



Transport and public health in China: the road to a healthy future

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Transportation-related risk factors are a major source of morbidity and mortality in China, where the expansion of road networks and surges in personal vehicle ownership are having profound effects on public health. Road traffic injuries and fatalities have increased alongside increased use of motorised transport in China, and accident injury risk is aggravated by inadequate emergency response systems and trauma care. National air quality standards and emission control technologies are having a positive effect on air quality, but persistent air pollution is increasingly attributable to a growing and outdated vehicle fleet and to famously congested roads. Urban design favours motorised transport, and physical activity and its associated health benefits are hindered by poor urban infrastructure. Transport emissions of greenhouse gases contribute substantially to regional and global climate change, which compound public health risks from multiple factors. Despite these complex challenges, technological advances and innovations in planning and policy stand to make China a leader in sustainable, healthy transportation.

Introduction

The health of China's populations, from cities to townships to villages, will partly be shaped by the investments, innovations, and policy actions that governments, institutions, and private organisations make in the transport sector in the coming years and decades. There are exciting developments in transportation infrastructure in China, including massive investments in high-speed rail, subway systems, and traffic management technologies. Meanwhile, a surge of entrepreneurial transportation activity is changing the lives of urban and rural citizens across the country. For example, innovations in public and private bike-sharing technologies involved the introduction of 1·9 million bicycles in urban centres by 2016,¹ and the use of innovative pricing schemes, bicycle reservation via social media, and rental designs that maximise accessibility and bicycle use by avoiding the need for a docking system (dockless bicycles). At the same time, other transportation

innovations, such as app-based taxi-hailing services, are creating new challenges for traffic management, passenger safety, and licensing schemes.²

As transportation transforms, so too does the health of China's population. Transport choices, technologies, and policies determine the exposure of people to certain environmental pollutants, the frequency and severity of traffic-related accidents and injuries, the strain placed on

Key messages

- Public sector transportation initiatives and technological innovation in urban transportation systems are advancing very rapidly in China, with major consequences for public health
- There are essential challenges facing the country's transport sector, including road-safety awareness, demand management, compliance with traffic law, the function and capacity of the emergency response system, and achievement of transportation air pollution targets
- China stands to become a world leader in the use of forward-looking technological innovation, proactive government action, and local-level advocacy and public-awareness raising to achieve healthy, 21st century transportation systems
- Because traffic accidents are responsible for such a large number of injuries and fatalities, immediate improvements are needed to legal requirements (eg, road-type-specific speed limits, improved seatbelt and helmet requirements and their enforcement) and associated infrastructure (eg, signage, lighting, road surface improvement, pedestrian and cyclist paths, and barriers)
- Further efforts should address the need to manage transportation demand through innovative planning, and to rapidly curb emissions of air pollution to protect public health and limit changes to the global climate system
- Improvements are needed on multiple fronts, such as in emergency response and trauma care, regulation, public awareness, and infrastructure, for health gains to be realised

Search strategy and selection criteria

We searched China National Knowledge Infrastructure and Wanfang for Chinese language papers and PubMed for English language papers, using the MeSH terms "transportation", "urbanization", and "motor vehicles", and the search terms "health", "healthcare", "injuries", "accident", "traffic", "road", "highway", "safety", "air pollution" and specific transport air pollutant names (eg, "PM2·5"), "physical activity", "chronic diseases", "public transportation", "cycling", "commute", "driver", "passenger", "rail", and "climate change". We also searched for geographical terms such as "China" and province and municipality names. Searches included appropriate wildcards and truncation, and we reviewed the references cited in relevant papers. We selected publications from the past 20 years (from Jan 1, 1996, to March 1, 2017) and manually reviewed Chinese health, demography, infrastructure and transportation statistical yearbooks published over the past 20 years, and Chinese Government reports published over the past 15 years.

Lancet 2017; 390: 1781-91

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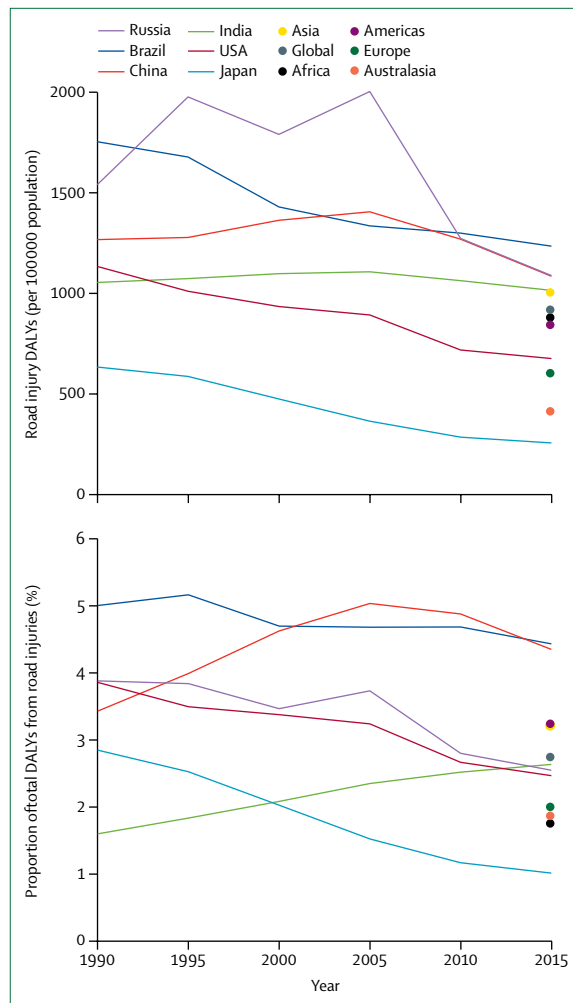


Figure 1: Disease burden of road injuries for several countries, 1990–2015
DALY=disability-adjusted life-year. Data from GBD Compare.

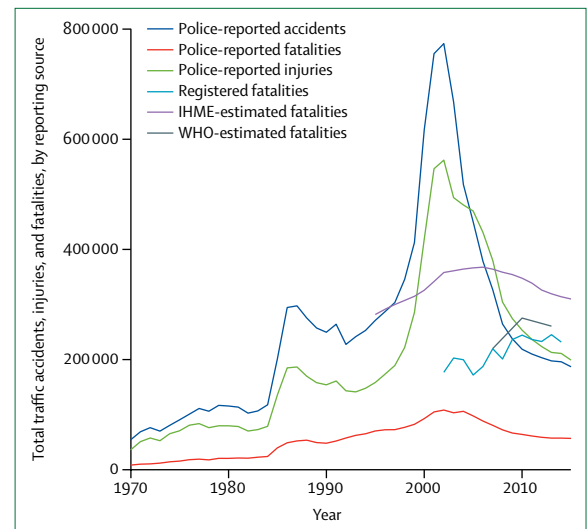


Figure 2: Traffic accidents, injuries, and fatalities in China, 1970–2015
IHME=Institute for Health Metrics and Evaluation. Data are from GBD Compare and other sources.^{20–22}

For more on GBD Compare see
<http://vizhub.healthdata.org/gbd-compare>

See Online for appendix

emergency rescue systems, the level and types of physical activity within a population, exposures to noise and the associated disruption of sleep and hearing, and to many other determinants of population health.^{3–8} These effects will extend far beyond China's borders as air pollutants from the country's transportation sector, which damage people's health and the climate, are dispersed internationally and intercontinentally.^{9,10} China's transport choices are set to be even more important in view of the tremendous expansion of the country's transportation network.

China is a country on the move: the nation has built the world's largest high-speed rail network,¹⁰ constructed more than 4 million kilometres of highways,¹¹ and has achieved a massive rollout of electric, zero-tailpipe-emission, two-wheeled vehicles.¹² Simultaneously, private motor vehicle ownership is skyrocketing, numbering 141 million vehicles,¹³ while use of active modes of transport, including walking and cycling, has decreased precipitously.^{14–16} The rapidly increasing number of vehicles has led to substantial

ill health that is associated with transportation combustion emissions, while the growing number of new and inexperienced drivers, low seatbelt use, and poor road design, with inadequate separation between pedestrians, cyclists, and motor vehicles, have led to large numbers of accidents and injuries.^{17,18} These realities are joined, and in part driven, by the rising dominance of car culture in China's cities and rural villages alike: pedestrians and cyclists are intimidated by aggressive driving, right-of-way rules are poorly codified and enforced, and the future of health in China is at risk from attitudes and policies that allow transportation hazards such as air pollution, noise, and dangerous road conditions to persist and grow, even as many other public health improvements sweep the country.

The last two decades of growth of China's transportation system are striking, with massive increases in numbers of automobile registrations and lengths of highways (appendix). These trends raise concerns about social equity because major transportation investments have focused on accommodating rapidly increasing numbers of motor vehicles, with less attention paid to public transport and non-motorised modes of transport, on which the poor depend. In this Review, we analyse the public health consequences of China's transportation decisions, technologies, and infrastructure, examine the transport trends that will define the health of China's population, and review the policy and technology options that are available to protect health while stimulating a more mobile and connected China in the decades to come.

Health consequences of transport associated with accidents and injuries

Road accidents and injuries

Road traffic injuries take a major toll on the health of China's population, and their burden is high relative to

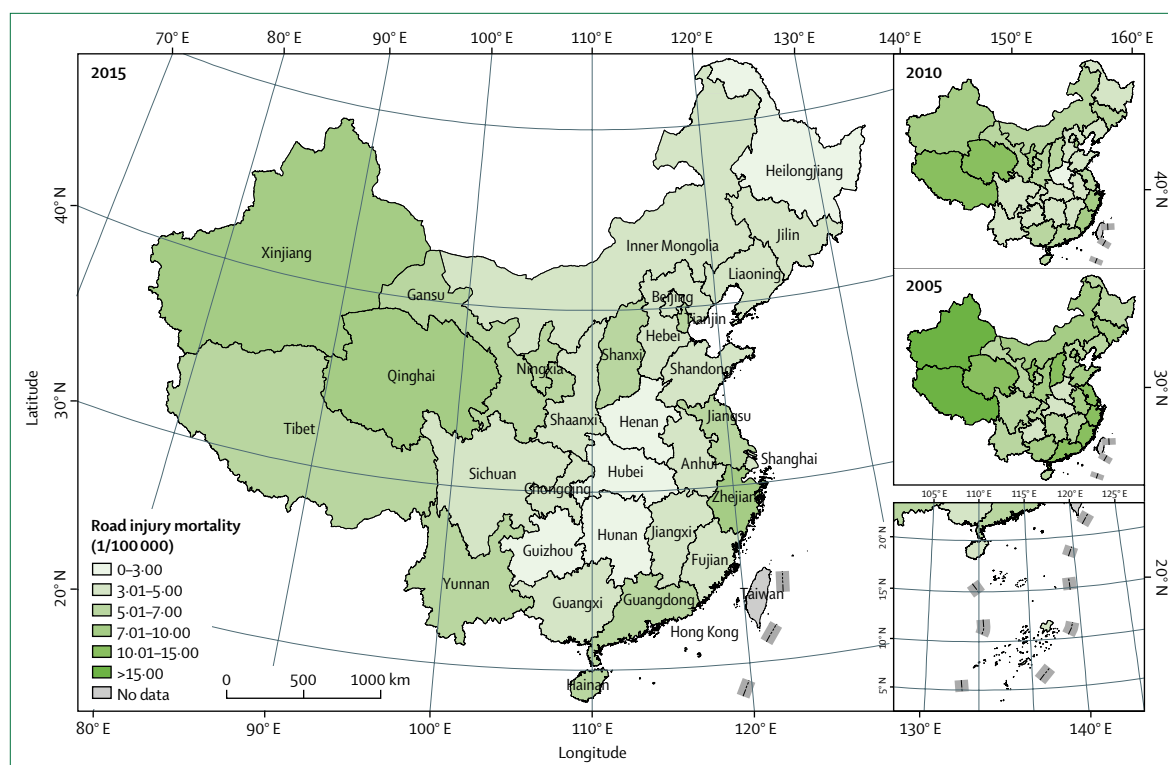


Figure 3: Road injury mortality rate by province in 2005, 2010, and 2015^{21,22,28}

other countries (figure 1). Traffic-related fatalities account for 80% of accidental deaths in China,¹⁹ and the country's reported rate of road traffic injuries and fatalities increased substantially, with rapid motorisation beginning in the late 1980s (figure 2; appendix). These increases continued until approximately 2003, when the country adopted and began enforcing its first major transportation and traffic law—the Road Traffic Safety Law of China. The result was a reduction in both injuries and fatalities associated with road accidents as reported by the police (figure 2), both in absolute number and on a population basis.²³ This decrease is despite the fact that road transport distance travelled per capita has increased sharply in the country, from 51.4 km per person per year in 2001 to 66.4 km per person per year in 2015.¹³ China's population is increasingly mobile, while road injuries and fatalities per capita are on the decline.

Although police-reported road injury data comprise the official road accident and injury dataset in China, and it is the only dataset that tabulates number of accidents and economic losses,^{24,25} its reliability has been questioned because of reporting challenges.²⁰ When adjusted to account for under-reporting, fatalities as estimated by China's cause-of-death reporting system exceed the police-reported data by a factor of two, and WHO estimates are higher (figure 2).²⁶ Possible explanations for this difference include different definitions of road-traffic deaths, different data collection methods, and under-reporting by traffic officers because of conflicts of interest, although the reporting rate has been increasing.^{24,26}

In 2015, 87% of road fatalities were caused by motor vehicles,²⁰ and clear disparities are evident in the burden of road accidents both regionally (figure 3)²⁹ and with respect to the affected population (appendix). The road-injury mortality rate is higher in China's rural areas when compared with urban areas (figure 4). In 2014, approximately 55% of road traffic deaths happened in rural areas, but these areas comprise only 45% of the total population of China. These areas have unique circumstances that increase the risk of road-traffic accidents and injuries, including more heavy vehicles (eg, tractors and trailers), high vehicle speeds (eg, because of weaker traffic law enforcement), isolation from emergency rescue response, older cars with poor safety equipment, poorer road lighting conditions, and more unlicensed drivers than in urban areas.^{25,30,31}

Pedestrian, cyclist, and motorcyclist injuries and accidents

China has witnessed a substantial shift away from active cycling and walking as means of transport. As recently as 1995, more than 540 million bicycles dominated China's streets in urban and rural areas alike, and pedestrian travel was common. The number of people using these modes of transport have substantially decreased, yet with the growth in vehicle traffic, road-traffic injuries and fatalities among pedestrians and cyclists have soared (appendix). Because of their vulnerability to vehicular collision, these road users contribute substantially to roadway

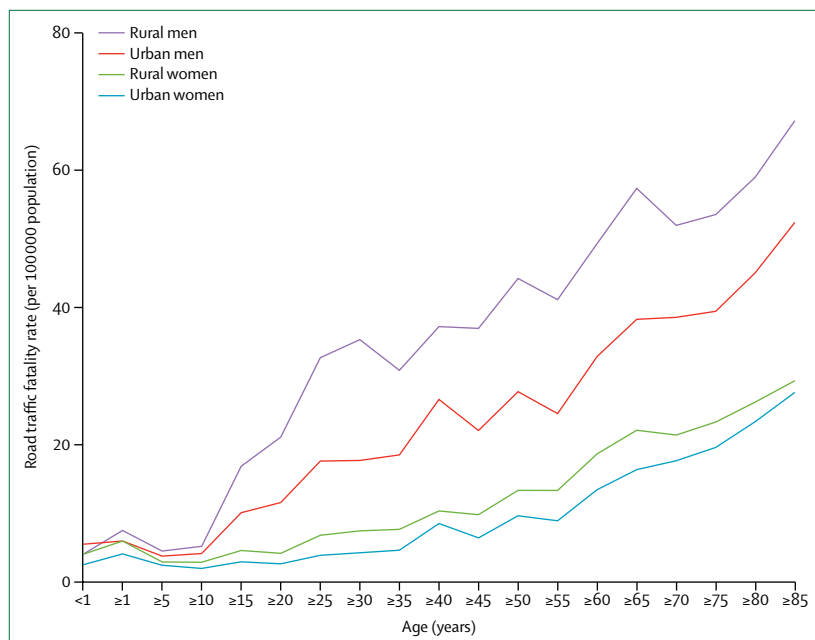


Figure 4: Age-specific road injury mortality 2014²²

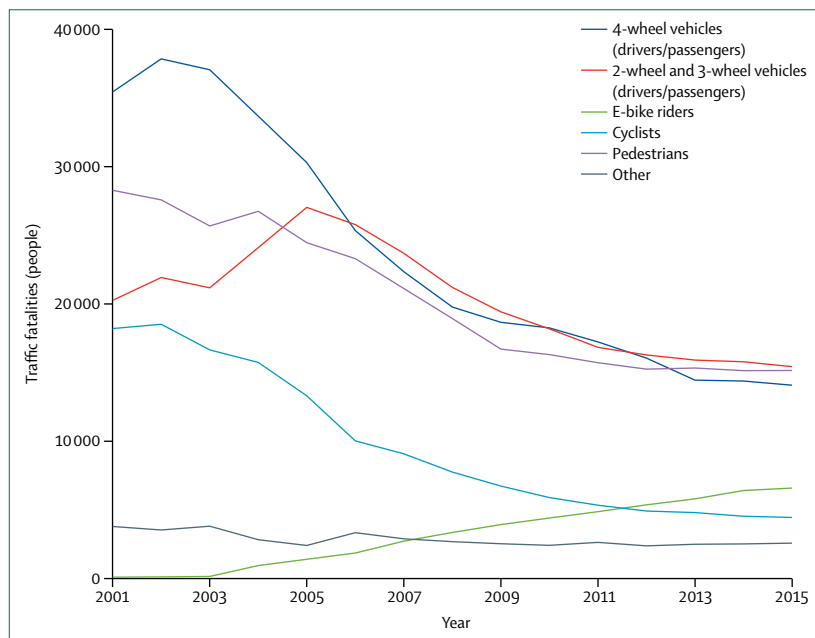


Figure 5: Police-reported traffic fatalities by road use type, 2001–15

Other refers to other motorised and non-motorised vehicles (eg, animal-drawn vehicles, farm vehicles).²¹

injuries and deaths, accounting for 25·5% (pedestrians), 11·9% (cyclists), 4·2% (electric bicycle [e-bike] riders), and 25·5% (motorcyclists) of all road-traffic deaths between 2001 and 2015. During this period, traffic fatalities decreased among pedestrians and cyclists, increased among e-bike riders, and peaked and then declined among motorcyclists (figure 5). The recent rapid growth in

dockless private and public bike sharing programmes could yield an increase in the number of cyclist injuries; however, there is some evidence that the number of accidents per kilometre decreases with increasing bicycle usage, according to the so-called safety-in-numbers effect that has been observed elsewhere.¹²

Because of their convenience and low cost, sales of e-bikes have increased from a few thousand in 1998 to an estimated 37 million in 2015, accounting for 92% of global sales.^{12,33} Unlike Europe, North America, and Australia, scooter-style e-bikes, which are heavier and have higher maximum attainable speeds, are more popular than are bicycle-style e-bikes in China.¹² The boom in e-bikes poses major concerns regarding the safety of riders and other road users. E-bike traffic shares crowded lanes with traditional bicycles, yet e-bikes achieve relatively high average speeds and riders generally have neither licences nor helmet requirements. Though e-bike related fatalities are currently on par with those of traditional bicycles—and about half that of motorcycle-related accident fatalities—they increased approximately 6-times from 2004 to 2015, even as overall traffic fatalities, and those related to traditional bicycle riding, have decreased over the same period (figure 5). The soaring number of scooter-style e-bikes is a phenomenon that is somewhat unique to China, and the country has an opportunity to lead the development of e-bike safety features, rider education, and road infrastructure interventions to mitigate this rising public health concern.

Emergency rescue system for transportation injuries and trauma

Transportation injuries and trauma can clinically manifest in many forms, from mild to severe. In China, the most common serious transportation injuries include injuries to the abdomen, limbs, craniocerebral injury, and thoracic trauma.^{34,35} The mortality rate from these and other traffic injuries is extremely high in the country, amounting to more than six deaths per 10 000 vehicles, by comparison with an average 1–2 deaths per 10 000 vehicles in developed countries.^{34,35} There are several reasons for this, largely reflecting weaknesses in the country's traffic injury rescue system. The emergency rescue system in China is primarily structured around local emergency centres or individual hospitals, consisting of pre-hospital emergency workers, and specialised departments within the hospital that coordinate care. Trauma specialisation is rare across China's medical system, and this is true even in advanced, comprehensive hospitals.³⁶ Additionally, emergency medical service workers are often poorly trained, and care received at the site of accidents is often substandard, resulting in a low rate of successful pre-hospital resuscitation.³⁷ Standardised procedures for emergency rescue are insufficient, often resulting in incorrect therapy and poor success at stabilisation of patients before hospital admission (appendix).^{37,38}

A study of multiple cities and regions across China found that more than 80% of general hospitals have emergency rooms with insufficient trauma care infrastructure, and identified a major shortage in comprehensive, well equipped rescue medical centres with well trained professionals, particularly pre-hospital workers.^{39,40} Gaps in information exchange between pre-hospital first aid and in-hospital emergency services, and weak communication between in-hospital emergency services and specialists, hindered emergency care for traffic-related trauma.^{39,40} Additionally, the consultation call time associated with emergency response in a study of 12 general hospitals in China ranged from 17 min to 54 min, representing substantial delays in the response of pre-hospital emergency systems.^{39,40} The dearth of specialised professionals in trauma, and poor coordination and communication between specific departments within hospitals, all contributed to delays in diagnosis and treatment of traffic accident injuries.^{39,40} These problems are compounded by long emergency rescue transport times that stem from inconsiderate road users, heavy traffic, and low service levels in isolated areas, which severely limit access to trauma care (appendix).

Health consequences of transport associated with physical inactivity and pollution

Physical inactivity and chronic disease

Transportation has strong linkages to physical activity and thus has consequences for the prevention of chronic diseases that are associated with inactivity. Transportation infrastructure, degree of access to public transportation, and the design and layout of cities and towns can either promote or hamper active modes of travel, which include walking and cycling, but also include active segments of public transport use, such as walking to bus stops or train stations.^{41,42} Active travel is also directly affected by the presence of traffic-related air pollution, since commuters might avoid active transport options on days of poor air quality.⁴¹

Some connections between physical activity and transportation are self-evident, such as when the central government promoted the use of motor vehicles in the mid-1990s, leading to the conversion of marked bicycle lanes in Beijing into temporary car parking lots, sharply diminishing cycling in the city.⁴¹ Other connections are indirect. For example, it has been established that physical activity, expressed and measured in multiple ways, increases when use of public transport increases, and much larger increases in physical activity are observed when active transport modes are adopted, such as walking or cycling.³

These findings have important consequences for public health in China (appendix). Physical inactivity and low physical activity were responsible for an estimated 0·25 million deaths in the country in 2015 (constituting 2·66% of total deaths), and the health-related economic burden of physical inactivity amounted to an estimated

US\$6·7 billion in 2007 through its association with coronary heart disease, stroke, hypertension, cancer, and type 2 diabetes.^{43,44} Even when taking into account the adverse health risks of active transportation (eg, road injuries, exposure to air pollutants), net health benefits have been shown (appendix). Despite the clear benefits of physical activity, and the strong association between transport and physical activity, increased car ownership in China has sharply reduced travel physical activity (appendix). Interventions that aim to increase physical activity through increased access or ease of active transport are known to be effective, and pose unique opportunities to reverse these downward physical activity trends (appendix).

Air pollution attributable to transport

A crucial link between transport and ill health in China stems from the substantial burden of disease associated with ambient air pollution in the country. Adverse health effects from transportation-sourced air pollutants in China are chiefly from exposure to particulate matter, ozone, nitrogen oxides, and a combination of these pollutants.⁴⁵ On-road vehicle emissions dominate the emission of air pollutants from the transportation sector, especially those from the combustion of diesel fuels.⁴⁶ These emissions include health-damaging emissions of particulate matter, specifically fine particulate matter of less than 2·5 microns in diameter that accounts for 90% of particulate matter from on-road vehicles in China; and smog precursors, such as nitrogen oxides, carbon monoxide, and volatile organic compounds including hydrocarbons, which contribute to the secondary formation of particulate matter and ozone.^{45,47,48} Overall, transportation is an important source of emissions of health-damaging air pollutants (appendix).

Even as Chinese ambient air quality standards are being strengthened, such as through the introduction of China's National Ambient Air Quality Standards in 2000, which helped reduce primary pollutants between 2000 and 2012 from sources such as coal burning, secondary pollutants emitted by transportation sources are a growing problem.⁴⁹ Between 1980 and 2005, total vehicle emissions of transportation air pollutants (particulate matter, nitrogen oxides, carbon monoxide, and volatile organic compounds) increased rapidly, after which emissions evened out or decreased, on average and in the long-term (5–10 years), for all major transportation air pollutants except nitrogen oxides (figure 6; appendix).^{49,50}

Short-term and long-term exposure to air pollution, including particulate matter, nitrogen oxides (especially NO₂), ozone, and carbon monoxide from transportation, are associated with substantial morbidity and mortality.^{51,52} Air pollutants have been positively and significantly associated with increased total, cardiovascular, and respiratory mortality across urban centres in China.^{52,53} Infants and children, adolescents, and the elderly, are more susceptible than are the general population to the

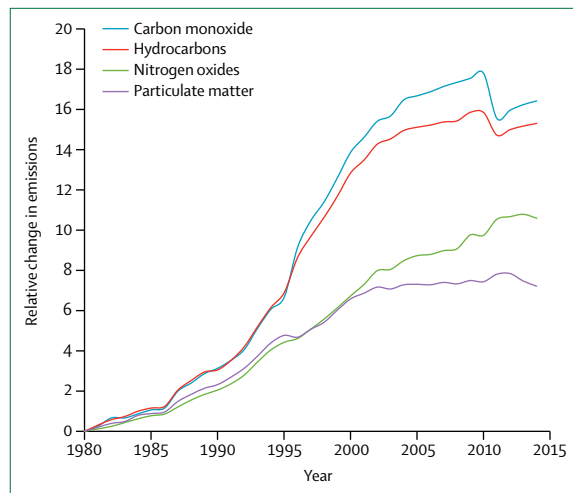


Figure 6: Relative change in transportation air pollutant emissions from passenger cars and trucks, 1980–2014

The relative change is the annual change in Mt emitted by passenger vehicles and trucks combined as a fraction of baseline 1980 emissions for carbon monoxide (1.7 Mt), hydrocarbons (volatile organic compounds, 0.2 Mt), nitrous oxides (0.5 Mt), and particulate matter (0.1 Mt).⁵⁰ Mt=million tonnes.

damaging effects of these pollutants,^{53,54} and ambient air pollution in China (especially particulate matter) is associated with adverse pregnancy outcomes such as lower birthweight, pre-term birth, and congenital anomalies, especially cardiovascular defects.⁵⁵ Epidemiological studies that assess exposure to air pollutants in relation to population proximity to roads shed some light on the unique role of transportation emissions in contributing to poor health (appendix).

Climate change dimensions of transport

Although direct emissions of health-damaging air pollutants from the transportation sector pose immediate threats to public health, the emissions of greenhouse gases from transportation also drive climate change,^{56,57} with important long-term consequences for public health in China. Fossil fuel consumption by transportation is responsible for a substantial proportion of China's greenhouse gas emissions (appendix),⁵⁸ and increased global temperatures have been, and will continue to be, attributable to increases in these emissions globally and in China.^{57,59} Whereas certain transportation-associated greenhouse gases (eg, carbon dioxide) contribute to global warming, others (eg, nitrogen oxides) have a net cooling effect,^{57,58} although these should not detract from efforts to reduce emissions in the transportation sector (appendix).⁵⁶ Certain transportation pollutants, such as black carbon, affect regional climate, and global climate change and weather will also in turn directly affect local air pollution in complex ways (appendix).⁴⁷

Transportation infrastructure itself creates susceptibility to the effects of climate change. The presence of urban heat islands, or urban areas with higher land surface and air temperatures than less urban surroundings, is partly a

function of heat storage by roads and buildings in heavily built-up cities, particularly in northern China.⁶⁰ Urban warming is further intensified by transportation-sourced urban haze,⁶¹ and urban heat islands exacerbate heat waves, increasing susceptibility to heat-related mortality.⁶² Expansion of impervious surfaces (concrete, asphalt, brick, stone, and compacted soils) used to construct surfaces (roads, sidewalks, driveways, parking lots, and roofs), and the accompanying urban development, also put cities at greater risk of flooding,⁶³ which can result in direct injuries and fatalities, and increased incidence of water-borne and water-related diseases.⁶⁴

Future of healthy transportation in China

Policy options to protect public health and improve transport safety

It is imperative that transport authorities take concrete steps to manage transportation demand, reduce road traffic accidents, develop safety-enhancing infrastructure, and improve regulation. High priority actions include expanding and separating lanes for pedestrians, motorcyclists, and cyclists (many of which have already been removed to alleviate congested roads); improving road conditions, lighting, and signage; implementing measures that prevent pedestrians from violating traffic rules; requiring vehicle safety inspections and safety training sessions for truck drivers; introducing road safety information campaigns in rural areas and for children and teens; and strengthening penalties for drunk driving, speeding, and driving without a licence.^{17,18,65} Evidence suggests that a multifaceted approach that includes infrastructure improvements, legal mandates and their enforcement, and public information campaigns is required in urban and rural China alike (appendix).

Speeding, which increases the likelihood and injury severity of traffic accidents, especially for non-drivers,⁶⁶ is a challenge that requires such a multifaceted approach. In developing countries, establishing speed limits with respect to the function of each road, enforcing those speed limits, and raising awareness about the dangers of speeding by public education campaigns can reduce speeding-related accident and injury (appendix).⁶⁷ Drunk driving is another example. While strict criminalisation of drunk driving in China has been effective in some settings (appendix), drunk driving behaviour persists, especially among men.^{68,69} Regulation should therefore be supplemented by increasing the number of traffic police officers such that routine enforcement, and awareness of enforcement, is improved;⁷⁰ conducting police enforcement at night and in low-visibility areas specifically;⁷¹ and educating the public about the dangers of drunk driving.⁷⁰

Given their dominant role in China's urban transportation, safety of e-bike transport should be urgently addressed by introducing modified (two-step) left turning at intersections, e-bike speed reduction and licensing requirements, amending and enforcing drunk driving and child passenger regulations specifically for e-bikes,

developing group-specific licensing connected to training (ie, for the elderly and those with less driver education), and launching e-bike awareness campaigns targeted at both e-bike and automobile drivers (appendix).^{33,72,73} E-bikes should require registration, clear rules for their use should be adopted, and manufacturing of e-bike equipment that meets national standards should be pursued (appendix).

Although education programmes for drivers and cyclists have been developed,¹⁸ research on their effectiveness is scarce, and training and education efforts in China—especially for children—might be most effective alongside or after other interventions, such as substantial improvement to road infrastructure, especially in rural areas (appendix). Although driver training and education programmes are internationally recommended as part of almost all traffic safety recommendations, there is a dearth of evidence supporting their effect in China. Cost-effective ways of reducing persistent, dangerous road conditions for drivers, cyclists, and pedestrians alike, should receive urgent priority if education programmes are to have an effect on road safety.

Initiatives to encourage safe active transport

To increase the use of active and public transportation in China, targeted policies are needed that mitigate traffic congestion in big cities, improve pedestrian and cyclist safety, and increase public transportation coverage, accessibility, and ticket subsidies. Doing so would boost the physical activity associated with active modes of transport.^{42,74} For example, because bike-sharing programmes can help solve the last mile problem of public transportation—ie, the requirement of active transport for the last mile between transit stations and final destinations—a study of car owners in Hangzhou found that 78% of participants turned to public bicycle sharing programmes to substitute for private car trips, and 63% to substitute for taxi trips.⁷⁵ Programmes that restrict car licence plate issuance through lotteries and which limit private vehicle usage on the basis of the last digit of licence plates continue to make important contributions in many Chinese cities, but crucial infrastructure improvements are also needed, including construction and enhancement of safe sidewalks and bicycle lanes.

Assuring appropriate space for pedestrians along roadways—for example, by use of unobstructed sidewalks, safety islands, and pedestrian signalling—is urgently required in many of China's cities, as is the enforcement of strict consequences for illegal parking or driving in pedestrian lanes. Similar improvements are needed in bicycle lanes, including ensuring appropriate width of bicycle lanes, and installing barriers between motor vehicle and bicycle lanes. China has made progress in several of these areas, yet without other essential measures, such as community-based or mass-media health campaigns and programmes that encourage behaviour change, the great

strides in physical infrastructure will not be sufficient for encouraging active transportation and increasing physical activity (appendix).

Vehicle safety equipment and new technologies to reduce injuries and fatalities

China has a range of available policy options to reduce vehicular injuries through improvements in, or mandates of, vehicle and personal safety equipment. There is a large evidence base, with some drawn from experience in China, that substantiates the link between use of such equipment and reductions in transportation-related injuries and deaths.^{17,20,76} Protective technologies and associated policies for specific transport modes in China include enforced use of seatbelts and child restraints in vehicles; helmet wearing for e-bike riders; helmet wearing, protective clothing, advanced braking systems, daytime running lights, and better guardrails for motorcycle riders; automatic emergency braking systems for passenger and cargo vehicles; alcohol locks; and improved truck safety equipment focused on the safety of other vehicles, including blind-spot-detection technology, underride protection on truck sides and rear, and energy-absorbing fronts.^{18,77}

Several of these recommendations are viable only for newer vehicles, yet enforcement of use for even simple protective equipment (eg, seatbelts, car seats, helmets) is very low in China, and thus supportive policies could generate cost-effective safety gains quickly (appendix).^{17,78} Simultaneously, leading-edge transport technologies could offer China the opportunity to make long-term investments in safety. Autonomous driving technologies (ie, automatic emergency braking, and potentially including autonomous steering, acceleration, and deceleration) and connected vehicle technologies (eg, dynamic routing systems) have the capacity to improve road safety and traffic flow,^{18,79} although there are potential adverse consequences of these technologies to consider (appendix).

Emerging emissions controls for motorised transport in China

Because both primary and secondary pollutants are important drivers of total pollution levels,⁴⁷ and the presence of multiple pollutants is thought to heighten morbidity and mortality, traffic-emission controls for all transportation-sourced air pollutants combined would best address the public health burden of transport-sourced air pollution.⁸⁰ Some of the most promising opportunities to strengthen emission controls across China's transportation sector have been partially implemented at the municipal or national level, including stricter emission standards for new vehicles, improved fuel quality, licence controls, driving restrictions, parking and congestion fees, and phasing out older vehicles.^{46,81}

Still greater progress could be made in reducing health-damaging emissions from vehicles in China by implementing policies that target trucks (appendix), promoting

alternative fuel vehicles and buses (battery electric and natural gas), and enforcing scrappage and retrofit programmes for older heavy-duty diesel vehicles.^{46,81} Traffic restrictions that were implemented to improve air quality during the Beijing 2008 Olympics are an example of one of the most noteworthy air pollution interventions ever documented through municipal traffic control measures, with major benefits accruing to public health (appendix).⁸²

Demand management, planning, and urban design solutions

Demand management will be essential to reducing the public health burden associated with transportation in China. With the reduced need to travel as distantly and as frequently will come reduced motor vehicle use, fewer emissions of health-damaging pollutants, reduced traffic congestion, lower population exposure to road hazards, and reduced greenhouse gas emissions.⁸³ Urban planning offers a range of policies that can improve public health while moderating demand and ensuring safe, efficient, and convenient transport. Many widely adopted urban planning strategies, such as the compact urban development model that promotes high urban density, are applicable to Chinese cities (appendix).^{84–86} These strategies involve mixed land uses, balancing jobs and housing development to reduce commute distances and times, establishing walkable neighbourhoods, and diverting traffic away from pedestrian and cyclist routes. Such compact city planning principles should be pursued alongside active transport subsidies, demand management, and driving disincentives, such as parking charges, that encourage non-automobile commuting in these areas.^{87,88}

Land-use zoning and land-use plans should separate areas near transportation emissions (ie, noise and air pollution) from residential areas,⁸⁹ and larger buffers should be implemented downwind of diesel railway corridors and large highways (appendix). Low impact development practices (eg, green roofs and urban green space, porous pavement) have the capacity to reduce urban heat island effects⁹⁰ and urban flooding,⁹¹ which would moderate the effects of transportation infrastructure on public health and which could be pursued in both old city centres and new towns and suburbs. Key to implementing such urban design policy recommendations will be to have close institutional coordination among government agencies (appendix).⁹²

Improvements to emergency response system for traffic accidents

China must overcome major issues facing comprehensive emergency rescue for traffic-related injuries, central to which is the absence of integrated and comprehensive treatment of trauma patients. There is an urgent need to develop a comprehensive trauma specialisation in hospitals, particularly large general hospitals, and to adapt medical school curricula and training accordingly. In

doing so, it will be crucial to take advantage of China's existing infrastructure and health-care resources to establish more effective regional rescue and treatment systems. Although there are no trauma rescue and treatment centres in large urban hospitals at present, these hospitals retain professionals of all specialisations, and are relatively well equipped and well resourced. One path forward would be to establish trauma rescue and treatment networks, each network comprising one trauma centre in a qualified general hospital, and between four and six trauma rescue and treatment stations in nearby secondary hospitals in specific areas, configured on the basis of their locations, population distribution and density, and local demand for first response and rescue.^{36,37} The Peking University Trauma Medicine Center has developed highly successful demonstration networks using such a models (appendix),^{37,93} and these efforts will need to be supported by programmes to train a robust pool of qualified first responders and health professionals (appendix).

Finally, any improvements to emergency response systems for traffic accidents must include reductions in pre-hospital response times. This will require more precise communication of the location of accidents and stricter enforcement of the right-of-way for privileged vehicles. For example, patients in Wuhan use mobile apps to send their GPS coordinates while calling for help,⁹⁴ and ambulances in Shenzhen are equipped with cameras that can be used as evidence for fining drivers who fail to yield for emergency vehicles.⁹⁵

China as a healthy transport leader

China is a country in which public sector initiatives and technological innovations in urban transportation systems are moving quickly, outpacing those of many developed, industrialised nations through a combination of novel bike-sharing programmes, supplementation of high-emission motorised transport (personal vehicles, motorcycles) with low-emission e-bikes, development of partial and fully autonomous driving systems, and construction and expansion of subway systems and high-speed rail. Nevertheless, crucial infrastructure development and maintenance, road-safety awareness, compliance with traffic law, emergency response system function and capacity, and achievement of transportation air pollution targets remain major challenges at scales akin to many developing countries. By addressing the unique challenge that exceptionally large-scale and rapid economic growth, urban expansion, and rural–urban connectivity bring to transportation, China stands to become a world leader in the use of forward-looking technological innovation, proactive government action, and local-level advocacy and raising of public awareness.

Yet paving a way for healthy transportation in the 21st century will require substantial change to the status quo in China. Namely, the current coupling of dense urban growth, diversification in modes of transport, and

outdated road infrastructure increases the odds that pedestrians, cyclists, and drivers are brought into close contact, increasing risk for all. Safety risk is compounded by insufficiently comprehensive traffic laws, poor awareness and enforcement of road safety laws that do exist, and inadequate emergency response. Because traffic accidents are responsible for such a large number of injuries and fatalities, efforts should first target improvements to legal requirements, such as road-type-specific speed limits, improved seatbelt and helmet requirements and their enforcement, and enforcement and awareness-raising of existing laws such as for drunk driving, and associated infrastructure (eg, signage, lighting, road surface improvement, pedestrian and cyclist paths and barriers). Efforts should then address the need to rapidly curb emissions of air pollution, which are increasingly from the transportation sector, to protect public health and limit changes to the global climate system. High priority air pollution controls should include demand management, licensing restrictions, parking and congestion fees, phasing in alternative fuel buses (eg, battery electric and natural gas), and enforcing scrappage and retrofit programs for older vehicles, especially heavy-duty diesel vehicles.

A chief feature of the Chinese transportation–health interface is interdependence of transportation–health pathways that are commonly understood in isolation. For example, the benefits of improved active transport (walking, cycling) are clear, but the capacity to realise those benefits is limited by transportation infrastructure and air pollution. Although pedestrians and cyclists might benefit from increased levels of exercise, they are put at substantial risk of accidents and injuries in urban and rural roadway environments because of poor infrastructure, outdoor air pollution, poor road-safety awareness, inadequate incentives to obey traffic law, and, in the case of an accident, an emergency medical service sector with insufficient training and inefficient triage systems. Improvements must be made on multiple fronts, such as infrastructure, emergency response, regulation, and public awareness, for health gains to be realised.

Contributors

JVR conceived and led the preparation of the report. All authors participated in data analysis, interpretation, discussion, and writing of the report.

Declaration of interests

We declare no competing interests.

Acknowledgments

JVR and ML are supported by the supported by National Institutes of Health (NIH) grants (R01TW010286, R01AI125842, and K01AI091864), by grants from the National Science Foundation Water, Sustainability and Climate (1360330 and 1646708), and by the University of California Multicampus Research Programs and Initiatives (award MRP-17-446315). SL is supported by an NIH grant (R01AI125842) and by National Science Foundation Water, Sustainability and Climate grants (1360330 and 1646708). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the paper. No payment was received by any of the co-authors for the preparation of this Review. The corresponding author had full access to all the data in

the study and had final responsibility for the decision to submit for publication.

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