEN KHREIS**

Transport planning and policy have a large impact on human health through, for example, air pollution, noise, heat islands, space allocation, physical activity, social exclusion, greenhouse gases, and vehicle crashes. The holistic impacts of transport on human health are generally not well recognized by the urban, transport, environment, and health sectors and therefore are often not incorporated in transport planning and policy.

***Advances in Transportation and Health: Tools, Technologies, Policies, and Developments*** provides state-of-the-art knowledge on the many linkages between transport and health, the available and needed tools to evaluate and estimate the health impacts of transport, future technologies and developments that can change the direction and magnitude of the health impacts, and policy and education issues that can result in better practice and knowledge translation. It provides valuable information on why and how to take health into consideration in transport planning and policy, showing how to incorporate the impacts of transport on health in planning, policymaking, education, and workforce development.

### Key Features

- Explores the latest advances on the full spectrum of connections between transport and health
- Offers a "road map" of how transport impacts health
- Includes tools for analyzing and estimating health impacts of transport
- Shows what research and practice gaps need attention
- Includes contributions from leading scholars, practitioners, and policymakers

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