
# Critical Issues in Transportation 2019 (2018)

## DETAILS

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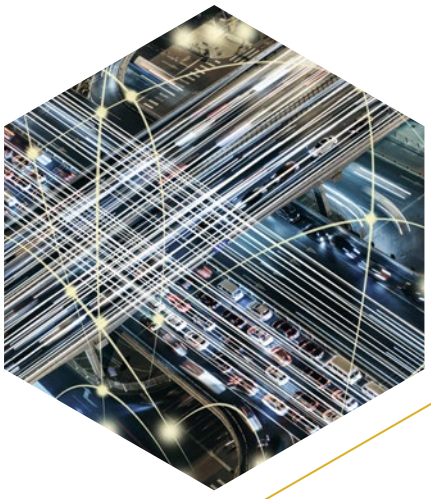

# CONTENTS



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# CRITICAL ISSUES IN TRANSPORTATION 2019

Modern economies and lifestyles would not be possible without extensive transportation systems. Yet, even as vital as they are, such systems mostly escape notice except when they do not function as expected. As the third decade of the 21st century approaches, however, expectations may well be turned upside down. Changes are coming at transportation from all directions, including potentially revolutionary technologies such as drones and automated vehicles, rapid innovations in urban transportation services, unreliable funding for infrastructure and operations, and possible changes in national policies affecting trade, climate, environmental protection, and sources of energy. The potential consequences of these changes could make future congestion, fuel consumption, and emissions either markedly better or markedly worse. Correspondingly, these potential changes could positively or adversely affect commercial truck, rail, aviation, and waterborne networks, with significant implications for the delivery of goods and services, personal travel, and the economy.

In this edition of *Critical Issues in Transportation*, the TRB Executive Committee poses a series of challenging questions about potential critical issues that may arise 10 to 20 years into the future. These questions include interest in the implications of developing trends that might not fully manifest until beyond this period. The intent is to frame high-level questions that can be addressed during the next 5 to 10 years through research, policy analysis, and debate to help society prepare for the potentially unprecedented changes that lie ahead. The identified critical issues deserve attention because of transportation's central and essential role in serving individuals and society and the many consequences it has, both favorable and not

favorable, for the economy, safety, public health, and sustainability. The Executive Committee hopes that this document can serve to sharpen the collective understanding of transportation and its ramifications and encourage the analysis and research that will inform decisions by individual citizens and officials in both the public and private sectors. Although the issues have been identified and documented from a U.S. perspective, many of the issues are common across developed nations.

Broad forces constantly affect transportation, including the daily personal travel aspirations of more than 300 million U.S. citizens, population growth and migration, economic growth and contraction, technological and scientific advances, human-made and natural disruptions, and changing trade relationships. These larger trends catalyze corresponding changes in transportation demand, passenger and freight flows, service preferences, and supply responses. The resulting transitions are inevitably a time of adjustment and lively debate about how transportation can, and should, most effectively evolve to support the changing social, economic, technological, environmental, and public policy context in which it must function.

Understanding the broader environment that drives the demand for transportation, such as demographic change and economic growth, must be coupled with an appreciation of the goals that transportation strives to achieve, such as providing mobility and access through efficient system performance, safety, equity, sustainability, and resilience, and the conditions that drive transportation supply, such as financial and energy resources, governance, institutional capacity, and innovation. Opportunities for decision makers to improve transportation system performance across all of these different domains influenced the Executive Committee's choice of critical issues.

Whereas the Executive Committee frames this document around current trends and potentially revolutionary technological change ahead, a healthy respect should be maintained about what can be known about future developments. Rarely do futures cooperate with the expectations of their predictors. Hence, a particularly important element in identifying critical transportation issues is preparing for the multiple evolutionary paths that may be taken by both the forces of change and society's attendant strategies to accommodate them.

The issues identified in this document were generated from discussions by the Executive Committee and its Subcommittee for Planning and Policy Review. In addition to the members of the Executive Committee who made individual contributions, 23 transportation experts provided a critical review of the initial list, which led to a number of revisions. TRB's Marine Board and the chairs of TRB's standing committees and groups reviewed the revised list for coverage and balance, which led to further changes.

Questions about critical issues, italicized in the text that follows, are grouped under 12 inter-related topics:

1. Transformational Technologies and Services
2. Serving a Growing and Shifting Population
3. Energy and Sustainability
4. Resilience and Security
5. Safety and Public Health
6. Equity
7. Governance
8. System Performance and Asset Management
9. Funding and Finance
10. Goods Movement
11. Institutional and Workforce Capacity
12. Research and Innovation

Many issues span more than one topic area. For example, automation of transportation is currently of great interest in its own right, but can also have

important consequences for sustainability, system performance, safety, equity, and goods movement. Future settlement and development patterns similarly affect future demand for infrastructure and energy, impacts on the environment, governance, and funding. Funding has broad implications for system performance, safety, goods movement, and institutional and workforce capacity. Grouping the issues into the 12 topic areas relies on judgment. More consequential than grouping the issues, however, are the choices of issues to address.

The Executive Committee does not claim that its list of topics and issues is comprehensive. Transportation is a broad field of human activity that spans many disciplines and bodies of policy analysis and research across both the private and public sectors. No single person, or even group of people, can claim to be fully cognizant of the importance, status, and direction of all of the efforts under way affecting transportation. Rather, this list highlights what the Executive Committee, based on extensive consultation and its own judgment, determines to be the key issues for the transportation community, writ large, to address over the next few years. TRB's Executive Committee will also draw on this document to select a limited number of priorities for TRB's next strategic plan with the goal of focusing TRB's research, studies, and activities on the most important transportation issues facing the nation.

This document has been independently reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures specified by the National Academies of Sciences, Engineering, and Medicine's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will help assure that the report is balanced, evidence based, and satisfies institutional standards for objectivity and responsiveness to the committee's charge. The reviewers' comments and the draft manuscript they were provided remain confidential to protect the integrity of the deliberative process.

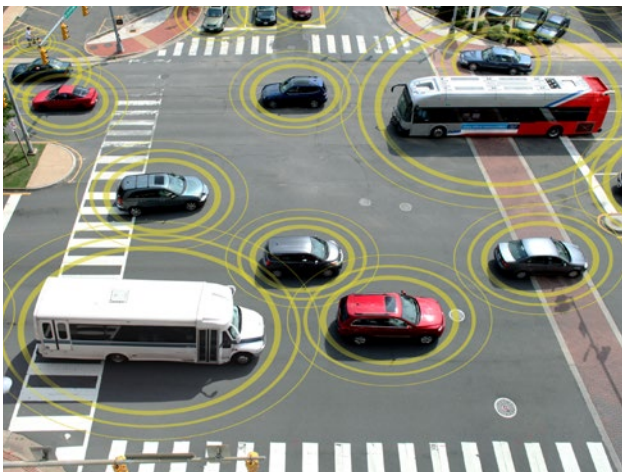
The Executive Committee appreciates the efforts of the individuals and groups who assisted in the preparation of this document and the critical review performed by 10 independent reviewers. The assistance that the Executive Committee has received has improved this report considerably. The selection and formulation of the topics and issues, however, are based on the Executive Committee's collective judgment and it assumes sole responsibility for this document.

## Transformational Technologies and Services

The potential autonomous operation of vehicles, vessels, and aircraft has captured the public's imagination, and understandably so. Despite a considerable overdose of hype, automation may one day revolutionize the movement of people and goods.[1] It will probably take longer to unfold than the general media implies, but advances in sensors, communication and information technologies, artificial intelligence (AI), and entrepreneurial business models may be at such an important point of inflection as to almost guarantee significant future changes and, hopefully, benefits. Advances in technology and entrepreneurship have already brought substantial innovations in service through ride-, car-, and bike-sharing services[2] and in the logistics systems that make e-commerce able to

provide next day and even same-day delivery of goods.[3] The potential benefits from increased levels of automation and service innovations include improved mobility, faster deliveries, fewer crashes, reduced congestion and emissions, and better accessibility for the disabled, elderly, young, and economically disadvantaged.[4] But equally possible are congested city streets and freight corridors, and more energy consumption and emissions from ubiquitously operating vehicles, as well as a sharp divide between those with the resources to purchase these services and those without them.[5]

Potentially most consequential in terms of passenger service, cost, and environmental impact is the combination of shared services, automation, and electric-drive technologies.[6] Creating and building on synergy among these three major changes enhances the probability of achieving the benefits previously listed. Consumer preferences and market pressures will play central roles in determining which technologies and services emerge and succeed, but public policies, if exercised, can also play a key role in encouraging and directing their commercialization for the common good. Vitally important questions include which technologies will prevail in the marketplace and what their implications will be for service, safety, and the environment. (This section primarily addresses passenger issues. Transformational technologies that affect freight are discussed in the Goods Movement section.)



1. The emergence of new transportation services and connected and automated motor vehicles (CAVs) raises a variety of questions about whether and how public policy can steer their development.[7]
   a. Fast-growing, app-based services, including transportation network companies (TNCs) such as Uber and Lyft, are providing new options for consumers but are also contributing to increased travel, congestion, and emissions in some cities.[8] *What policies could encourage more riders to take advantage of pooled ride options to reduce the number of trips? How can support for urban area policies, such as congestion pricing, be developed to manage demand for congested urban roads by TNCs as well as the single-occupant vehicles that account for the majority of peak travel?*
   b. Fully automated vehicles, despite likely having a higher cost than conventional vehicles, might appeal to consumers as they could spend their time on other tasks than driving and dispatch their vehicles for other purposes during the workday. Automated vehicles operated by commercial services and optimized with AI could one day have much lower operating costs than conventional services, owing to higher asset use and reduced labor costs. They could


**Between Public and Private Mobility**
*Examining the Rise of Technology-Enabled Transportation Services*

operate almost continuously, and not always occupied. On the one hand, vehicle miles of travel, congestion, and emissions could potentially all be significantly reduced. On the other hand, automated vehicles could result in more vehicle trips and allow commuters to live even farther from where they work, facilitating additional sprawl, which could also increase total travel, congestion levels, and energy consumption. *Which policy options can and should be exercised to achieve net social benefits from automated vehicles?*

c. Federal policy promotes connectivity among vehicles and with infrastructure (connected vehicles) that would communicate with one another at a high bandwidth to enhance safety.[9] Even as automakers begin to roll out connected vehicles, they are also offering semiautomated vehicles that can take over the driving task in some applications. Many companies have promised to begin offering fully automated vehicles in the near future. Assuming a likely gradual market penetration of automated vehicles,[10] it will take several decades before most of the automotive fleet is fully automated. As a result, there will be a long time span during which CAVs operate side by side with conventional driver-operated vehicles. *How can the public sector foster technological innovation and steer the transition to CAVs to improve safety during this transition period? Which issues will need to be addressed to reduce risk when semiautomated and automated vehicles operate in mixed traffic with drivers of conventional vehicles? How does society approach managing public opinion and expectations and regulating semiautomated and automated technologies that may sometimes fail but nonetheless operate more safely than current vehicles?*[11]

d. Connected vehicles may arrive much sooner than automation. Their safety benefits will be enhanced if the public sector invests in adding sensors and communications technologies to traffic signals, signs, and other infrastructure. Public investment in infrastructure, however, occurs much more slowly than new technologies enter the vehicle fleet. Indeed, the auto industry is forging ahead with CAVs that will have benefits independent of public investment in smart infrastructure. *How can the misalignment between investment by the public and private sectors be overcome? What should be the highest priorities for publicly funded connected vehicle infrastructure improvements? What are the potential roles for public–private partnerships in accelerating the pace of public investment?* Another important factor for connected vehicles to move forward is resolving the current debate within industry

over whether the initiative should rely on existing digital short range communications (DSRC) technology or LTE-V2X short range communications and the forthcoming 5G direct communications evolution. The alternative to DSRC would require some reallocation of the 5.9 GHz spectrum currently set aside for DSRC.[12] *What is the complete set of information that policy makers need to resolve this debate over communications technology?*

2. Other side effects of shared mobility services raise questions about the need for additional federal, state, or local policies.[13]
   a. TNCs, as well as shared car, bike, and electric scooter programs, are expanding consumer options and affecting existing modes and services in different ways. In major cities total automobile use is increasing, even with TNC pooled-ride options, at the expense of transit and nonmotorized modes, even as they provide "first and last mile connections."[14,15] *What and where are the opportunities for demand-responsive, app-based services to complement or link with conventional transit services, while also ensuring that the mobility disadvantaged are adequately served?* (See also the discussion of access under this report's Equity topic.)
   b. Many jurisdictions regulate TNCs, taxis, and other "for-hire" services differently with regard to (a) driver and vehicle safety and (b) geographic service.[16] *Although the regulations applied across different services may differ, how can and should this regulation allow competition to play out with a focus on achieving a consistent set of outcomes?*[17]
3. As TNCs proliferate and companies experiment with automated vehicles, a debate has opened up about the respective safety regulatory roles of the federal government and the states.[18] *What is the appropriate balance of both state and federal safety regulatory oversight while enabling private-sector transportation technology development and innovation?* Automated vehicles are currently being tested and developed on public roads under a voluntary federal safety framework with limited state and local oversight that is providing little disclosure to the public about the potential public risks of these tests. *How much information should companies be required to share with the public about these experiments and technology development efforts?*

4. Automation depends on advances in AI, software, and sensors to substitute for human operators of transportation systems. *How can we ensure the consistent and safe performance of AI, software, and sensors in a diversity of both conventional and unanticipated situations? How can regulatory agencies develop expertise in overseeing performance assessment and safety assurance of the technologies behind automation?*[19] *As automated vehicle use increases reliance on AI, software, and sensors, all of which can fail, how will product liability laws need to evolve to serve the public interest?*[20]
5. Regardless of which transformational technologies win consumer acceptance, human beings can be expected to respond in multiple ways, including unexpected ones. Possible behavioral responses to transformational technologies are listed below. Their implications are explored further in the sections that follow addressing settlement patterns, energy consumption and emissions, demand for infrastructure, and safety.

a. Many questions remain about how transformational technologies will affect travel behavior in the short term. *How much will consumers value new products and services and how much will they be willing to pay for their safety, energy saving, and emission reduction attributes? How will these technologies affect the number of trips, modal preferences, and willingness to pool rides?*[21]
b. Consumer response to services offering automated vehicles with low operating costs could reduce the need for automobile ownership, and thereby, among other effects, free up space for urban redevelopment as such a large share of urban space is devoted to parking.[22] *How might transformational technologies affect auto ownership? Will the other attributes of auto ownership (flexibility, independence, status) continue to outweigh the cost advantages of using other modes? If auto ownership does diminish, how might requirements for parking diminish and what opportunities exist to repurpose on- and off-street parking for other uses?*
c. Over the long term, transformational transportation technologies may affect where people and businesses choose to locate, in turn affecting consumption of space, demand for infrastructure, energy consumption, and emissions.[23] *Will transformational technologies encourage more or less low-density residential and commercial location?*
d. In response to some vehicle technologies introduced to enhance safety, human beings apparently drive in ways that can negate some of their benefits; in the case of antilock brakes, for example, long-term evidence indicates no reduction in fatal crashes.[24] *During the long transition period of simultaneous operation of conventional and semiautomated and automated vehicles, how will drivers adapt to the safety features of semiautomated safety technologies? How will drivers of conventional vehicles respond to CAVs that may operate more slowly and cautiously?*
e. The general public judges risks and behaves accordingly differently than experts do for a wide variety of reasons, such as the perceived degree of control, voluntary exposure to risk, and familiarity.[25] Society implicitly recognizes public perceptions by requiring far less risk from flying on a commercial flight than driving on a rural highway. *What level of risk will the public require of automated vehicles? How much safer will they have to be than conventional vehicles to gain public acceptance?*

## Serving a Growing and Shifting Population

Future population growth in the United States is expected to average about 1 percent annually, with increases in highway vehicle miles of travel of similar magnitude,[26] but past trends imply that this growth will not be even across the country. Included among these trends are population growth in several megaregions;[27] regional migration, particularly toward the Southeast, Mountain West, and West Coast; and population declines in rural areas across the country.[28] (More recent counter trends to growing urbanization in the largest metro areas may suggest rebounding population growth in medium size and smaller cities.[29])

Regardless of where it is located, low-density residential development at the periphery of existing development continues to grow the fastest.[30] Many future demographic changes (internal migration, aging population, immigration, and household size) will influence the demand for transportation. Yet, where people choose to settle explains much about the modes they will rely on and the volume of future travel. These residential settlement patterns, combined with the commercial development that tends to follow, have broad implications for infrastructure demand, travel time, and the environment.[31] As the largest population cohorts, the preferences of the Baby Boom and Millennial generations will have outsized impacts on future travel demand.

6. Megaregions are emerging as the engines of the national economy.[32] The concentration of growth into these regions is also resulting in the worst traffic congestion,[33] which continues to grow faster than capacity can be provided. Much of the traffic growth in megaregions occurs between urban cores, and most of these trips are by automobile.[34] Long-distance passenger and freight movements, concentrated in corridors connecting the megaregions and the facilities that generate these trips, are facing more and more congestion. Solving megaregion transportation problems that involve both internal and external connectivity will be important in ensuring their continued vibrancy and contribution to the national economy. *What are the most cost-effective transportation policies for improving internal megaregion travel and ensuring that megaregions are well connected to the rest of the nation and the world?*

7. Although large metropolitan areas continue to have the highest population growth rates, growth in small metropolitan areas and nonmetropolitan counties is rebounding from losses during the Great Recession, and growth rates in these small metro areas may once again exceed those of large metro areas.[35] *What are the implications for local and intercity travel demand and infrastructure investments and operations if these trends persist?* Regardless of the region of the country, the dominant share of residential development is occurring in suburbs and exurbs that are expensive to serve using traditional public transportation operations, which have important implications such as growing demand for road capacity and increasing auto emissions. *What transportation policies and programs are most cost effective in mitigating the congestion and environmental costs of automobile trips in these settings? What role can new transportation services such as TNCs play in these areas? What role can land use policies play in shaping future development and transportation demand?*
8. If the rural population shifts previously described persist, they could have broad implications for the transportation policies and programs needed to serve these distinct areas of the country.

a. *How can rural and farm access to services and markets be sustained as populations and resources for infrastructure decline and if competition among freight carriers for transporting goods decreases? As populations and tax bases decline, how will rural highway routes be funded?*
b. Access is a particular challenge for the economically disadvantaged, the elderly, and the disabled, who lack transit options and service by TNCs due to low population densities and an absence of high-speed Internet service in many rural areas. *How can rural populations be ensured adequate access to jobs and services? How is that access changing? Which policies are needed to provide adequate rural access?*

9. Although many Millennials, the largest population cohort, are living in center cities, the largest portion are settling in the urban periphery or in areas between urban centers within megaregions,[36] making it more difficult to provide nonautomobile options. Most Baby Boomers continue to prefer single-family homes in the suburbs (about two-thirds) or in rural areas (more than one-quarter).[37] *What are the transportation implications of these trends among the largest population cohorts? How can adverse environmental effects from transportation be minimized?*

## Energy and Sustainability

Drastic reductions in greenhouse gas (GHG) emissions are needed in the coming decades from all sectors to avoid the possibility of catastrophic climate change.[38] Transportation now accounts for the largest share (28.5%) of U.S. GHG emissions.[39] Moreover, other sectors are reducing carbon emissions much faster than transportation.[40] Transportation may be the most challenging sector to address because of its requirements for high-energy density fuels, particularly for aviation, large ships, and long-haul trucking. Largely for this reason, even if and when the nation confronts transportation's role in climate change, oil and natural gas will continue to be major sources of transportation energy in the United States and internationally for many years to come. Adverse environmental effects result not only from producing, shipping, and combusting energy, but also from mining and manufacturing the many components of vehicles, including the materials needed for rechargeable batteries.[41] (The public health consequences of vehicle emissions are discussed in the Safety and Public Health section of this report.)

Critical questions in moving toward sustainability include determining the most cost-effective strategies for reducing GHG emissions; accounting for the full environmental consequences of mining, producing, and consuming transportation fuels and vehicle and battery components; deciding on the appropriate public- and private-sector roles in facilitating and achieving the conversion to both battery and hydrogen powered electric-drive vehicles; and building public and political support for implementing the most effective strategies. Research challenges include addressing a transition to low-GHG energy sources for transportation that is more driven by public good than private benefits, uncertainty about both future technologies and their economics, and consumer willingness to pay for energy efficiency, among other topics.

10. Transportation in the United States generates more GHG emissions than any other sector and its share is growing, largely due to fossil fuel consumption.[42] To make a proportional contribution to reducing GHGs, however, reductions from transportation would need to go beyond the aggressive federal fuel economy and GHG standards adopted in 2012 (which themselves are being reconsidered as too

aggressive at the time of this writing).[43] *What are the most cost-effective strategies to stabilize and ultimately reduce GHG emissions? What is the role of transportation in achieving this goal?*[44] Other key challenges include reliably monitoring and confirming progress toward GHG reduction goals; the potential for public–private collaboration in achieving reduction goals; the respective sectoral roles in increasing energy efficiency and reducing carbon intensity, reducing motorized travel, and improving system efficiency; identifying the necessary policy actions and technological advances; and managing the transition to automated vehicles to reduce GHGs rather than increase them.[45]

11. The price of transportation fuel and motor fuel taxes and other transportation fees do not reflect the social and environmental costs that transportation imposes. Hence, society cannot depend on market forces alone to identify and apply environmentally sustainable energy sources for motor vehicles, aircraft, and vessels in the coming decades. *What are the most consequential and cost-effective public policy strategies to move the transportation sector toward sustainable energy sources while taking into account the full environmental consequences from the energy source through consumption, emissions, and recycling of spent vehicles and components?*
12. As major industrialized nations impose zero- and low-emission requirements, automakers are responding with promises to shift to the production of electric, plug-in hybrid, and hydrogen fuel cell vehicles, which raises questions about the public role in encouraging electrification of the fleet and the impact that growing electricity demand will have on the energy grid and overall emissions.
    a. *How can public policy influence consumer acceptance of electric vehicles?*[46] *What is the appropriate public role in facilitating the distribution and adequate coverage of hydrogen and battery refueling and recharging infrastructure? What policies will work and be most cost effective?*
    b. *What are the implications of the growing reliance on electrical power in transportation and how can electrification be managed to gain the most societal benefit?*
        i. Using electricity to power transportation vehicles could reduce GHG emissions, but the scale of the benefits depends on the source of energy (coal, gas, petroleum, nuclear, renewables)[47] that electric utilities choose or are incentivized to employ. *How can the public sector best affect these choices?*
        ii. *What will be the impact of growing demand from transportation on the electric grid? How can utilities and public agencies, as needed, encourage the timing of recharging to maximize benefits for the grid and users?*[48]
    c. *What is the potential for transportation infrastructure itself to generate energy from solar radiation, wind, or other environmentally sound sources?*
13. Sustainability requires that there be long-term consideration of the implications of decisions and policies on social, economic, and environmental systems. Examples include making decisions based on life-cycle cost considerations and the long-term vitality of communities and key natural environmental systems. *How can consideration of long-term sustainability goals be better incorporated into public policy debates and decisions about transportation?*

## Resilience and Security

Recent intense floods, super storms, and hurricanes have disrupted the lives of millions and caused hundreds of billions of dollars' worth of damage.[49] Combined with the vulnerability of transportation facilities to terrorism, these events have made public and private officials acutely aware of the need to identify community vulnerabilities and plan for responses to natural and human-caused disasters, including near- and long-term climate change effects on sea level rise, droughts, forest fires, and heat waves.[50]

Communities face differing threats and will need strategies fitted to their circumstances. Businesses, shippers, and carriers must anticipate and plan for supply chain resilience in the face of broad disruptions. An equally compelling set of questions addresses the larger challenge of protecting, modifying, rebuilding, or relocating highly vulnerable highways, bridges, transit facilities, railroads, waterways, airports, and ports to make them more resilient; it may be necessary to add redundancy where possible and even abandon some facilities. It is critically important to determine how to pay for improved resilience in the short term to save money in the long term.

14. Terrorist strikes worldwide continue to demonstrate the vulnerability of transportation facilities where masses of people gather.[51] Aviation has developed layers of security to protect against terrorism, albeit at a high cost. Other modes are more open and vulnerable—including airports, rail and transit stations, and seagoing vessels (piracy). Improved analysis of trade-offs between security and the efficiency of freight and passenger movement is needed to inform policy makers. *How can strategies appropriate for each mode be developed to apply layers of security without excessively impeding the movements of passengers and goods?*[52]
15. The development of robust risk assessment and management methods for vulnerable assets and policies and designs for extreme events is an important next step in preparing for resilience.[53] *What kinds of decision-making tools can best help transportation agencies make appropriate decisions about climate change and terrorism in a risk-management framework? How can risk management approaches be incorporated into transportation planning and decision making? How can results from climate models be translated into changes in design standards for severe weather events?*
16. Proposals to adapt, operate, and strengthen infrastructure to be more resilient raise a number of key questions.[54]
    a. *Which policies, programs, research topics, and investments can and should be undertaken to adapt existing transportation facilities and systems to rising sea levels, stronger storm surges, more frequent flooding, and other powerful and damaging weather extremes?*
    b. *How can the experiences of communities and states that are beginning to adapt and change*[55] *be best evaluated and shared?*
    c. *In light of the inability to be precise about the scale and timing of future impacts, how can funding policies, designs, and standards be modified to build in flexibility to allow for needed adaptation, including the rebuilding of more resilient infrastructure after it is damaged or destroyed?*
    d. *What evidence would convince policy makers and the public of the need to incur the extra, near-term costs of adaptive management?*

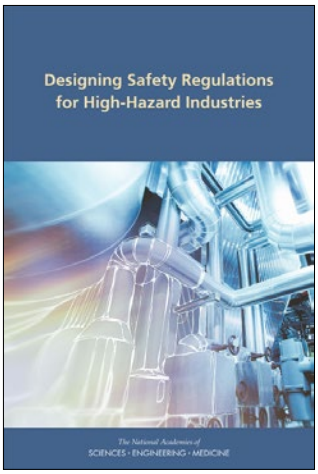
e. *What are feasible strategies for defending or retreating from the highest-risk areas and avoiding continued investment in the most vulnerable ones?*

17. Drones used for transportation—large and small—raise questions about their use by terrorists or for illegal purposes such as smuggling drugs or the delivery of explosive devices to areas with large numbers of people. The aviation and defense sectors are working on drone detection and interdiction technologies. *How can security forces most effectively mitigate the security risk from drones?*
18. Partially automated and, eventually, fully automated vehicles, vessels, and aircraft and smart infrastructure remain vulnerable to hackers in ways that threaten safety and public confidence. *How can and should cybersecurity for these systems be made as robust as possible?*[56] *What capabilities will public agencies need to verify whether cybersecurity is being managed effectively?* Cybersecurity concerns for transportation extend far beyond automation. Myriad public and private systems for managing flows of vehicles, accounting records with personal information, and other systems are vulnerable to hacking and ransomware. *What are best practices, how can they be shared, and what role should the public sector play in overseeing and enhancing cybersecurity?*
19. All transport modes are highly dependent on the Global Positioning System (GPS) for guidance and navigation,[57] but there is no national or regional backup should GPS systems fail for a period of time. Systems across all modes that rely on GPS are also vulnerable to "spoofing" that threatens guidance systems. *How can these vulnerabilities be overcome or managed effectively?*
20. As a result of more severe massive storms and threats of terrorist attacks, large-scale evacuations will become more common. The transportation system, however, is incapable of evacuating entire metropolitan areas on short notice. *What strategies are needed for better preparation, response, communication, and sheltering in place on a regional scale*?


## Safety and Public Health

The economy and lifestyles of U.S. citizens depend on transportation, but they exact a large toll in the form of deaths and injuries to travelers, suffering by their loved ones, and adverse health effects from transportation operations and emissions. Media depictions of catastrophic airline and train crashes garner the most attention, but 95% of transportation fatalities,[58] roughly 35,000 to 40,000 annually, and most transportation emissions harmful to public health, result from routine highway travel that receives little public notice. Despite ongoing improvements to vehicles and infrastructure that have reduced injury risk, many highway casualties nonetheless result from predictable causes that can be reduced by using proven strategies.[59] Although highway safety remains a primary safety focus, new risks are emerging from rapidly expanding transportation and recreational applications for drones, and potential terrorist applications of drones as well.

Major challenges that need greater insight are how to overcome barriers to the use of the safest road and vehicle designs, adopt proven techniques for reducing alcohol- and drug-impaired operations




**Designing Safety Regulations for High-Hazard Industries**

and speeding, and implement effective policies to manage operator fatigue across all transportation modes. Additional important questions include how to reduce distractions to operators and pedestrians and incorporate semiautonomous driving technologies in ways that reduce rather than increase risk. The public health consequences of transportation emissions and noise and the consequences of chronic fatigue in 24-hour operations also demand greater understanding and action. Once a world leader in highway safety, the United States has become a laggard: accordingly, thousands, if not millions, are injured every year in crashes that could have been avoided. Averting these tragedies makes it all the more important to understand the most effective highway safety strategies being employed in other nations, as well as in the safest U.S. jurisdictions, and building popular and political support to implement them.[60]

21. The public and private sectors have made great strides in protecting vehicle occupants from highway crashes. *How can we accelerate the adoption of crash protection measures that have been proven effective, such as air bags, energy-absorbing materials, and safety belt use and helmet laws, as well as the adoption of the safest road designs? What transferable lessons can be learned from those states and localities that have been successful in reducing deaths and injuries through implementing safety countermeasures that work? How can we reverse the sharp decline in highway traffic safety enforcement in some jurisdictions?*
22. Many driver warnings and semiautomated features being added to motor vehicles today provide the opportunity to avoid crashes,[61] but some may also increase unintended overreliance on technologies.[62] *How can semiautomated driving, which requires driver vigilance even when relying on the vehicle to steer and brake, be most effectively regulated to address the risks of increased distraction and inattentiveness?*[63] *As ever more technology is available and used by transportation operators, how do we reduce the death and injury resulting from related distractions,*[64] *such as cellphone use by both vehicle operators and pedestrians,*[65] *or from erosion of operator skills as reliance on semiautomation grows? What are the net safety benefits of semiautomated technologies even if they do increase distraction-related crashes?*
23. Transportation's role in public health is widespread, including the effects of emissions,[66] noise,[67] and urban heat islands;[68] the spread of infectious diseases;[69] and fatigue, stress, and chronic disease among transportation operators.[70] Access to public health facilities, particularly for the disabled, elderly, and economically disadvantaged, continues to be a challenge. *How can we develop a deeper appreciation and management of public health outcomes related to transportation and promote healthier approaches?*
24. Pollution is a leading cause of disease and premature death, with the majority of pollution-related deaths attributed to local air pollution.[71] People living or working near roadway environments or near ports, rail yards, airports, and other transportation facilities appear to be at an increased risk from motor vehicle emissions.[72] This increased risk disproportionately affects lower-income groups and minorities. *Which mitigation measures can be justified and implemented and which need more research to reduce health risks for those living near major transportation emission sources?*

25. Operator fatigue is an ongoing major safety concern and a source of incidents and accidents in all modes of transportation.[73] *What are the most effective regulatory, management, and technological approaches to detecting and managing fatigue?*[74] *How can proven strategies gain more widespread application? What evidence would inform policy makers about the benefits of additional appropriate requirements for transportation operators to reduce the risk to their workers and the public?*
26. New technologies are emerging that could introduce new sources of risk.
    a. The use of unmanned aircraft systems (UASs), also known as drones, is growing rapidly—the use of recreational UASs is expected to triple by 2021 to as many as 3.5 million units and the use of commercial UASs may grow 10-fold to reach more than 400,000 units.[75] Meanwhile, sightings of nearby UASs by commercial pilots and near misses are also growing. *How can the risk to the traveling public be most effectively managed as these new technologies proliferate?*
    b. Short-haul, low-altitude passenger aviation trips by battery-powered aircraft may become viable[76] and could reduce congestion on urban streets and highways, but they also raise a number of questions about how low-altitude air space would be managed.[77] *How could such aircraft be regulated? How could airspace be most effectively managed to avoid conflicts between such passenger trips and low-altitude drones? What public-sector infrastructure would be needed and how could it be paid for?*
    c. Large freight drones that operate in the air and on the sea may emerge and lower the costs of freight transportation. For these technologies to advance, however, they would have to be managed to avoid conflicts with other aircraft and vessels. *How could aviation drones be safely and efficiently integrated into managed airspace? How could maritime drones, autonomous vessels, and manned vessels coexist and be safely managed in existing traffic lanes?*

27. As transportation systems become more complex and confront risks that are hard to estimate, it becomes increasingly difficult for safety regulators to write simple and effective rules to ensure safety. *How can regulators and industry be incentivized to strengthen their safety management systems and safety cultures in ways that will encourage firms to achieve safety levels beyond what can be realized through compliance with existing rules and standards?*[78]
28. Marijuana legalization and growing opioid addiction may increase drug-related deaths and injuries in transportation. Early evidence from the first states to legalize marijuana shows an increased number of vehicle crashes compared with states that have not legalized it.[79] The effects of marijuana on driving performance are much more difficult to discern, measure,

and enforce than those of alcohol.[80] *What might expanded legalization of marijuana and increased opioid abuse mean for impaired driving in the years ahead and for appropriate safety responses? How do other legal and illegal drugs affect driving performance and which drugs should drivers be tested for following incidents and crashes?*

29. Despite long-term trends in reduced death and injury rates in highway transportation due to improved vehicles and infrastructure, the United States is experiencing rapid growth in pedestrian and cyclist deaths (a 46% increase in pedestrian deaths since 2009)[81] and is falling behind the safety level being achieved in other industrialized democracies. *Which strategies would be most effective in reducing the growing number of pedestrian and cyclist deaths and injuries?*

## Equity

The United States is a prosperous nation, but its benefits are not equally shared. More than 40 million citizens live below the poverty line, 23 million of whom are working-age adults.[82] An estimated 9% of households lack an automobile,[83] and this percentage grows to 21% in households earning below $25,000.[84] Being employed without an automobile is manageable in some central cities with good public transportation and taxi and ride-sharing services, but can be a genuine hardship in places where access to jobs requires a personal vehicle.[85] Transportation equity has many dimensions, including affordable access to transportation for workers to reach job sites and for the aged and disabled to reach health care facilities, family members, and services. Yet, a different equity dimension exists with regard to the disproportionate impact that transportation operations and emissions have on low-income and minority neighborhoods (also discussed in the previous section).

Nearly 17.5 million workers live in households that lack cars or have more workers in the household than vehicles.[86] Nearly 40 million Americans have some form of disability, almost 16 million of whom are age 35 to 64.[87] All of these equity issues are compounded in suburban areas with limited public transportation and rural areas that lack public transportation entirely. Moreover, the population is aging: the 49 million citizens currently over age 65 (15% of the population) will increase to 73 million (21% of the population) by 2030.[88]

These problems are not new, but they are particularly hard to solve and evolving technology and services may create new barriers to the disabled and economically disadvantaged. Access to employment, health care, and services can be expanded through transportation policies and programs, but strategies need to be affordable and effective, which are significant challenges in sparsely populated areas. Ensuring that the negative consequences of expanding transportation networks and operations do not fall disproportionately on low-income and minority neighborhoods is an ongoing challenge that is rarely fully met.

30. Many new transportation services, such as TNCs, car sharing, and bike sharing, depend on user access to smartphones and credit cards, yet 23% of adults (57 million people) lack smartphones[89] and 7% of households (9 million people) lack bank accounts and credit cards.[90] *How can people without bank accounts, credit cards, or smartphones gain access to new transportation services? Which transportation services and technologies, including automated vehicles, TNCs, and enhanced transit services, are best suited for maintaining independent living for the disabled and older travelers who do not drive?*[91] *How can the addition of new barriers be avoided and the utility be maximized of technological innovations for older and disabled travelers?* Many local jurisdictions in the past have mandated that taxi operators provide accessible vehicles for the disabled, as well as trained drivers to operate them, and some have added surcharges on taxis and, more recently, TNC trips, to generate revenues for this service.[92] *In light of the decline in taxi service since the advent of TNCs, what are better ways for local jurisdictions to fund and provide transportation services for the disabled?*[93]
31. The number of people in poverty in suburban areas now exceeds that of cities.[94] Low-density suburbs are difficult to serve well by transit. *How does transportation access affect economic opportunities and outcomes for the economically disadvantaged? Which transportation technologies and policy interventions would be most effective and affordable for enhancing access to employment opportunities, health care, shopping, and education? Which transportation policies would be most successful and cost effective in addressing the growth of low-income populations in suburban and exurban areas?*
32. As transportation facilities are expanded and improved to serve a growing population and economy, *how can we best ensure that minority and low-income communities receive adequate service and that any adverse effects from new facilities or expanded operations do not fall disproportionately on them?*
33. As general revenues and sales taxes replace user fees, it raises basic questions because (1) sales taxes are more regressive than fuel taxes and (2) the funding for transportation services becomes disconnected from its use.[95] *What are the implications for both fairness and efficiency resulting from this trend? What are the full consequences of alternative funding mechanisms for transportation to the accessibility of those with the least resources? How can the inequities of existing user fees be ameliorated?*
34. As financially strapped public transportation agencies increasingly turn to public–private partnerships to provide new infrastructure, which typically requires some form of toll or charge to repay private investors, *what are the equity implications for low-income highway users?*


## Governance

Layers of institutional complexity confound the creation of efficient transportation networks and intermodal connections in ways that even the most creative minds struggle to resolve. Devolution of federal responsibilities and funding to state and local governments in recent years has compounded the difficulties in overcoming institutional inertia due to weakening federal incentives and leadership in addressing multi-state problems.

Transportation infrastructure and services in the United States have long been provided or regulated at multiple levels of government, including municipalities, cities, counties, special districts, regional planning organizations, states, and federal agencies, each of which has a role in planning, funding, and managing some aspect of transportation infrastructure. Many transportation functions such as public transit, airports,

waterways, and ports are also planned for, or provided, through thousands of special authorities. Added to this mix is the interdependence of the public and private sectors as private trucks, aircraft, barges, and ships use public infrastructure for the movement of people and freight and the growing dependence on private companies to finance, build, manage, and maintain public infrastructure.

The transportation systems that support metropolitan areas and megaregions typically span myriad jurisdictional lines, raising questions about which level of government should be responsible for, and what aspects of, network planning, funding, and management are appropriate for these evolving and increasingly important geographies. As metropolitan areas grow into megaregions spanning multiple states, questions arise about institutional reform, as well as models of successful cross-agency cooperation,[96] that facilitate the establishment of integrated and efficient transportation networks. The dependence of private carriers on public infrastructure raises important questions about the appropriate regulations to ensure that private carriers pay their fair share, have a level playing field for competition, and serve the public interest.

35. States and local governments are assuming greater responsibility for transportation services and infrastructure in response to a declining federal role and reduced funding support. *How does this shift in the federal role and support affect state and local commitment to facilitating interstate and international commerce? How is devolution affecting net infrastructure investment across all levels of government?* Cross-border coordination among states in planning and policy making is a major gap, particularly with regard to freight movements. Metropolitan areas that host major ocean ports and airports that serve international and interstate commerce bear the brunt of local noise and traffic caused by these facilities. *What best practices can be put in place to ensure effective and equitable treatment of these cross-border externalities?*
36. Major bottlenecks to traffic flows spanning modes and jurisdictions are well known, but are particularly hard problems to solve. The Chicago Region Environmental and Transportation Efficiency (CREATE) program is an example of a $30 billion-plus list of projects, far from funded, that involve rail systems, highways, public transportation, and multiple private carriers and public jurisdictions.[97] The New York/New Jersey Gateway program,[98] a critical node on the most heavily trafficked passenger rail corridor in the country, is another example of an unfunded, high-cost local project that affects travel across multiple states. *How can financial, institutional, and competitive barriers be overcome to reduce nationally significant bottlenecks at large-scale, complex transportation facilities?*
37. Hundreds of metropolitan planning organizations exist, but many are too limited in scope and scale to take on multimodal planning for transportation at the metropolitan-wide or megaregion scale.[99] *As metropolitan*

*areas and megaregions grow in significance and as sources of economic prosperity, what is the appropriate institutional form for making transportation investments at this scale given the many and complex jurisdictions and state interests?*[100] *What institutional reforms are needed to serve the public more effectively and efficiently and how can these determinations be made? In light of the considerable experimentation going on, how can jurisdictions best learn from each other about effective strategies for meeting their regions' multimodal transportation needs*?

38. Mobility as a Service could provide real-time, traveler-specific information on travel options, thereby making both travelers better off (by allowing them to select their preferred mode of travel based on time, price, and trip time uncertainty) and society better off (by allowing travelers to consider shared driving options, thus increasing the use of modes with lower public and private costs).[101] The concept of bundling mobility services into subscription programs has garnered global attention and traction, but requires solving barriers to integrated fare payments, data sharing and developing, and supporting a common mobile application that provides consumers with a fair and integrated perspective on all of their travel options. *What are the appropriate public and private roles in providing Mobility as a Service by leading, supporting, or at least not inhibiting the development and deployment of such options? How can institutional and modal funding barriers be overcome and partnerships be built across levels of government and between the public and private sectors? Is the concept of regional transportation agencies as coordinators of mobility services and service contracts an institutional model worthy of consideration going forward?*
39. Transformational technologies and alternate infrastructure funding strategies have intriguing implications for existing transportation institutions. *If highways become more automated and are funded through direct user charges, for example, what are the appropriate institutions for operating and managing these systems most efficiently and safely, particularly for networks that span multiple jurisdictions?*

40. TNCs, and potentially CAVs, generate massive amounts of data about trips, thereby providing cities that have successfully negotiated access to such information with improved awareness about services offered, safety, and network performance. Negotiated agreements and sophisticated data-sharing arrangements are needed to protect the competitiveness of the companies while also providing a boon to cities and regions trying to better manage their transportation systems.[102] Data from other infrastructure and service providers can enhance overall infrastructure performance in "smart cities" by, for example, sharing real-time traffic flows with police, fire, and other emergency responders.[103] *Who should have access to anonymized data on items such as trip patterns and volumes,*[104] *and who should be responsible for analyzing them? How can these data be kept secure to protect personal privacy and proprietary information? How can data from transportation be integrated with data from other sectors to improve city and regional public services? How can unconventional data sources about travel and risk exposure be used to analyze safety risks?*

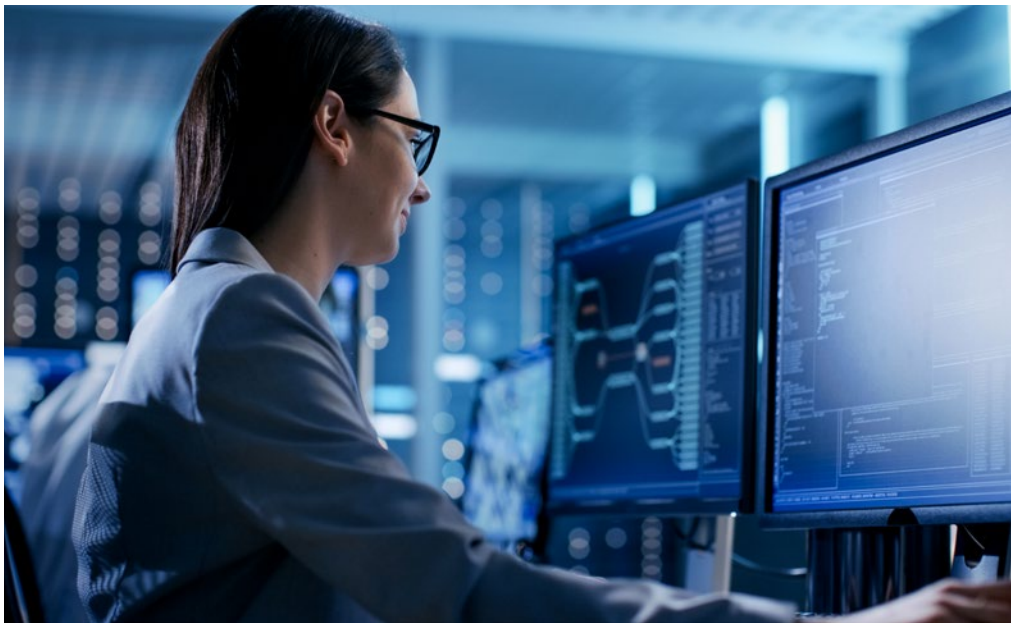
## System Performance and Asset Management

Although an imperfect estimate, highway congestion may have cost the nation as much as $300 billion in 2016—$1,400 for every motorist.[105] The trucking industry estimates its cost of highway congestion at $74.5 billion in the same year.[106]

Flight delays add at least another $30 billion.[107] Although these costs may be overstated, ever-growing congestion indicates that the demand for transportation infrastructure is outpacing supply and imposing high costs on society. Limited opportunities and high costs to expand facilities in already congested areas will result in a greater emphasis on maximizing the performance of the existing transportation network. As travel volumes continue to grow and funding remains highly constrained, state and local agencies are struggling to add capacity and maintain the performance and condition of the nation's infrastructure, the value of which is in the trillions of dollars.[108]

As part of squeezing more performance out of existing assets, transportation officials are struggling to maintain the assets' physical condition for as long as possible. Much better estimates are needed for the life-cycle performance of materials, infrastructure designs, and deployment strategies to develop better predictive models to guide decision making. If analyses can account for local conditions, traffic, materials, and weather, such information could help maintenance managers extend the expected life and life-cycle performance for highways, bridges, rail lines, ports, waterways, and airports. Ongoing improvements in material performance, construction, and maintenance are all essential for improving the life-cycle performance of new and existing assets. Equally important are questions about how public officials can place greater priority on managing existing assets before choosing to expand them or build new ones.

41. Technological innovation may make it possible to move CAVs through existing networks more efficiently at much shorter headways on narrowed lanes without harming safety, possibly even improving it. Pricing road use, as applied in new urban express lanes, is providing some congestion relief as well as new funding for alternative modes. In the shorter term, corridor-level performance can be enhanced through the use of technologies that improve communication between vehicles and infrastructure and provide better information for travelers about system performance. *How can officials responsible for public infrastructure improve the performance of the existing system of roads, public transit, airports, waterways, and ports? What types of tactics, data, vendor contracts, and tools will help? Would institutional reforms, such as transferring air traffic control to an independent public corporation or placing more highway and transit assets and operations under private management, enhance system performance?*
42. Continued population growth in megaregions and urban areas promises continued growth in travel. Adding capacity to all modes of transportation in growing urban areas faces many constraints, such as the high cost of developed land, protections against



environmental damage, and neighborhood opposition. *How much can shared transportation services, personal bicycles, and electric scooters substitute for growth in single-occupant auto trips, many of which are less than three miles? How can new capacity be added, where justified, while incorporating expected benefits from technology, pricing, and other strategies, and also responding to environmental concerns of additional road capacity and traffic?*

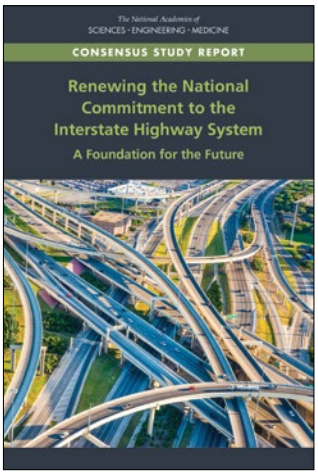
43. With constrained budgets, public officials must always weigh trade-offs between investing in new facilities and providing adequate funding for the maintenance of existing facilities. *How can support be developed at the federal, state, and local levels to give greater weight to investing in system preservation and maintenance? How can decision makers be convinced to invest in longer-lasting facilities and systems when initial costs may be higher, even though life-cycle costs are lower?*
44. Advanced materials and construction techniques and improved maintenance strategies are needed to cost-effectively enhance infrastructure performance over its full life cycle. *How can such innovations be developed, proven, and moved into practice more quickly? Which areas of research and analysis on materials, construction, and maintenance have the most promise to improve life-cycle infrastructure performance and how can that performance best be demonstrated?* Part of the challenge is overcoming the inherent caution of infrastructure managers responsible for assets with long service lives, who are hesitant to use new materials and techniques without extensive field testing. *What are the barriers to and opportunities for moving promising approaches into practice more quickly through certification or warranties based on accelerated testing done by third parties?*

## Funding and Finance

For generations, user-fee funding has provided a steady and, at times, ample source of funding for highways, bridges, airports, ports, and public transportation,[109] but this reliable mechanism has become imperiled by an aversion to raising taxes

of any kind at the federal level. User-fee funding has many efficiency, efficacy, and equity merits, but despite the majority of the public supporting paying motor fuel taxes if the funds are dedicated to maintaining roads and highways,[110] elected federal officials have been reluctant to raise these taxes to account for inflation, declining revenues as fuel economy improves, and growing demand. The unwillingness to increase federal motor fuel taxes has caused Congress to increase reliance on general tax revenues to support surface transportation and to shift more responsibility for highways, including those serving interstate transportation, to the states. Congress has resisted airport owner and operator requests to increase passenger facility charges to expand terminal and gate capacity and enhance competition. Shortfalls in revenue from aviation ticket taxes constrain budgets for air traffic control.[111] Inland marine transport moves low-cost shipments of bulk products and helps sustain agricultural exports, yet user-fee revenues to the Inland Waterways Trust Fund are well below the levels required to sustain and operate the system.[112]

Motor fuel taxes have been the principal user fee providing federal support for highways and transit, but they are becoming less reliable as fuel economy improves.[113] As a result of revenue shortfalls, jurisdictions are turning to less efficient and less equitable sources, such as sales taxes.[114] Highway, transit, airport, and port officials are also increasingly reliant on public–private partnerships that depend on tolls or future government funding from a source, as well as profit for investors. Tolls, the ultimate user fee, encourage efficient system use, but they are not always feasible for low-traffic

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network links, and they also raise equity concerns. Charging for highway use by the mile can be done efficiently and accurately because of advances in technology, and might one day be a replacement for motor fuel taxes, but the practice raises privacy concerns that must be resolved.[115] The U.S. economy cannot function without its transportation networks, but paying for the public infrastructure it depends on raises many vexing questions and vigorous debate, and so far there is no consensus on how to proceed at the national level.

45. Given declining federal support and the growing share of capital funding by states and local governments, *what can be done to better articulate the rationale for federal funding for transportation systems and services and how can the federal share be determined for facilities serving interstate travel and other different contexts in which it might apply? What are the most cost-effective, cost-beneficial, and equitable ways to pay for the federal share of transportation?*
46. The majority of the public has consistently supported an increase in the motor fuel taxes if the funds are dedicated to maintenance.[116] The motor carrier industry voiced support in early 2018 for a 20 cent increase in motor fuel taxes to help fund the highway system,[117] as did the U.S. Chamber of Commerce.[118] AAA has also endorsed a fuel tax increase to pay for highways.[119] Most states have raised their motor fuel taxes since 1993, the last time that federal fuel taxes were raised for transportation.[120] *How can political support be found for raising the federal motor fuel taxes or introducing alternative user fees to provide public infrastructure that serves interstate travel? What are the consequences of the trend away from user-fee funding and how can states and the nation as a whole steer toward more efficient, effective, sustainable, and equitable forms of user-fee funding for transportation services and systems in the future? How can funding be sustained for modes such as public transportation and inland waterways that cannot rely wholly on user fees?*
47. The merits of motor fuel taxes as the main source of user fees weakens as vehicles become more fuel efficient and some alternatively fueled vehicles pay no fees at all for highway use. *As vehicle energy efficiency improves, resulting in less fuel tax revenue, and as alternatively fueled vehicles become more common, further depleting revenue, how can states and the federal government respond? Can user fees be expanded and extended? Can other, more promising funding approaches be pursued?* Mileage-based user fees (MBUFs) could serve as a replacement for, or supplement to, the fuel taxes relied on for highway infrastructure,[121] and multiple pilot programs of this concept are under way around the country. In concept, MBUFs could be adjusted to charge premiums for driving on congested roads during high-demand time periods and base fees on vehicle fuel economy. Barriers to feasibility include concerns about the cybersecurity of billing records showing the details of trips and administrative costs that exceed those of motor fuel taxes. *What version of an MBUF best protects privacy, allocates resources according to demand, minimizes administrative expenses, and could gain public and political acceptance?*

## Goods Movement

Our economy and lifestyles depend on an efficient system for moving freight, both domestically and internationally, and adequate public infrastructure for the private carriers that must rely on it. After completing the Interstate Highway System, expanding airports and ports in response to improved aviation and marine technologies, and deregulating the freight sector, the United States had a logistics and freight infrastructure system without parallel. More recently, however, rankings of U.S. logistics and freight infrastructure systems show the United States lagging behind its trading partners.[122] Freight movement is expected to continue to grow dramatically in the coming decades to serve an expanding population and growing economy.[123] Without a resolution to funding shortfalls for public infrastructure,[124] however, additional freight movements will increasingly contribute to bottlenecks and capacity problems. Growing expectations about the rapid delivery of goods ordered online and the need to solve the complexities and costs of urban freight movements, especially the "last mile" problem, are particularly acute topics for the freight sector. Also pressing in light of labor shortages, especially in trucking, is whether, how, and how quickly greater automation of freight movements can be accomplished safely and cost effectively.[125] A growing public policy challenge is how to reduce the freight sector's large share of carbon emissions through technology, alternative fuels, and overall improvements in efficiency.

Private companies deliver the goods that the public demands, but other than freight rail and pipelines, which are almost exclusively private, other freight modes depend on public infrastructure—roads and highways, airports and airways, and ports, channels, and waterways. Determining whether private carriers are paying their fair share for public infrastructure and the costs they impose, as well as whether existing regulations provide for a level playing field for modal competition, are important and never-ending sources of debate and controversy. Determining what the public role should be in helping private carriers make transformational changes in goods delivery through new technologies and services, and how private carriers can do so safely and while reducing environmental harm, have become new sources of concern and debate.

48. Growth in demand for goods movement in excess of infrastructure supply will create impediments to the efficient flow of goods to producers and consumers. Automation in freight may move ahead faster than in passenger transportation because of private incentives and competitive pressures and may increase throughput on existing corridors. Freight railroads and pipeline owners can be expected to continue to invest in capacity in response to market signals. The ability of the public sector to expand capacity as freight demand grows is less clear, particularly in densely developed urban areas. *How can society provide adequate capacity for the anticipated volume of future freight in the most cost effective and responsive way? How might freight demand change in the future from such varied influences as fundamental changes in trade policies to innovations in manufacturing such as three-dimensional (3D) printing?*[126] To the extent that automation can provide greater service on existing highway corridors, *how can regulators at the federal and state levels respond most effectively to the potential that*

*automated technology offers while protecting the public from additional risk? How can policy makers ensure that any public infrastructure required for the automation of long-distance trucks does not provide indirect subsidies to motor carriers at the expense of other private freight modes?*

49. Electrification of freight movements through improved batteries and fuel cells can potentially play a significant role in reduced emissions, as can shifting urban freight deliveries to nighttime hours.[127] Also important for reducing emissions are continued improvements in overall freight efficiency to maximize asset utilization and reduce empty backhauls. *What policies and strategies can make freight equipment and vehicles less polluting and less reliant on fossil fuels? How much additional emissions reduction could be achieved through automation?*
50. Trucking, rail, aviation, and maritime companies are experiencing labor shortages that are projected to continue into the future as the wave of Baby Boomer retirements passes through the economy. *What is the potential for automation to ameliorate these worker shortages*[128] *and reduce the high occupational disability rate in long-haul trucking? How quickly can automation occur?* (Dislocation of transportation workers because of automation is discussed in the Institutional and Workforce Capacity section that follows.)

51. The overall efficiency of freight movement can also be enhanced through technology and innovative business practices. However, a lack of data and quantitative measures hampers the management of supply chain performance and resiliency. *How can public agencies partner with the private sector to use proprietary data to pinpoint critical infrastructure bottlenecks to efficient freight flows that the public sector could address?* Efficiency gains can also be achieved through such varied approaches as regulations that provide for strong intra- and intermodal competition as well as continued improvements in freight logistics systems. *What are the potential logistics efficiency gains over the next decade from strategies such as the "Uberization" of the last mile of deliveries; AI applications; blockchain distributed ledgers; and increased robotics and automation of warehousing?*[129]
52. Transformational changes in goods delivery may place new burdens on public infrastructure.
    a. The growing public expectation of same-day delivery in urban areas could further increase the number of small freight delivery vehicles in operation and thereby increase congestion and emissions, but goods ordered electronically may also be reducing consumer shopping trips by personal vehicle. *What are the net effects on traffic and emissions of increased e-commerce? If overall trips and emissions are increasing, how can and should the public sector manage this problem?*
    b. Delivery vehicles themselves may transform from package trucks and vans to drones that

fly packages to suburban and rural areas and robots that operate on urban streets and sidewalks. *How can policy makers anticipate, monitor, plan for, and regulate such potentially revolutionary changes?*

53. Trucks in the United States dominate freight logistics costs[130] and move almost three-quarters of the value of domestic and international freight and about 60 percent of the total tonnage.[131] The enormity of the trucking industry has pervasive influences on national economic efficiency, modal competition, safety, and the environment. Regulation of the size and weight of trucks may seem to be a mundane subject, but it becomes vitally important when commercial interests press regularly for increased truck sizes and weights at both the state and national levels. Past analyses of proposed changes in truck size and weight have foundered due to lack of both data and robust technical tools for estimating their impacts.[132] *What evidence will inform decisions by public officials to make the substantial investments in the tools, models, and data required to understand the ramifications of changes in truck size and weight regulations?*
54. Ocean carriers continue to exert formidable pressure on seaports and trade corridors to keep pace with the economies of scale realized by megavessels that carry 20,000 containers or more. These vessels require deeper channels, more efficient port terminals, and hinterland intermodal capacity and connectivity to accommodate short-term surges in demand, which in turn demands massive infrastructure funding. *To what degree is this sustainable and what should the public sector's role be in reacting to these pressures from world trade and shipping?*
55. Despite the need to move away from fossil fuels, until more sustainable options are widely available, the nation will continue to rely on fossil fuel sources, particularly domestically produced petroleum and natural gas. Moving petroleum by truck, as well as moving commodities to support fracking, can do major damage to parts of the transportation system that are aging or inadequate from a structural or a capacity standpoint to handle the movements of these heavy products. Moving petroleum by rail raises many concerns to those communities exposed to such traffic. *How can these issues be planned for and addressed? How can expanded domestic energy production be distributed to consumers in a manner that best serves the public interest?*[133]

## Institutional and Workforce Capacity

The ability of transportation agencies to address the challenges highlighted in this report depends heavily on the capabilities of their workforces. Local and state transportation agency staff are struggling to address transformational changes and disruptions, but often without adequate financial and technical resources to meet their needs. Transportation funding for local and state agencies has been tightly constrained in most jurisdictions for more than a decade. Moreover, as transportation systems become more technologically complex, the future workforce will need higher skill levels in fields such as information technology (IT), as well as diverse disciplinary perspectives, to address increasingly complex social and environmental issues.

The challenge for all levels of government is how to attract, train, and retain enough people with a broad and diverse set of needed skills when the wages offered cannot match those of the private sector.[134] As agencies increasingly rely on private providers, another problem to address is how to ensure that public agency staff have the requisite skills to manage contractors. These familiar challenges are becoming increasingly difficult to address given the pace of technological change and the scale of climate change.

56. Agencies at all levels are being pressed to address the challenges of growing and shifting population and transportation demand, rapid technological change, and climate change. Even as the problems become more complex, the institutions themselves lack the resources and technical capacity to address them. A lack of expertise and skill is most acute in local governments, which rarely have the savvy to negotiate with TNCs, the expertise to address the ramifications of climate change, or simply

the time to manage the more complex systems required for the infrastructure to support connected vehicles (local governments are responsible for roughly 80% of the traffic signal infrastructure required for such systems[135]). *How can local institutional capacity be enhanced to address these tremendous challenges?*

57. Funding shortfalls, the retirement of highly experienced Baby Boomers and other staffing reductions, and the inability to offer the wages demanded by high-skill workers are placing increasing pressure on government agencies to develop and retain a highly capable workforce. They are increasingly turning to private providers for transportation goods and services and high-skill support services such as IT. Contracting for services from the private sector, however, requires a new and broader set of managerial and evaluative skills for public-sector transportation planners, engineers, and managers. *How do we ensure that the public sector has the expertise and skills to negotiate contracts and oversee contractors in ways that best serve the public interest?* Regulatory workforces in agencies responsible for public safety and environmental protection will need to be as educated, trained, and skilled as their industry counterparts in order to understand the implications of new technologies and services and to avoid undue economic losses in protecting safety and the environment. *How can public officials be better prepared and retained to regulate, and provide oversight of, private providers of transportation vehicles and services?*

58. Given the growing, shifting, and increasingly diverse population of the United States, the perspectives of a variety of racial and ethnic communities are needed to inform transportation planning and decision making at all levels. *How can we best attract more students and professionals from underrepresented racial and ethnic groups to transportation?*
59. The tremendous innovations resulting from the broader application of IT and automation will also be disruptive to the workforce. *What are the likely impacts of transformational technologies on transportation-related jobs over time*[136] *and how can displaced workers best be assisted in finding meaningful and rewarding work? What are the workforce challenges associated with the nascent phases of the adoption of automation in freight transportation? How will the skills of pre-, post-, and phased-automation workforces be maintained on parallel tracks in the intermediate term?*

## Research and Innovation

Innovation has been the hallmark of the United States since its founding, driven by an entrepreneurial spirit and openness to disruptive change. Public investments in basic research have long been recognized as providing substantial economic returns.[137] These investments, coupled with public investments in applied research and human capital development, intellectual property protections, venture capital, and more, have created a virtuous cycle of innovation that has driven the U.S. economy forward for generations.[138] Examples abound today of transformative transportation technologies and business models that build on decades of public investments in basic research that lead to breakthroughs in electronics, IT, sensors, AI, and other areas.

Public ownership and management of transportation infrastructure have a different set of incentives than those that drive private-sector innovation; these public-sector incentives inhibit risk taking and reward caution.[139] Even so, steady incremental gains in infrastructure design, construction, operation, and management—identified through applied research funded by

public agencies—have provided great benefits to the public over time. Public investment in research and human capital development has yielded many benefits and has never been as important as it is today, but whether and how it can be sustained remain open questions.

60. The remarkable degree of innovation in transportation and efforts to meet the great challenges of disruptive technological changes and climate change are resulting in myriad natural experiments across the country. *How can these experiences be carefully evaluated and results disseminated to allow for broader social learning and improved service delivery?* As noted above, many of the consequences of continued innovation and automation of transportation depend heavily on how people will respond and adapt to these changes, which is not always predictable. As important as human behavior is to understanding transportation and its side effects, however, only a very small share of transportation data gathering and research and development funding addresses human behavior in transportation in a rigorous or systematic fashion. *Given its importance, how can greater priority be placed on data gathering and studies of travel behavior and to the public's short- and long-term responses to transformational technologies?*
61. Accelerating private product development and deployment cycles is posing new challenges. Witness the deployment of pilot autonomous vehicles into the field using machine learning to improve service and safety more rapidly and effectively than could be achieved in a lab, as well as the sweeping disruption of urban taxi markets by TNCs. Cities and states, however, are allowing experiments to go forward on public roads, potentially exposing their populations to risks to which they have not consented.[140] *What does the accelerating change in transportation product development and deployment portend for society more generally and the traditional research enterprise more specifically?*
62. Growing demands on the transportation system and declining investments in public-sector research and development are coupled with the challenges of managing the explosion of private-sector innovations in transportation amid the strong disincentives for risk taking in the public sector. *How can we build and sustain a culture of innovation in public-sector airport, highway, port, and transit infrastructure and operations; accelerate the pace of research to keep up with technological change; and move proven innovations into practice, codes, and standards more quickly?*

63. With all of the innovations and changes taking place, and despite the many challenges, transportation has never been a more important or exciting field of employment and inquiry. Transportation educators and researchers at the undergraduate and graduate levels play an essential role in attracting and training the next generation of professionals. Public agencies and private companies turn to such individuals for insight and guidance, particularly in these times of deep uncertainty. However, declining public research support makes it more challenging to sustain faculty positions in transportation and keep college and university programs on the cutting edge of knowledge. *How can we foster the development and retention of the teachers and researchers needed to improve society's understanding of transportation and its ramifications and attract and develop future generations of transportation professionals?*

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This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

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## ENDNOTES


1. Sperling, D., E. van der Meer, and S. Pike. Vehicle Automation: Our Best Shot at a Transportation Do-Over? In *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future*. Island Press, Washington, D.C., 2018. https://islandpress.org/books/three-revolutions. See also S. Olson (ed.). *Autonomy on Land and Sea and in the Air and Space: Proceedings of a Forum*, National Academy of Engineering, The National Academies Press, Washington, D.C., 2018. https://www.nap.edu/catalog/25168.
2. Shaheen, S., H. Totte, and A. Stocker. Future of Mobility White Paper, 2018. https://escholarship.org/uc/item/68g2h1qv.
3. Berg, N. The E-Commerce Revolution: Online Shopping Boom Testing Infrastructure's Limits. *InTransition Magazine*, 2016. http://intransitionmag.org/Winter_2016/ecommerce-revolution.aspx.
4. Montgomery, W.D. *Public and Private Benefits of Autonomous Vehicles*, 2018. https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/W.-David-Montgomery-Report-June-2018.pdf.
5. This paragraph draws heavily from Sperling, D., et al. *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future*. Island Press, Washington, D.C., 2018. https://islandpress.org/books/three-revolutions. See also Schaller, B. *The New Automobility: Lyft, Uber and the Future of American Cities,* 2018. http://www.schallerconsult.com/rideservices/automobility.htm. See also World Economic Forum and Boston Consulting Group. *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston*, 2018. http://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf.
6. Sperling et al., 2018.
7. Sperling et al., 2018.
8. Schaller, B. *The New Automobility: Lyft, Uber and the Future of American Cities*, 2018. http://www.schallerconsult.com/rideservices/automobility.htm. See also Henao, A., and W. Marshall. The Impact of Ride-Hailing on Vehicle Miles Traveled. *Transportation*, Springer. Published online September 20, 2018. http://link-springer-com-443.webvpn.jxutcm.edu.cn/article/10.1007%2Fs11116-018-9923-2.
9. U.S. Department of Transportation, Intelligent Transportation Systems, Connected Vehicles, ITS Research 2015-2019. https://www.its.dot.gov/research_areas/connected_vehicle.htm.
10. Forsgren, K.E., et al. *The Road Ahead for Automated Vehicles*. S&P Global Ratings, 2018. https://www.ibtta.org/sites/default/files/documents/SP%20Global%20Ratings%20-%20Road%20Ahead%20For%20Autonomous%20Vehicles-Enhanced%20May-14-2018.pdf.
11. Kalra, N., and D. Groves. *The Enemy of the Good: Estimating the Cost of Waiting for Nearly Perfect Automated Vehicles*. RAND Corporation, Santa Monica, CA, 2017. https://www.rand.org/pubs/research_reports/RR2150.html. See also Fraade-Blanar, L., et al. *Measuring Automated Vehicle Safety: Forging a Framework*. RAND Corporation, Santa Monica, CA, 2018. https://www.rand.org/pubs/research_reports/RR2662.html.
12. Lewis, P. Point/Counterpoint: 5G or DSRC for Connected Vehicle Technology, *Eno Transportation Weekly*, September 2018. https://www.enotrans.org/article/point-counterpoint-5g-or-dsrc-for-connected-vehicle-technology.
13. Committee for Review of Innovative Urban Mobility Services. *Special Report 319*: *Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services*. Transportation Research Board, Washington, D.C., 2016. http://www.trb.org/Publications/Blurbs/173511.aspx.
14. Feigon, S., and C. Murphey. *Broadening the Understanding of the Interplay Among Public Transit, Shared Mobility, and Personal Automobiles*. Transit Cooperative Research Program, Transportation Research Board, Washington, D.C., 2018. https://www.nap.edu/catalog/24996.
15. Schaller, 2018, Henao and Marshall, 2018.
16. Committee for Review of Innovative Urban Mobility Services, 2016.
17. Committee for Review of Innovative Urban Mobility Services, 2016, pp. 38–59. See also Schaller, B. Second Chances: Regulation and Deregulation of Taxi and For-Hire Ride Services, *TR News* 315, May–June 2018. http://www.trb.org/Main/Blurbs/177762.aspx.
18. Clearly the federal government has priority, but states have roles to play as well. See Hedlund, J. *Autonomous Vehicles Meet Human Drivers: Traffic Safety Issues for States,* Governors Highway Safety Association. https://www.ghsa.org/sites/default/files/2017-01/AV%20 2017%20-%20FINAL.pdf.
19. For an overview of the challenges of safety assurance of complex software and electronic sensors, see Committee on Electronic Vehicle Controls and Unintended Acceleration. *The Safety Promise and Challenge of Automotive Electronics: Insights from Unintended Acceleration*. National Academies of Sciences,

Engineering, and Medicine, The National Academies Press, Chapter Three, 2012. http://www.trb.org/main/blurbs/166563.aspx.
20. Smith, B.W. Automated Driving and Product Liability. *Michigan State Law Review*, Vol. 1, 2017. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2923240. See also Glancy, D.J., R.W. Peterson, and K.F. Graham. *NCHRP Legal Research Digest 69: A Look at the Legal Environment for Driverless Vehicles*. Transportation Research Board, Washington, D.C., 2016. https://www.nap.edu/catalog/23453.
21. Shaheen, S. Shared Mobility: The Potential of Ride Hailing and Pooling, in Sperling et al., 2018.
22. Chapin, T., et al. *Envisioning Florida's Future: Transportation and Land Use in an Automated Vehicle World*. Florida State University, 2016. https://fpdl.coss.fsu.edu/sites/g/files/imported/storage/original/application/abfcc477779dobcoea825c8011011939.pdf.
23. Heinrichs, D. Autonomous Driving and Land Use. In Maurer et al. (eds.). *Autonomous Driving: Technical, Legal, and Social Aspects*. Springer-Verlag GmBH, Berlin, 2016.
24. Kahane, C., and J. Dang. *The Long-Term Effect of ABS in Passenger Cars and LTVs*. National Highway Traffic Safety Administration, U.S. Department of Transportation, 2009. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811182.
25. Slovic, P. Perception of Risk. *Science*, Vol. 236, 1987. http://science.sciencemag.org/content/236/4799/280.
26. Polzin, S. Vehicle Miles Traveled Trends and Implications for the U.S. Interstate Highway System. In, Committee for a Study of the Future Interstate Highway System, *Renewing the National Commitment to the Interstate Highway System: A Foundation for the Future*, National Academies of Sciences, Engineering, and Medicine, forthcoming.
27. Kotkin, J., and M. Schill. A Map of America's Future: Where Growth Will Be Over the Next Decade. *NewGeography*, September 9, 2013. http://www.newgeography.com/content/003914-a-map-of-americas-future-where-growth-will-be-over-the-next-decade. See also Y. Hagler. *Defining U.S. Megaregions. America 2050*, 2009. http://www.america2050.org/upload/2010/09/2050_Defining_US_Megaregions.pdf. See also Nelson, G.D., and A. Rae. *An Economic Geography of the United States: From Commutes to Megaregions*. *PLoS ONE*, Vol. 11, No. 11, 2016. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166083.
28. Cromartie, J., *Rural Areas Show Overall Population Decline and Shifting Regional Patterns of Population Change. U.S. Department of Agriculture Economic Research Service*, September, 2017. https://www.ers.usda.gov/amber-waves/2017/september/rural-areas-show-overall-population-decline-and-shifting-regional-patterns-of-population-change.
29. Frey, W. *U.S. Population Disperses to Suburbs, Exurbs, Rural Areas, and "Middle of the Country" Metros*. The Brookings Institution, March 26, 2018. https://www.brookings.edu/blog/the-avenue/2018/03/26/us-population-disperses-to-suburbs-exurbs-rural-areas-and-middle-of-the-country-metros/?utm_campaign=Metropolitan%20Policy%20Program&utm_source=hs_email&utm_medium=email&utm_content=61738659.
30. Kolko, J. *Neighborhood Data Show that U.S. Suburbanization Continues (Wonkish)*, 2016. http://jedkolko.com/2016/03/25/neighborhood-data-show-that-u-s-suburbanization-continues.
31. Committee for the Study on the Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy Consumption. *Special Report 298: Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and $CO_2$ Emissions*. Transportation Research Board, Washington, D.C., 2009. https://www.nap.edu/catalog/12747.
32. Nelson, A.C. Megaregion Projections 2015–2045 with Transportation Policy Implications. *Transportation Research Record, Journal of the Transportation Research Board*, No. 2645, 2017. https://trrjournalonline.trb.org/doi/abs/10.3141/2654-02.
33. Nelson, 2017, p. 13.
34. Nelson, 2017, p. 13.
35. Frey, 2018, Figure 2.
36. Blumenberg, E., et al. *Typecasting Neighborhoods and Travelers: Analyzing the Geography of Travel Behavior Among Teens and Young Adults in the U.S. Institute of Transportation Studies*, University of California, Los Angeles, Luskin School of Public Affairs, 2015. https://www.lewis.ucla.edu/wp-content/uploads/sites/2/2015/10/Geography-of-Youth-Travel_Final-Report.pdf?mc_cid=68d255b9a1&mc_eid=c362ec69d8.
37. Building for Boomers: Housing Preferences of the Boomer Generation. http://newsletter.rismedia.com/news/view/85545.
38. Committee on Atmospheric Stabilization Targets for Atmospheric Greenhouse Gases Concentrations. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. National Academies

of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2011. https://www.nap.edu/catalog/12877.
39. U.S. Environmental Protection Agency. Total U.S. Greenhouse Gas Emissions by Economic Sector 2016. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
40. Green, D.L., and G. Parkhurst. Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate. In *Conference Proceedings 54: Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate*. Summary of the Fifth EU–U.S. Transportation Research Symposium, Transportation Research Board, Washington, D.C., 2017. http://www.trb.org/main/blurbs/177088.aspx.
41. Yu, Y., et al. Environmental Impact Assessment and End-of-Life Treatment Policy Analysis for Li-Ion and Ni-MH Batteries. *International Journal of Environmental Research and Public Health*, Vol. 11, No. 3, 2014. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3987029.
42. Green and Parkhurst, 2017, p. 51.
43. Committee for a Study of Potential Energy Savings and Greenhouse Gas Reductions from Transportation. *Special Report 307: Policy Options for Reducing Energy Use and Greenhouse Gas Emissions from U.S. Transportation*. Transportation Research Board, Washington, D.C., 2011. http://www.trb.org/Publications/Blurbs/165535.aspx.
44. Committee for a Study of Potential Energy Savings and Greenhouse Gas Reductions from Transportation. 2011.
45. Green and Parkhurst, 2017, p. 57.
46. Sperling et al., 2018, pp. 46–52. See also Committee on Overcoming Barriers to Electric-Vehicle Deployment. *Overcoming Barriers to Deployment of Plug-in Electric Vehicles*. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2015. https://www.nap.edu/catalog/21725. See also Lutsey, N., et al. *Power Play: How Governments Are Spurring the Electric Vehicle Industry*. International Council on Clean Transportation, 2018. https://www.theicct.org/publications/global-electric-vehicle-industry.
47. Committee on Determinants of Market Adoption of Advanced Energy Efficiency and Clean Energy Technologies. *The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies*. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2016. https://www.nap.edu/catalog/21712.
48. Coignard, J., et al. Clean Vehicles as an Enabler for a Clean Electricity Grid. *Environmental Research Letters*, 13, 2018. http://iopscience.iop.org/article/10.1088/1748-9326/aabe97/pdf.
49. Billion-Dollar Weather and Climate Disasters: Overview. National Centers for Environmental Information. National Oceanic and Atmospheric Administration. https://www.ncdc.noaa.gov/billions.
50. Turnbull, K. (ed.). *Conference Proceedings 53: Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events*. Summary of the Fourth EU–U.S. Transportation Research Symposium. Transportation Research Board, Washington, D.C., 2016. https://www.nap.edu/catalog/24648.
51. Riedman, D. The Cold War on Terrorism: Reevaluating Critical Infrastructure Facilities as Targets for Terrorist Attacks. *Homeland Security Affairs Journal*, Vol. 14, Figure 5, 2017. https://www.hsaj.org/articles/13976.
52. Panel on Transportation, Committee on Science and Technology for Countering Terrorism. *TRB Special Report 270: Deterrence, Detection, and Preparation: The New Transportation Security Imperative*. Transportation Research Board, Washington, D.C., 2003. http://www.trb.org/Publications/Blurbs/161061.aspx.
53. Schwartz, H.G., and L. Tavasszy. Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events, In *Conference Proceedings 53: Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events*. Summary of the Fourth EU–U.S. Transportation Research Symposium. Transportation Research Board, Washington, D.C., 2016. https://www.nap.edu/catalog/24648.
54. Schwartz and Tavasszy, 2016.
55. See, for example, Schwartz, J. *Surrendering to Rising Seas: Coastal Communities Struggling to Adapt to Climate Change Are Beginning to Do What Was Once Unthinkable: Retreat*. Scientific American, Vol. 319, No. 2. August 2018.
56. Weimerskirsch, A., and D. Dominic. *Assessing Risk: Identifying and Analyzing Cybersecurity Threats to Automated Vehicles*. University of Michigan, 2018. https://mcity.umich.edu/wp-content/uploads/2017/12/Mcity-white-paper_cybersecurity.pdf.
57. Wallischeck, E. *GPS Dependencies in the Transportation Sector: An Inventory of Global Positioning System Dependencies in the Transportation Sector, Best Practices for Improved Robustness of GPS Devices, and Potential Alternative Solutions for Positioning, Navigation and Timing*. John A. Volpe National Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 2016. https://www.hsdl.org/?abstract&did=798941.

58. Bureau of Transportation Statistics, Transportation Fatalities by Mode, https://www.bts.gov/content/transportation-fatalities-mode.
59. Committee for the Study of Traffic Safety Lessons from Benchmark Nations. *Achieving Traffic Safety Goals in the United States: Lessons from Other Nations*. Transportation Research Board, Washington, D.C., 2011. http://www.trb.org/Publications/Blurbs/164388.aspx. See also, Ecola, L., et al. *The Road* to *Zero: A Vision for Achieving Zero Roadway Deaths by 2050*. RAND Corporation, Santa Monica, CA, 2018. https://www.nsc.org/Portals/0/Documents/DistractedDrivingDocuments/Driver-Tech/Road%20to%20Zero/The-Report.pdf?ver=2018-04-17-111652-263. See also National Transportation Safety Board, *Reducing Speeding-Related Crashes Involving Passenger Vehicles*. Safety Study NTSB/SS-17/01. https://www.ntsb.gov/safety/safety-studies/Documents/SS1701.pdf.
60. Committee for the Study of Traffic Safety Lessons from Benchmark Nations, 2011. See also Centers for Disease Control and Prevention, *Motor Vehicle Crash Deaths: How is the U.S. Doing?* https://www.cdc.gov/vitalsigns/motor-vehicle-safety.
61. Harper, C., et al. Cost and Benefit Estimates of Partially-Automated Vehicle Collision Avoidance Technologies. *Accident Analysis & Prevention*, Vol. 95, Part A, Elsevier, 2016.
62. Insurance Institute for Highway Safety. Reality Check: Research, Deadly Crashes Show Need for Caution on the Road to Full Autonomy. *Status Report*, Vol. 53, No. 4, 2018. https://www.iihs.org/externaldata/srdata/docs/sr5304.pdf.
63. International Transport Forum. *Safer Roads with Automated Vehicles?* Organisation for Economic Co-operation and Development, 2018. https://www.itf-oecd.org/safer-roads-automated-vehicles-0.
64. National Highway Traffic Safety Administration. Distracted Driving Overview. https://www.nhtsa.gov/risky-driving/distracted-driving.
65. AAA. *Distraction Tops Drivers' List of Growing Dangers on the Road*, 2018. https://newsroom.aaa.com/2018/03/distraction-tops-drivers-list-growing-dangers-road. See also, National Safety Council. Understanding the Distracted Brain: Why Driving While Using Hands-Free Cell Phones is Risky Behavior. White Paper, 2012, https://www.nsc.org/Portals/0/Documents/DistractedDrivingDocuments/Cognitive-Distraction-White-Paper.pdf.
66. Krzyzanowski, M., B. Kuna-Dibbert, and J. Schneider (eds.), *Health Effects of Transport-Related Air Pollution*. World Health Organization, 2005. http://www.euro.who.int/__data/assets/pdf_file/0006/74715/E86650.pdf.
67. Clark, C., and S. Stansfield. The Effect of Transportation Noise on Health and Cognitive Development: Review of Recent Evidence. *International Journal of Comparative Psychology*, Vol. 20, 2007, pp. 145–158.
68. Heaviside, C., H. Macintyre, and S. Vardoulakis. The Urban Heat Island: Implications for Health in a Changing Environment. *Current Environmental Health Reports*, Vol. 4, No. 3, 2017. https://link.springer.com/article/10.1007%2Fs40572-017-0150-3.
69. Tatem, A., D. Rogers, and S. Hay. Global Transport Networks and Infectious Disease Spread. *Advances in Parasitology*, Vol. 26, 2011. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3145127.
70. Panel on Research Methodologies and Statistical Approaches to Understanding Driver Fatigue Factors in Motor Carrier Safety and Driver Health. *Commercial Motor Vehicle Driver Fatigue, Long-Term Health, and Highway Safety: Research Needs*. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2016. https://www.nap.edu/catalog/21921. See also Committee on the Effects of Commuting on Pilot Fatigue. *The Effects of Commuting on Pilot Fatigue*. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2011. https://www.nap.edu/catalog/13201.
71. The Lancet Commission on Pollution and Public Health. *The Lancet*, Vol. 391, No. 10119, 2017. https://www.thelancet.com/commissions/pollution-and-health?code=lancet-site. For health effects from traffic emissions, see Health Effects Institute National Particle Component Toxicity (NPACT) Review Panel. *Executive Summary: National Particle Component Toxicity Initiative*. HEI Research Reports 177 and 178, 2013. https://www.healtheffects.org/publication/national-particle-component-toxicity-npact-initiative-integrated-epidemiologic-and.
72. U.S. Environmental Protection Agency. How Mobile Source Pollution Affects Your Health. https://www.epa.gov/mobile-source-pollution/how-mobile-source-pollution-affects-your-health.
73. Markus, J.H., and M. Rosekind. Fatigue in Transportation: NTSB Investigations and Safety Recommendations. *Injury Prevention*, Vol. 23, No. 4, August 2017. https://www.ncbi.nlm.nih.gov/pubmed/26929259.
74. Panel on Research Methodologies and Statistical Approaches to Understanding Driver Fatigue

Factors in Motor Carrier Safety and Driver Health, 2016.
75. *Aerospace Forecast Report Fiscal Years 2017 to 2037*. Federal Aviation Administration, U.S. Department of Transportation, 2017. https://www.faa.gov/news/updates/?newsId=87746&cid=TW502.
76. Hawkins, A.J. The Kitty Hawk Flyer Is Your Own Personal Electric Aircraft. *The Verge*, 2018. https://www.theverge.com/2018/6/9/17438012/kitty-hawk-flying-flying-car-vtol-larry-page.
77. See remarks of C. Tomlin as summarized in S. Olson (ed.), *Autonomy on Land and Sea and in the Air and Space: Proceedings of a Forum*. National Academy of Engineering, The National Academies Press, 2018. https://www.nap.edu/catalog/25168.
78. Committee for a Study of Performance Based Safety Regulation. *TRB Special Report 324: Designing Safety Regulation for High-Hazard Industries*. Transportation Research Board, Washington, D.C., 2017. https://www.nap.edu/catalog/24907.
79. Insurance Institute for Highway Safety. Crashes Rise in First States to Begin Legalized Retail Sales of Recreational Marijuana. 2018. https://www.iihs.org/iihs/news/desktopnews/crashes-rise-in-first-states-to-begin-legalized-retail-sales-of-recreational-marijuana.
80. Compton, R. *Marijuana-Impaired Driving—A Report to Congress*. DOT HS 812 440. National Highway Traffic Safety Administration, U.S. Department of Transportation, 2017. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812440-marijuana-impaired-driving-report-to-congress.pdf.
81. Hu, W., and J.B. Cicchino. *An Examination of the Increase in Pedestrian Motor Vehicle Crash Fatalities during 2009–16*. Insurance Institute for Highway Safety, May 2018. http://www.iihs.org/frontend/iihs/documents/masterfiledocs.ashx?id=2160.
82. Semega, J.L., K.R. Fontenot, and M.A. Kollar. *Income and Poverty in the United States: 2016*. Current Population Reports. U.S. Census Bureau, U.S. Department of Commerce, 2017. https://www.census.gov/content/dam/Census/library/publications/2017/demo/P60-259.pdf.
83. Polzin, S., and A. Pisarksi. Brief 7: Vehicle and Transit Availability. In *Commuting in America 2013: The National Report on Commuting Patterns and Trends*. American Association of State Highway and Transportation Officials, Washington, D.C., 2013. http://traveltrends.transportation.org/Documents/B7_Vehicle%20and%20Transit%20Availability_CA07-4_web.pdf.
84. Brown, A., and B. Taylor. Bridging the Gap Between Mobility Haves and Have Nots. In Sperling et al., 2018.
85. Brown, A., and B. Taylor, 2018.
86. Polzin and Pisarksi, 2013.
87. Bialik, K. *Seven Facts About Americans with Disabilities*. Pew Research Center, 2017. http://www.pewresearch.org/fact-tank/2017/07/27/7-facts-about-americans-with-disabilities.
88. Vespa, J., D. Armstrong, and L. Medina. *Demographic Turning Points for the United States: Population Projections for 2020 to 2060*. Current Population Reports. U.S. Census Bureau, U.S. Department of Commerce, 2018. https://www.census.gov/content/dam/Census/library/publications/2018/demo/P25_1144.pdf.
89. Smith, A. *Record Shares of Americans Now Own Smartphones, Have Home Broadband*. Pew Research Center, 2017. http://www.pewresearch.org/fact-tank/2017/01/12/evolution-of-technology.
90. *National Survey of Unbanked and Underbanked Households*. Federal Deposit Insurance Corporation, 2015. https://www.fdic.gov/householdsurvey.
91. Brown and Taylor, 2018.
92. Committee for Review of Innovative Urban Mobility Services, 2016, pp. 134–137.
93. Kim, S.J., and R. Puentes. Taxing New Mobility Services: What's Right? What's Next? *Eno Brief*, 2018. https://www.enotrans.org/etl-material/eno-brief-taxing-new-mobility-services-whats-right-whats-next.
94. Kneebone, E. The Changing Geography of U.S. Poverty. The Brookings Institution, 2017. https://www.brookings.edu/testimonies/the-changing-geography-of-us-poverty. See also Brown and Taylor, 2018.
95. Committee on Equity Implications of Evolving Transportation Finance Mechanisms. *Special Report 303: Equity of Evolving Transportation Finance Mechanisms*. Transportation Research Board, Washington, D.C., 2011. https://www.nap.edu/catalog/13240.
96. Innes, J.E., D.E. Booher, and S. Di Vittorio. *Strategies for Megaregion Governance: Collaborative Dialogue, Networks, and Self Organization*. Working Paper 2010-03. University of California, Berkeley, Institute of Urban and Regional Development, 2010. https://iurd.berkeley.edu/wp/2010-03.pdf.
97. Chicago Region Environmental and Transportation Efficiency Program. http://www.createprogram.org/about.htm.
98. The Gateway Program Development Corporation. http://www.gatewayprogram.org.
99. Nelson, 2017.

100. Committee for a Study of Intercity Passenger Travel Issues and Opportunities in Short-Haul Markets. *Special Report 230: Interregional Travel: A New Perspective for Policy Making*. Transportation Research Board, Washington, D.C., 2017. https://www.nap.edu/catalog/21887.
101. Jittrapirom, P., et al. Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. *Urban Planning*, Vol. 2, No. 2, 2017. https://www.cogitatiopress.com/urbanplanning/article/view/931/931.
102. Committee for Review of Innovative Urban Mobility Services, 2016, p. 165.
103. Cuddy, M., et al. *The Smart/Connected City and Its Implications for Connected Transportation*. White Paper FHWA JPO-14-148. John A. Volpe National Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 2014. https://www.its.dot.gov/itspac/Dec2014/Smart_Connected_City_FINAL_111314.pdf.
104. Committee for the Review of Innovative Urban Mobility Services, 2016, pp. 165–166.
105. INRIX Traffic Scorecard–U.S., 2016. http://inrix.com/resources/inrix-2016-traffic-scorecard-us. See also Cortwright, J. Yet Another Flawed Congestion Report from INRIX. http://cityobservatory.org/yet-another-flawed-congestion-report-from-inrix.
106. Hooper, A. *Cost of Congestion to the Trucking Industry: 2018 Update*. American Transportation Research Institute, Atlanta, Ga., 2018. http://atri-online.org/wp-content/uploads/2018/10/ATRI-Cost-of-Congestion-to-the-Trucking-Industry-2018-Update-10-2018.pdf.
107. Ball, M., et al. *Total Delay Impact Study: A Comprehensive Assessment of the Cost and Impacts of Flight Delay in the United States*. National Center of Excellence for Aviation Operations Research, 2010. https://www.isr.umd.edu/NEXTOR/pubs/TDI_Report_Final_10_18_10_V3.pdf.
108. *Value of and Investment in Transportation Infrastructure and Other Assets*. Bureau of Transportation Statistics, U.S. Department of Transportation, 2017, Ch. 8. https://www.bts.gov/browse-statistical-products-and-data/transportation-economic-trends/tet-2017-chapter-8-value-and.
109. National Surface Transportation Policy and Revenue Commission. *Transportation for Tomorrow*. Report to Congress, 2007. https://rosap.ntl.bts.gov/view/dot/18125.
110. Various surveys of public opinion about fuel taxes and other user fees report different results depending on how questions are framed and sampling techniques. For a particularly well framed set of questions, repeated over time to random samples, see Agrawal, A.W., and H. Nixon. *What Do Americans Think About Federal Tax Options to Support Public Transit, Highways, and Local Streets and Roads? Results from Year Nine of a National Survey*. Mineta Transportation Institute, 2018. https://transweb.sjsu.edu/research/1828-Survey-Transportation-Tax-Year-Nine. See also Zmud, J., and C. Arce. *NCHRP Synthesis 377: Compilation of Public Opinion Data on Tolls and Road Pricing*. Transportation Research Board, Washington, D.C., 2008. https://www.nap.edu/catalog/14151.
111. Committee for a Study of Air Traffic Controller Staffing. *Special Report 314: The Federal Aviation Administration's Approach for Determining Future Air Traffic Controller Staffing Needs*. Transportation Research Board, Washington, D.C., 2014, Ch. 6. https://www.nap.edu/catalog/18824.
112. Committee on Reinvesting in Inland Waterways. *Special Report 315: Funding and Managing the U.S. Inland Waterways System*. Transportation Research Board, Washington, D.C., 2015. https://www.nap.edu/catalog/21763.
113. Committee for the Study on the Long-Term Viability of Fuel Taxes for Transportation. *Special Report 285: The Fuel Tax and Alternatives for Transportation Funding*. Transportation Research Board, Washington, D.C., 2006. https://www.nap.edu/catalog/11568.
114. Committee on Equity Implications of Evolving Transportation Finance Mechanisms, 2011.
115. Agrawal, A.W., H. Nixon, and A. Hooper. *NCHRP Program Synthesis 487: Public Perception of Mileage-Based User Fees*. Transportation Research Board, Washington, D.C., 2016. https://www.nap.edu/catalog/23401.
116. Agrawal and Nixon, 2018.
117. American Trucking Associations. *America's Truckers Challenge Policymakers to Support Bold Infrastructure Plan*, 2018. http://www.trucking.org/article/America%E2%80%99s-Truckers-Challenge-Policymakers-to-Support-Bold-Infrastructure-Plan.
118. U.S. Chamber of Commerce. *Modernizing America's Infrastructure Requires Adjusting the Federal Motor Vehicle User Fee*, 2018. https://www.uschamber.com/issue-brief/modernizing-america-s-infrastructure-requires-adjusting-the-federal-motor-vehicle-user.
119. AAA. *AAA, ATA, and U.S. Chamber Ask Congress to Fund Roads and Bridges*, 2015. https://newsroom.aaa.com/tag/gas-tax.
120. Davis, C. *Most States Have Raised Gas Taxes in Recent Years*. Institute on Taxation and Economic Policy, 2018. https://itep.org/most-states-have-raised-gas-taxes-in-recent-years.

121. *Paying Our Way: A New Framework for Transportation Finance*. National Surface Transportation Infrastructure Financing Commission, 2009. https://financecommission.dot.gov.
122. See the World Bank Logistics Performance Index. https://lpi.worldbank.org. See also, *The Global Competitiveness Report 2016–2017*. The World Economic Forum, 2016, Table 2. http://www3.weforum.org/docs/GCR2016-2017/05FullReport/TheGlobalCompetitivenessReport2016-2017_FINAL.pdf.
123. *Freight Shipments Projected to Continue to Grow*. Bureau of Transportation Statistics, U.S. Department of Transportation. https://www.transportation.gov/connections/freight-shipments-projected-continue-grow. See also Freight Analysis Framework. Federal Highway Administration, U.S. Department of Transportation. https://ops.fhwa.dot.gov/freight/freight_analysis/faf.
124. Committee for the Study on Funding Options for Freight Transportation Projects of National Significance. *Special Report 297: Funding Options for Freight Transportation Projects*. Transportation Research Board, Washington, D.C., 2009. https://www.nap.edu/catalog/24702.
125. Groshen, E., et al. *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*. Prepared for Securing America's Future Energy, 2018. https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Groshen-et-al-Report-June-2018-1.pdf. See also Autor, D.H. Why Are There Still So Many Jobs? The History and Future of Workforce Automation. *Journal of Economic Perspectives*, Vol. 29, No. 3, 2015. https://economics.mit.edu/files/11563.
126. McKinnon, A.C. The Possible Impact of 3D printing and Drones on Last-Mile Logistics: An Exploratory Study. *Built Environment*, Vol. 42, No. 4, 2016.
127. Holguín-Veras, J., et al. Direct Impacts of Off-Hour Deliveries on Urban Freight Emissions. *Transportation Research Part D*, Vol. 61, Part A, pp. 84–103, 2018.
128. Groshen et al., 2018, and Autor, 2015.
129. Ward, A., et al. *2018 State of Logistics Report—Steep Grade Ahead*. A.T. Kearney, Chicago, Ill., 2018. https://www.atkearney.com/transportation-travel/state-of-logistics-report. See also Ward, A., et al, 2018, as cited by Council of Supply Chain Management Professionals. https://cscmp.org/CSCMP/Footer/Press_Release/CSCMP_Unveils_the_29th_Annual_State_of_Logistics_Report.aspx.
130. Ward et al., 2018.
131. Bureau of Transportation Statistics. Freight Facts and Figures 2017. Tables 2-1 and 2-2, U.S. Department of Transportation, Washington, D.C., 2017. https://www.bts.gov/sites/bts.dot.gov/files/docs/FFF_2017.pdf.
132. Committee for the Review of the U.S. Department of Transportation Truck Size and Weight Study. *Review of U.S. DOT Truck Size and Weight Study—Second Report: Review of USDOT Technical Reports*. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2015. https://www.nap.edu/catalog/22092. See also Truck Size and Weight Limits Research Plan Committee. *Research to Support Evaluation of Truck Size and Weight Regulations*. National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., forthcoming.
133. For a discussion of safety issues in transporting hazardous materials, see Committee for a Study of Domestic Transportation of Petroleum, Natural Gas, and Ethanol. *Special Report 325: Safely Transporting Hazardous Liquids and Gases in a Changing U.S. Energy Landscape*. Transportation Research Board, Washington, D.C., 2018. https://www.nap.edu/catalog/24923.
134. Committee on Future Surface Transportation Agency Human Resource Needs. *Special Report 275: The Workforce Challenge: Recruiting, Training, and Retaining Qualified Workers for Transportation and Transit Agencies*. Transportation Research Board, Washington, D.C., 2003. https://www.nap.edu/catalog/10764.
135. Federal Highway Administration. Regional Traffic Signal Operations Programs: An Overview. U.S. Department of Transportation, 2009. https://ops.fhwa.dot.gov/publications/fhwahop09007/index.htm.
136. See Groshen et al., 2018, and Autor, 2015.
137. Salter, A.J., and B.R. Martin. The Economic Benefits of Publicly Funded Basic Research: A Critical Review. *Research Policy*, Vol. 30, No. 3, 2001. https://www.sciencedirect.com/science/article/pii/S0048733300000913.
138. Atkinson, R. *Understanding the U.S. National Innovation System*. The Information Technology and Innovation Foundation, 2014. http://www2.itif.org/2014-understanding-us-innovation-system.pdf.
139. Downs, A. *Inside Bureaucracy*. Little, Brown and Company. Boston, Mass., 1967.
140. Cummings, M. The Brave New World of Driverless Cars: The Need for Interdisciplinary Research and Workforce Development. *TR News*, No 308, March–April 2017. https://hal.pratt.duke.edu/sites/hal.pratt.duke.edu/files/u24/TRN_308_Cummings_%20pp34-37%20web.pdf.

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