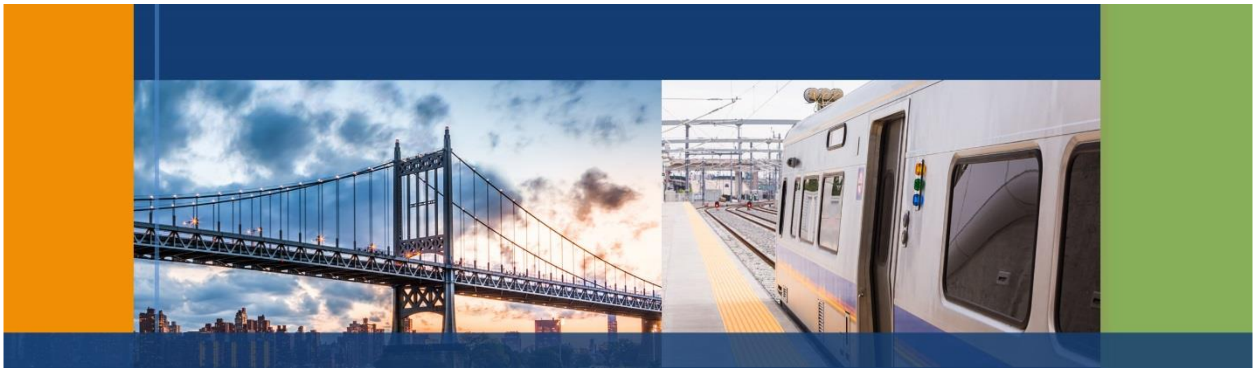


CHAPTER 12: Transformative Technologies

Transformative Technologies – Highways

Technology has always been an important engine for the U.S. economy, and innovation and ingenuity are fundamental elements of American culture. As technology becomes more advanced, the growing reliance on applications in daily activities is changing the way Americans live, shop, communicate, work, and travel. During the coronavirus disease 2019 (COVID-19) pandemic, people and businesses across the United States used technology to gain access to many social, economic, and educational activities. Advances in technology provide America with the potential to transform the future of transportation while increasing economic growth and overall productivity.

The transition from travel by horse and buggy to mass adoption and use of motor vehicles was a major socioeconomic transformation of the 20th century. Since then, the capacity, speed, efficiency, and geographic coverage of the surface transportation system have improved dramatically. However, changes in surface transportation have been largely incremental or stepwise improvements to existing transport technologies or operations.

For about a decade, technology has been changing the interface between users and the transportation system, particularly in urban environments. Wireless connectivity has made the sharing of information and modes of travel more efficient and user friendly. It also has allowed new transportation services to emerge. In the goods sector, technology enables more refined tracking and monitoring of shipments as they move from the warehouse to the customer's door, with this information shared more widely with clients and customers online. Technology is enabling alternative transportation options, such as autonomous goods and people movement, to become a more likely possibility.

KEY TAKEAWAYS

- Over the past decade, surface transportation has been revolutionized by major technological innovations.
- In 2018, 77 percent of Americans owned smartphones and about 57 percent of all digital media was consumed through mobile apps. This popularity has spurred advances in transportation technology such as real-time travel information and app-based on-demand transportation.
- The percentage of all U.S. households without a vehicle is 8.9 percent.
- Travelers can now request a ride; access a shared car, bicycle, or scooter for a short trip; ride a private shuttle on demand; and have groceries, packages, or take-out food delivered using internet-enabled smartphones and tablets.
- Up to 32 percent of car sharing members sold their personal vehicles, and between 25 percent and 71 percent of members avoided an auto purchase because of car sharing.
- In a recent pilot, Chicago estimates that scooters help to eliminate 300,000 miles of vehicle travel.
- According to the Bureau of Labor Statistics, almost one-third of workers said they could work from home in 2017–18.
- Rapid progress is being made in AV development with Level 3, 4, and 5 technologies (having higher levels of automated driving systems).

The major technological innovations discussed in this chapter that are likely to affect the amount and distribution of travel include:

- Information Technology
- Innovation in Transportation Services
- Emerging Modes, and
- Technology and Infrastructure.

Information Technology

The emergence of smartphones and the subsequent advancement and widespread adoption of smartphone technology fundamentally changed the availability, quality, and content of travel information. Smartphone technology has spurred the creation of countless "on-the-go" traveler mobile apps that are now key sources of information for travelers and service providers alike. The Pew Research Center estimates that, as of 2018, 77 percent of Americans own smartphones, compared with just 35 percent in 2011.[90] An estimated 57 percent of all digital media consumption now occurs through mobile apps as opposed to larger devices such as computers or tablets.[91] Although smartphones are no longer an emerging technology, the maturation of smartphone technology and mobile apps continues to shape the field of traveler information.

Exhibit 12-1 ■ Types of Information from the Consumer Point of View

• Predicted travel times	• Weather conditions/alerts	• Price/fare/cost
• Travel speeds	• Road/facility closures	• Alternative modes of travel
• Service schedules/ wait times • Areas of congestion	• Location of cameras, police, school zones, etc.	• Nearby services (e.g., gas stations, charging stations)
• Alternative routes to destination	• Snow plow status	• Vehicle availability
• Presence of tolls	• Wait times	• Parking availability
• Work zone locations	• Vehicle location	• Fitness goals
• Crash/incident locations	• Planned limited service (e.g., transit)	• Walking distance/time
• Special events	• Unplanned service interruptions	• Emissions/Fuel Use

Source: FHWA.

Traveler information encompasses a wide variety of media, modes, and types of information. From its roots in radio, television, and phone, traveler information has evolved at a rapid rate over the past decade, a trend that is expected to continue toward increasingly real-time, easily accessible information. As shown in *Exhibit 12-1*, a wide range of information is available to system users, in most cases at the touch of a button in real time.

The emergence and application of big data, the ability of public- and private-sector organizations to disseminate information, and the addition of vehicle-smartphone integration platforms to most new vehicles have significantly improved quality, accessibility, and usability of traveler information for trip making. With technology-enabled apps, increasing data availability, and more and more transportation services entering the information space, the variety of information available to system users is impressive.

Innovation in Transportation Services

During the latter half of the 20th century, the transportation system emphasized personal vehicle ownership and use and, to a lesser extent, the use of other modes such as transit, walking, biking, and taxis. However, recent technology innovations have expanded beyond traditional transportation and ownership models; more change has occurred in the last 6 years than in the last 60 years in terms of transportation options. The expansion of technology innovations into the transportation space is enabling new business models, providing new transportation choices for people and businesses, and increasing the private sector's participation in for-profit transportation services.

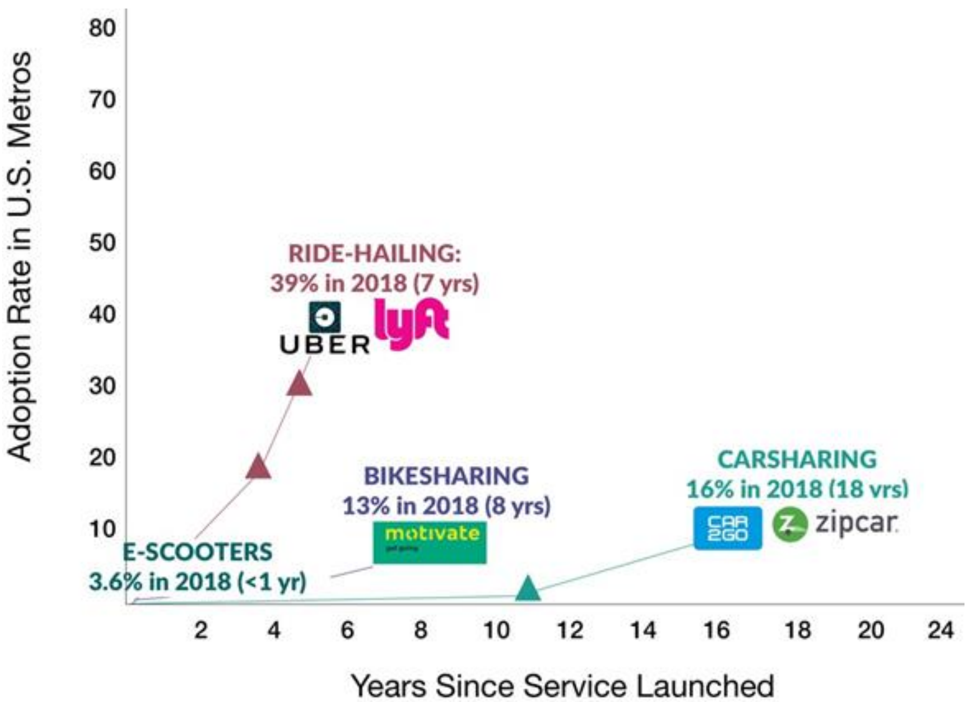
The changes underway in transportation services are sparking new innovations and shaping travel behavior in the United States. The options for accessing transportation are expanding for many users. People who were previously limited to auto ownership, biking, walking, calling a taxi, getting

[90] Pew Research Center (2018). *Mobile Fact Sheet*. http://www.pewinternet.org/fact-sheet/mobile/
[91] ComScore (2017). *The 2017 U.S. Mobile App Report*. https://www.comscore.com/Insights/Presentations-and-Whitepapers/2017/The-2017-US-Mobile-App-Report

a ride from a family member, or using transit if available now have a myriad of transportation options, in terms of the modes available (bike, car, transit, scooter), in terms of vehicle type (electric, gas, hybrid), and in terms of cost and ownership. Through innovations in transportation services, travelers can request a ride; access a shared car, bicycle, or scooter for a short trip; ride a private shuttle on-demand; and have groceries, packages, or take-out food delivered, all using internet-enabled smartphones and tablets.

In addition, new leasing models offered by several car manufacturers provide long-term vehicle subscriptions for an all-inclusive monthly fee. The subscription often includes insurance, roadside assistance, maintenance, and concierge service for on-demand car exchanges.[92] Other major business models emerging include shared mobility, on-demand services, microtransit, and broadband as a travel alternative.

Exhibit 12-2 ■ Transportation Services Adoption Curves in the United States[93]



Sources: National League of Cities, Micromobility in Cities—A History and Policy Overview; Clewlow and Mishra, 2017. Disruptive Transportation.

Shared Mobility

Shared mobility is a term used to describe motorized or nonmotorized vehicles that are shared among users. Shared mobility is one manifestation of the sharing economy and includes a variety of options, such as car sharing, bike sharing, and scooter sharing. These transportation options are typically membership-based services that provide short-term access to a motorized or nonmotorized vehicle for a fee. The services are provided mainly in urban areas, where auto ownership is lower and most trips involve shorter distances compared with those in suburban or rural areas.

> **Shared mobility** is an umbrella term that encompasses a variety of membership-based transportation modes, including car sharing, ride sharing, bike sharing, and scooter sharing.

[92] https://www.edmunds.com/car-leasing/what-are-car-subscription-services.html
[93] https://www.nlc.org/sites/default/files/2019-04/CSAR_MicromobilityReport_FINAL.pdf

Shared mobility is having a transformative impact on many cities by providing new ways to access goods and services. Shared mobility services can be *station-based*, in which the mode of transportation is picked up and returned to a fixed location, or *free-floating*, in which the mode of transportation can be picked up and dropped off in different locations. Peer-to-peer models also exist in which individuals rent out their personal transportation modes to others when not in use.

Shared mobility includes a variety of service models and transportation modes that meet the diverse needs of travelers, such as car sharing, station-based bike sharing (a bicycle picked up from and returned to any station or kiosk) and dockless bike sharing and scooter sharing (a bicycle or scooter picked up and left at any location).[94]

Car Sharing

Car sharing is a membership-based service that provides members access to an insured vehicle. Fuel (whether gas or electric) and free dedicated parking may also be included with membership. Car sharing is distinct from on-demand transportation services in that users are actually driving a vehicle themselves rather than being picked up and driven. Car sharing fundamentally changes the cost structure of driving: instead of using a private auto with fixed costs, car share users access a shared vehicle with variable costs. This "pay as you go" pricing model provides vehicle access on an as-needed basis without the cost of ownership. Access to vehicles via car share may have important impacts on household vehicle ownership levels, overall mode use, and the way emerging modes, such as automated vehicles (AVs) are marketed and available to the public. The most current studies and member survey results released by U.S. and Canadian car-sharing organizations show that up to 32 percent of car-sharing members sold their personal vehicles and between 25 percent and 71 percent of members avoided an auto purchase because of car sharing.[95]

Bike and Scooter Sharing

Bike sharing and scooter sharing are typically structured to provide customers point-to-point transportation for short-distance trips for a fee; membership in a sharing program typically reduces the fee paid. Most bike- and scooter-sharing operators are responsible for redistribution, maintenance, storage, and any parking costs. Electric scooter sharing is a recent outgrowth of the popularity of bike-sharing schemes. Bike sharing has two basic models:

- **Station-based:** Users can access bikes on an as-needed basis from a network of docking stations. Users can pick up and drop off bikes at different docking stations. The stations are unattended and accessible at all hours.
- **Dockless:** Dockless bike- or scooter-sharing systems do not require a docking station. With dockless systems, bicycles can be parked within a defined district at a bike rack or along the sidewalk. Smartphones are used to locate, unlock, and pay for dockless bikes or scooters.

Scooter sharing typically follows the dockless model.

Sharing is becoming a familiar practice and has the potential to impact vehicle miles traveled (VMT), mode choice, and car ownership. Although some shared mobility services such as car sharing and ride sharing have operated for decades, their impacts on these important mobility indicators are not well explored and require further research. Barriers to access and impact on travel demand are two important considerations. The location in neighborhoods, the payment requirements, and infrastructure suitability for use are just a few factors that influence whether the people who need more mobility options can actually use these travel modes. It is unclear, based on research conducted to date, whether shared mobility complements or substitutes for public transit. A few studies have attempted to quantify the impact of sharing on mobility indicators: for example, a 2016 Transportation Sustainability Research Center study of Car2Go members in Calgary, Canada;

[94] https://escholarship.org/uc/item/0z9711dw
[95] https://ops.fhwa.dot.gov/publications/fhwahop16022/ch3.htm

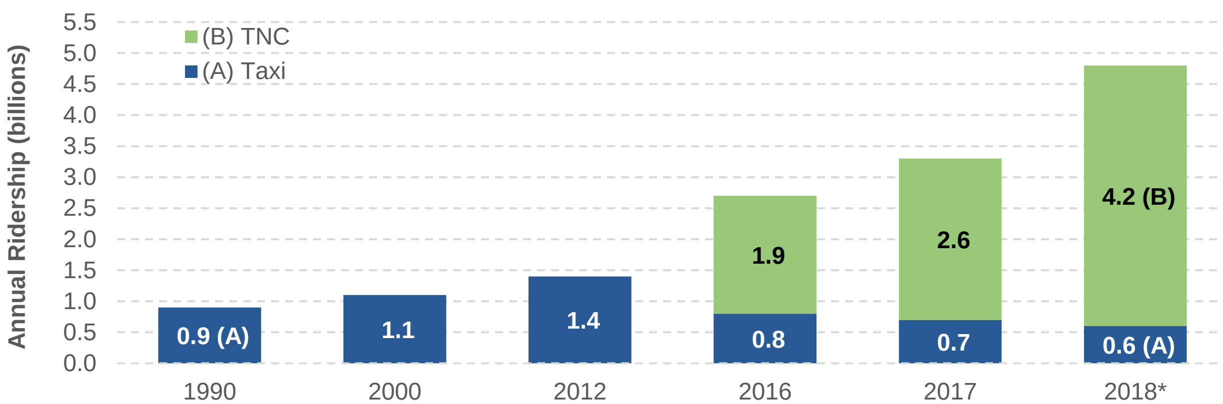
Vancouver, Canada; San Diego, California; Seattle, Washington; and Washington, DC, estimated a 6- to 16-percent decrease in VMT among members.[96]

On-Demand Ride Services (Ride Hailing)

On-demand ride services are provided by transportation network companies (TNCs), which offer app-based on-demand transportation. Travelers request a ride through a smartphone app that connects a driver to a traveler's location for pickup. Location, destination, time, payment, and basic safety functions are all integrated into a single app.[97]

The TNC service model has the potential to provide an additional travel option for users, including traditionally underserved populations such as older adults, low-income individuals, individuals with disabilities, or people living in rural areas. On-demand ride services fill gaps in transportation service as an alternative to vehicle ownership or taxi, bus, and subway services. TNCs also provide a means to avoid the cost or lack of off-street parking, as well as to avoid drinking and driving.[98] Between 2012 and 2017, the ridership for TNCs tripled (see *Exhibit 12-3*). The TNC service model, however, is not without other system impacts including curb space demands, trips without passengers (deadheading), and decreased demand for traditional ride-hailing services such as taxis.

Exhibit 12-3 ■ TNC and Taxi Ridership in the United States, 1990–2018[99]



Note: *The latest available data are for 2017; at that time, the ridership was projected to reach an annual rate of 4.2 billion passengers by the end of 2018.

TNC is Transportation Network Companies.

Source: The New Automobility: Lyft, Uber, and the Future of American Cities, by Schaller Consulting. (http://onlinepubs.trb.org/onlinepubs/sr/sr319AppendixB.pdf)

The true potential of on-demand services to fill mobility and access gaps is unclear. As with the shared mobility service model, it is unclear whether on-demand transportation will help to fill mobility gaps for traditionally underserved populations, for whom the availability and accessibly of new travel modes and transportation services is especially important. For example, the availability of a household vehicle varies across racial and ethnic groups, with minority populations being less likely to own a vehicle (See *Exhibit 12-4*).

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[96] Martin, E., and S. Shaheen (2016). *Impacts of Car2Go on Vehicle Ownership, Modal Shift, Vehicle Miles Traveled, and Greenhouse Gas Emissions: An Analysis of Five North American Cities*. http://innovativemobility.org/wp-content/uploads/2016/07/Impactsofcar2go_FiveCities_2016.pdf

[97] https://policy.tti.tamu.edu/congestion/policy-implications-of-transportation-network-companies/

[98] National Academies of Sciences, Engineering, and Medicine (2020). *Transportation Network Companies (TNCs): Impacts to Airport Revenues and Operations Reference Guide,* Chapter 2. https://www.nap.edu/download/25759

[99] Schaller, B. (2018). *The New Automobility: Lyft, Uber and the Future of American Cities*. http://www.schallerconsult.com/rideservices/automobility.pdf

Exhibit 12-4 ■ Zero-Car Households by Race and Ethnicity, 2017

Race	White	African American	Hispanic	Asian
Percentage of Zero-Vehicle Households	8.9%	23.3%	11.4%	11.2%

Note: Race is self-identified. Other race categories are not included due to insufficient sample size. For the full list of Census race categories see https://www.census.gov/mso/www/training/pdf/race-ethnicity-onepager.pdf.

Source: 2017 National Household Travel Survey data.

The limited information available about TNC users and service areas suggests that TNCs primarily serve users who are younger, more educated, and have higher income. In the nine densest metropolitan areas,[100] TNC use is highest among:

- 25- to 34-year-olds, followed by those ages 18 to 24 and 35 to 54;
- Residents with a college degree; and
- Residents living in households with incomes of $50,000 or more.[101]

TNC use is a growing, substantial mode of travel in urban areas. Whether a variation on the TNC business model can be viable in suburban or rural areas remains to be determined.

A related business model that is gaining popularity is paired on-demand passenger ride and courier services, in which on-demand transportation service providers (e.g., TNCs) also provide package deliveries. Deliveries via these modes can either be made in separate trips or with mixed-purpose trips (e.g., for-hire drivers can transport packages and passengers in the same trip). Three major TNC operators (Lyft, Sidecar, and Uber) have in some form expanded their ride services to include package/item delivery, food delivery, or both.

Contingent-labor-driven platforms like Uber and Lyft use ride-hailing drivers that are categorized as "gig economy" workers, the implications of which must be considered. The Bureau of Labor Statistics estimated that there were 10.6 million "gig economy" workers (independent contractors by definition) in May 2017, making up 6.9 percent of the U.S. workforce.[102] One study focusing specifically on Uber estimated that the 832,655 drivers that worked on the Uber platform in 2016 represented about 0.56 percent of total full- and part-time employment in the economy.[103] Since the average driver works for just one-fourth of the year, Uber drivers accounted for 0.14 percent of total employment after adjusting to the full-year measure. Furthermore, if the part-time nature of Uber driving in a week is taken into account, Uber drivers were 0.07 percent of total full time equivalent employment, as the average driver worked less than half of a 40-hour week. Based on total hours worked and hourly compensation, however, Uber drivers accounted for roughly 0.022 percent of aggregate national compensation; their share of aggregate compensation was lower than their share of employment, as their average hourly compensation was substantially less than the average hourly compensation of private-sector workers. A separate review of empirical studies of TNC driver compensation found that a substantial portion of TNC drivers in California earned less than the equivalent of the State's minimum wage, when waiting time, maintenance expenses, and work time are fully accounted for.[104] In addition, "gig economy" workers usually lack employment benefits, such as health insurance and paid time off. Working with a wide variety of stakeholders to protect and support workers must remain a top policy priority.

[100] Composed of Boston, Chicago, Los Angeles, Miami, New York, Philadelphia, San Francisco, Seattle, and Washington, DC.
[101] http://www.schallerconsult.com/rideservices/automobility.pdf
[102] Bureau of Labor Statistics. Contingent and Alternative Employment Arrangements — MAY 2017.
[103] Lawrence Mishel. 2018. Uber and the Labor Market: Uber Drivers' Compensation, Wages, and the Scale of Uber and the Gig Economy. Economic Policy Institute, Washington, DC.
[104] Michael Reich. 2020. Pay, Passengers and Profits: Effects of Employee Status for California TNC Drivers. UC Berkeley: Institute for Research on Labor and Employment Working Paper No. 107-20.

Microtransit

> When introduced in American cities at the turn of the century, **jitneys** could be any vehicle that transported passengers for a cheap fare. Eventually the term was applied specifically to small buses.

Also in the category of on-demand ride services is microtransit or shuttle-based transit. Microtransit services are enabled by technology similar to the mobile smartphone apps underpinning the on-demand ride services discussed earlier in this section, and have been deployed as privately owned, on-demand alternatives to traditional transit service. These services often operate in areas that are not well served by existing bus lines or where travelers need better first/last-mile options. Costs are generally less than ride-sourcing but more than transit.

Microtransit is a more technology-enabled type of on-demand transit that can incorporate flexible routing, flexible scheduling, or both.[105] These services operate much like jitneys[106] of the past but are enhanced with information technology. Existing microtransit operators target commuters, primarily connecting residential areas with downtown job centers. Microtransit's use of smartphone technology avoids traditional and costly methods of booking rides, such as call centers or booking websites. The use of advanced technology has the potential to lower operating costs for services that target special populations, such as disabled individuals, older adults, and low-income groups.[107]

Broadband as a Transportation Alternative

The same enhanced communication capabilities that have enabled real-time traveler information have also enabled potential travelers to substitute communication for travel. Be it e-commerce, distance learning, remote banking, or electronic document transfer (among others), one of the most pervasive influences of communication capabilities on travel has been the opportunity to avoid travel and use communication tools instead.

Internet access has become a requirement for participating in the modern global economic system, and broadband internet has become an increasingly important factor in the economic health and sustainability of a region. The benefits of broadband can be especially powerful in rural communities where it can provide residents with nontravel options to access employment, education, medical care, shopping, and social activities. To a large extent, broadband is now viewed as part of basic infrastructure, much like paved roads and an electrical grid.

The importance of broadband access became hugely apparent with the onset of the COVID-19 pandemic, where the response to stay at home orders and transition to mandatory telework and distance learning made it clear that an in-home connection is vital to the functioning of the 21st century economy.

From 2010 to 2020, Americans with access to broadband internet increased from an estimated 74.5 percent to 93.5 percent.[108] Just under one-third of workers said they could work from home, according to Bureau of Labor Statistics estimates from the 2017–18 American Time Use Survey,[109] although this number has recently jumped significantly to 40.8 percent during the height of the COVID-19 pandemic.[110]

E-commerce is another important area linked to both the economy and travel. Consumers spent $601.75 billion online with U.S. merchants in 2019, up 14.9 percent from $523.64 billion the prior

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[105] Cohen, A. and Shaheen, S. (2016). Planning for Shared Mobility. Prepared for American Planning Association, Washington, DC.
[106] https://www.merriam-webster.com/dictionary/jitney
[107] https://escholarship.org/uc/item/0z9711dw
[108] https://broadbandnow.com/research/broadband-2020
[109] https://www.bls.gov/news.release/flex2.t01.htm
[110] COVID-19 Impact Analysis Framework, 2021. University of Maryland CATT Laboratory. Last access 5/17/2021. https://data.covid.umd.edu/

year, according to the U.S. Department of Commerce.[111] That was a higher growth rate than that observed in 2018, when online sales reported by the Commerce Department rose 13.6 percent year over year.

As the number of the products and services available and the speed and quality of connectivity continue to increase, broadband service as an alternative to transportation is becoming more commonplace. Shopping, work, medical care, and education, among other activities, can now be accomplished without physical travel. As a means to access goods, services, and economic opportunities, the application of broadband service to fill transportation service gaps may be useful in maximizing access, mobility, and safety for all Americans.

Emerging Trends

Internet access, information technology, and new transportation service models have facilitated the emergence of new modes of travel and new ways of using traditional travel modes. The use, testing, and deployment of micromobility, vehicle automation, drones, and robotics have become common in the transportation sector. Coupled with advances in vehicle electrification, artificial intelligence, and mapping, these advances in how people and goods move through the system provide new opportunities and challenges for transportation workers and the safety, accessibility, and mobility of transportation users.

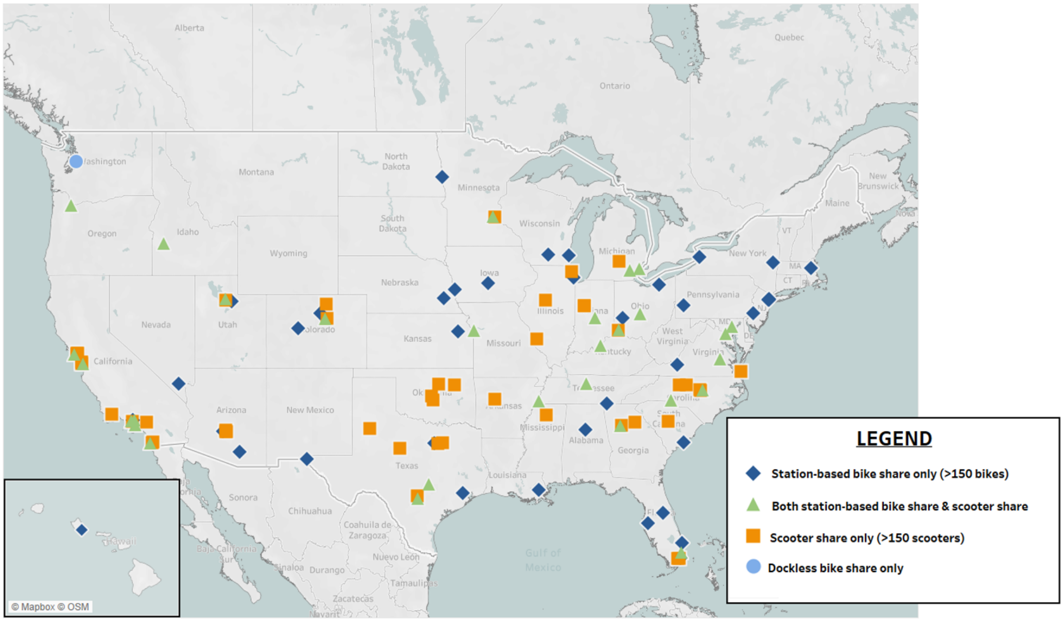
Micromobility

Micromobility is a broad term used to describe the use of a bicycle, scooter, or other low-speed transportation mode. As a primarily shared mobility service, micromobility enables users to have short-term access to a transportation mode on an as-needed basis.

Although docked bicycles continue to be a growing option in urban areas, dockless bikes have largely disappeared from most U.S. cities, in part replaced by shared scooters. E-scooters started appearing in cities across the United States in the autumn of 2017 and spring of 2018.[112] According to the National Association of City Transportation Officials, 84 million trips were taken on shared bikes and scooters in 2018.[113] In 2020, the number of permitted e-scooters in Washington, DC was expected to grow from 5,235 to at least 10,000,[114] and in San Francisco from 2,500 to at least 4,000.[115]

[111] https://www.census.gov/retail/index.html
[112] https://slate.com/business/2020/02/e-scooters-regulations-bird-lyft-lime-cities.html
[113] https://nacto.org/2019/04/17/84-million-trips-on-shared-bikes-and-scooters/
[114] https://wtop.com/business-finance/2019/12/10000-scooters-5000-e-bikes-approved-for-dc-streets-in-2020/
[115] https://abc7news.com/5568711/

Exhibit 12-5 ■ Shared Micromobility Across the United States.[116]



Source: NACTO, 2018.

The impact of micromobility on travel demand and mode share is still unclear, but early indications are that micromobility is used as an alternative to urban vehicle travel. In Chicago, a survey of e-scooter riders suggested that almost two-thirds of e-scooter trips would otherwise have been taken by car, taxi, or ride hail.[117] In Minneapolis, the city's Department of Public Works ran a similar survey, concluding that 55 percent of e-scooter trips would have been taken by personal vehicle, taxi, or on-demand ride services such as Uber or Lyft.[118]

Automated Vehicles

Automated vehicles represent a spectrum of levels of responsibility for the driving task from human to machine. Automated vehicles encompass a diverse range of automated technologies, from relatively simple driver assistance systems to Advanced Driver Assistance Systems (ADAS) (e.g., adaptive cruise control or parallel parking assist) to Automated Driving Systems (ADS), also known as autonomous vehicles.

The National Highway Traffic Safety Administration has adopted a framework for automated driving developed by the Society of Automotive Engineers International, which categorizes automation into six levels:

- Level 0 refers to vehicles with no automated technologies.
- Vehicles at Levels 1 and 2 control some aspects of steering, braking, or acceleration. Vehicles at these levels are already available for private ownership and currently operate on public roadways.
- Vehicles with Level 3, 4, and 5 technologies have ADS. Vehicles with ADS are still in development, and automakers and technology firms are actively testing them on public roads.

A Level 5 *ADS equipped vehicle* is the highest level of automation. AVs at Levels 4 and 5 do not require a steering wheel, a brake pedal, or an accelerator pedal. All driving functionality is handled through onboard computers, software, maps, and radar and light detection and ranging (LIDAR) sensors. Such vehicles are not yet operating freely on public roads other than as pilot programs with some developers testing on public roads in limited areas.

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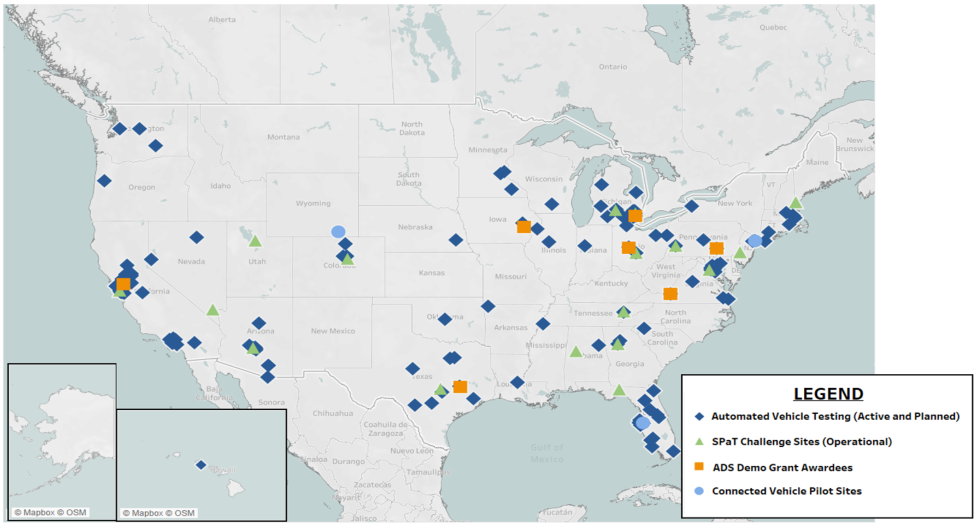
116 https://nacto.org/shared-micromobility-2018/
117 https://www.smartcitiesdive.com/news/breakdown-of-chicago-scooter-pilot-by-the-numbers/571461/
118 https://slate.com/business/2020/02/e-scooters-regulations-bird-lyft-lime-cities.html

A variety of private entities are partnering with local jurisdictions to participate in the deployment and testing of Level 3 and 4 vehicles across the Nation, with more than 500 active domestic testing demonstrations. These deployments assist jurisdictions in understanding the organizational, operational, and technical interfaces that may support the safe and effective integration of ADS into the roadway environment.

Exhibit 12-6 ■ Automated Vehicle Testing and Pilots in the United States.



Note: Based on publicly available information. This does not represent procurement-sensitive information.
Source: U.S. DOT

Pennsylvania DOT is conducting a demonstration to solve the challenge of safely integrating AVs in work zones to improve worker safety.

In addition, DOT has awarded grants to eight sites under the ADS Demonstration Grants program.[119] These grant recipients will deploy ADS in the context of a variety of safety and operational scenarios in real roadway environments that will also provide information on how to safely integrate ADS into the transportation system. Pennsylvania DOT, for example, received a grant to develop a consistent approach to the safe integration of AVs in work zones by examining whether improved connectivity, enhanced visibility, and high-definition mapping will enable AVs to safely travel in and around work zones.[120]

Work is also occurring in the area of infrastructure uniformity for ADS. In January 2020, the National Committee on Uniform Traffic Control Devices provided new recommendations to FHWA regarding pavement markings for ADS.[121] The recommendations describe pavement marking changes that will support safe ADS navigation. The committee based the recommendations on research that analyzed the needs for machine vision to detect roadway features that help ADS correctly perceive roadway lanes. The committee considered pavement marking width and contrast.

Although fully automated vehicle technology or self-driving vehicles could bring in many benefits, including safety and efficiency, these technologies could also impact the labor market and employment in the transportation industry and beyond. Understanding the effects of automation on workers, supporting and empowering workers, and mitigating potential negative impacts are all critical. On one hand, new jobs would be created with ripple effects of automated vehicle technology on the overall

[119] https://www.transportation.gov/av/grants
[120] https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/351461/36-penndot.pdf
[121] https://ncutcd.org/wp-content/uploads/meetings/2020A/04.19B-MKG-02.LineWidthforCAV.pdf

economy. On the other hand, some positions may be eliminated among vehicular drivers and at rest stations or in other hospitality sectors. The future is highly uncertain and it is challenging to predict how and when the automation technologies will be adopted, or to comprehend their full impacts on employment; however, several studies have attempted to estimate the potential job gains and losses. Although these studies use different methods, assumptions, and level of automation to examine the employment effect of automation on truck and bus industries, they all recognize potential negative impacts of vehicle automation on employment, especially for truck drivers. Despite the possible job impacts, some studies also note that lost jobs of truck and bus drivers can be offset by an expansion of the overall economy, leading to a net increase in jobs.

The Government Accountability Office (GAO) examined the potential impacts of automated trucking technology on the workforce.[122] Based on analysis of data, review of literature, and interviews with stakeholders, the GAO report suggests that the number of heavy truck jobs that might be lost is anywhere from under 300,000 to over 900,000, over a period of 10 to 20 years, depending on level of automation.

One recent FHWA report estimates potential job impacts from the adoption of automated truck technology using a general equilibrium model of the U.S. economy.[123] The study presents three scenarios to reflect the adoption of new trucks that are fully automated (SAE Level 4 and Level 5) in fleets.[124] The slow adoption scenario assumes 19 percent of newly purchased trucks would be fully automated in 10 years after the technology becomes available, and the fast adoption scenario assumes this ratio would reach 75 percent of new truck purchases in 10 years. The analysis estimates that the technology would lead to a net increase in overall employment in the economy, yielding between 26,400 jobs for the slow scenario and 35,100 jobs for the fast scenario each year. This expansion in employment is the result of broad economic growth in investment and consequent rise in labor demand. However, some industries, such as for-hire and in-house trucking, could suffer from fast adoption of automated trucks. It is estimated that a maximum loss of 11,000 jobs a year, or a decline of 1.7 percent of the long-haul driver workforce could result. This reduction in the workforce may last up to 5 years before the labor market absorbs the unemployed drivers.

There are still many open questions and unclear outcomes that affect cost, access, and safety as well as system performance, transportation revenue, and investment priorities. These include questions regarding private household vs. fleet ownership; the extent of mixed fleets (AV and non-AV) on roadways; infrastructure requirements such as traffic control devices, parking, and curb spaces; and how AVs intersect with emerging business models and technologies such as shared mobility and electrification. Labor unions, industry, local/state government, nonprofits, academia, and other stakeholders can work with DOT to examine and shape the impacts of new technologies on the transportation workforce.

DOT is actively preparing for the continual change from emerging technologies, including AVs. As such, DOT's mission is to ensure that the system of the future improves the quality of life for all people and communities. It is a DOT priority to engage with emerging technologies and guide the transportation future with an approach that keeps traveling Americans safe and promotes the improvement of transportation infrastructure.

Unmanned Aircraft

The adoption of Unmanned Aircraft Systems (UAS) is growing rapidly among both consumers and companies.

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[122] U.S. Government Accountability Office. *Automated Trucking: Federal Agencies Should Take Additional Steps to Prepare for Potential Workforce Effects.* GAO-19-161. Washington, DC: March 2019.
[123] U.S. Department of Transportation, Federal Highway Administration (FHWA). *Macroeconomic Impacts of Automated Driving Systems in Long-Haul* Trucking. FWHA-JPO-21-847. January 28, 2021.
[124] Society of Automotive Engineers (SAE) level is a framework for automated driving that was developed by the Society of Automotive Engineers International, which categorizes driving automation into six levels. Level 4 is high automation and level 5 is full automation.

In 2016, the Federal Aviation Administration (FAA) issued a final rule to allow for routine civil operation of small UAS (including drones) in the National Airspace System.

Through the UAS Integration Pilot Program, FAA is also issuing air carrier certificates to selected commercial applications.[125] UPS Flight Forward was the first company to receive an air carrier certificate to operate a drone aircraft. UPS Flight Forward is focusing on drone delivery in healthcare operations, where the shorter transit times can have a large impact on healthcare.[126] Wing Aviation, a Google company, also received FAA approval to operate drone aircraft and is currently offering trial drone deliveries in Christiansburg, Virginia.

Other companies such as Walmart, Domino's, FedEx, and Amazon are working on approaches to drone-based package delivery. Amazon Prime Air is a service that aspires to deliver packages up to five pounds in 30 minutes or less using small drones.[127]

Infrastructure and Technology

Technology enables transportation agencies to enhance the way they operate and manage transportation systems. Infrastructure and technology, often via intelligent transportation systems (ITS), improve transportation safety and mobility through the integration of advanced communications technologies. Infrastructure and technology applications focus on both the infrastructure and vehicle as well as integrated applications between the two.

Payment Systems

New advancements in payment systems have increased the convenience of payment for all goods and services, including travel. In general, these technologies improve the efficiency of payment for road use and public transportation, and in some cases, allow for new forms of payment for road use such as mileage-based user fees and tolls. Whether through a vehicle-based transponder, a user's phone, or a digital card, the ability to pay without cash or cashier has opened up many opportunities to easily integrate pricing and fees into transportation services. Automated payments can now be found throughout the U.S. transportation systems.

Several toll facilities in the United States are now electronic-only. States such as California and Colorado have managed lanes that are all-electronic tolls only, requiring roadway users to have a toll pass or risk being fined.[128] Additionally, as consumers demand a more seamless interface with payment, there will be more opportunity for coordinated payments across modes and agencies. The Chicago region has a payment platform that works for Chicago Transit Authority, Metra commuter rail, and Pace suburban bus services.[129] In the future, such platforms may expand to include bike sharing, car sharing, TNCs, and other modes, giving consumers more choice.

Linked with dynamic management, new advances in payment systems also enable congestion pricing or other variable pricing applications. Emerging technologies such as open bankcards and pay-by-phone fare payment systems have been well received by system users and transportation agencies. Increased links between cellular GPS information and revenue are also creating more options for both customers and agencies in providing services and revenues. Digital payments are popular with transportation agencies from rail transit to toll operators. Common methods of digital payment include websites, smartphone apps, or "tap and go" kiosks on buses and train platforms. Smartphone apps also rely on digital payment, specifically on-demand transportation apps or transit apps that allow the user to purchase a trip in advance.

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[125] https://www.faa.gov/uas/advanced_operations/package_delivery_drone/

[126] https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1569933965476-404

[127] https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011

[128] San Joaquin Hills Transportation Corridor Agency—FasTrak, website, accessed February 2019, https://thetollroads.com/accounts/fastrak

[129] https://www.transitchicago.com/howto/pay-for-your-fare/

Digital and automated payments are not uniformly supplied by the same organizations across the transportation system, and supply can vary by mode. Most current payment systems are mode-, area-, and agency-specific, but payment systems are moving toward integrated payment capability and national interoperability. Future technology that combines communication technology and payment applications may enable not only payment of tolls but also parking, transit, and TNC consumer travel payments under one account.

Connected Vehicles and Infrastructure

Modern communication technology is becoming more embedded within vehicles and the roadway infrastructure, allowing for continuous communication and data exchange between individual vehicles (V2V), or infrastructure and the greater transportation system (V2I). The term vehicle-to-everything (V2X) is often used to label all incoming or outgoing communications, including pedestrians, cyclists, mobile devices, the cloud, or even the electrical grid.[130]

The overall V2X technology has developed as a result of innovation during the past two decades in communication and location-sensing technology. ITS, more robust telecommunications networks, and GPS-based services have served as steps toward higher levels of connected vehicle technology.

Connected vehicles (CVs) are those with communications technologies that enable them to send and receive data and information, sense the physical environment around them, and interact with other vehicles or entities. Connectivity can be enabled through a variety of technologies. CV application areas include safety, navigation, diagnostics, convenience, and infotainment systems.

Connected vehicle technology has the potential to significantly improve safety through the avoidance of millions of accidents every year.[131] In addition, the presence of CVs is widely expected to have a positive impact on the performance of the road network by optimizing traffic flow and easing congestion. The Signal Phase and Timing (SPaT) Challenge provides an example of these technological advancements being put to use. Through the leadership of the Cooperative Automated Transportation Coalition, 26 States have responded to the challenge to deploy SPaT-enabled signalized intersections. Using dedicated short-range communication technology, the SPaT message defines the current intersection signal light phases including the current state of all lanes at the intersection. This technology allows CVs to plan their intersection approach, improving throughput and intersection safety. As of early 2020, 216 intersections transmit SPaT information, with 2,121 additional intersection being deployed.[132] A follow-on challenge is being developed in which the States that have responded to the SPaT challenge will be further challenged to outfit and deploy fleet vehicles equipped to receive and process SPaT messages.

Individual States have also begun V2X system testing and deployments. For example, the Colorado Department of Transportation is partnering with the private sector to build the largest network of connected vehicle infrastructure in the United States capable of real-time communication with roadway users.[133] The Virginia Department of Transportation has developed the Virginia Connected Corridors plan to test deployment of 64 roadside units deployed in the Fairfax area near Washington, DC.[134] Virginia also has a 2.2-mile test track, the Virginia Smart Road, which allows for the testing and development of CV technology on a controlled facility before real-world road testing.

DOT has played a significant role in supporting the research, development, and piloting of in-vehicle connectivity for safety purposes through its Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program. The ATCMTD program funds grantees to deploy

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[130] National Academies of Sciences, Engineering, and Medicine (2018). Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 2: Guidance. Washington, DC: The National Academies Press. https://doi.org/10.17226/25332
[131] https://www.its.dot.gov/research_areas/connected_vehicle.htm
[132] https://transportationops.org/spatchallenge
[133] https://www.codot.gov/programs/operations/intelligent-transportation-systems/innovation/connected-and-autonomous-technology-program
[134] Virginia Tech Transportation Institute, accessed February 2019, https://www.vtti.vt.edu/

advanced technologies to improve safety, efficiency, system performance, and infrastructure return on investment. Grantees in the ATCMTD program represent a diverse set of metropolitan and rural areas located across the United States and are deploying a range of advanced technologies, including CV applications, automated vehicles, adaptive signal systems, integrated corridor management, real-time traveler information systems, green technologies (e.g., electric vehicles), and infrastructure maintenance and monitoring systems, among other technologies.[135]

DOT is also sponsoring three CV pilot deployment tests in New York, Wyoming, and Tampa, Florida.[136] The New York and Tampa pilots are meant to provide valuable insight and data on the safety and congestion-relieving application of V2X technology in dense urban environments, and the Wyoming pilot focuses on safety benefits of V2X to the freight community.

To fully leverage the potentials of V2X and AVs to improve transportation safety, efficiency, and mobility, FHWA led the development of the Cooperative Automation Research Mobility Applications (CARMA) platform. CARMA is a multimodal effort among FHWA, the Federal Motor Carrier Safety Administration, the Intelligent Transportation Systems Joint Program Office, and the Volpe National Transportation Systems Center that is evaluating the concept of cooperative driving automation (CDA). Under CDA, vehicles exchange information with other vehicles and the infrastructure to perform shared maneuvers when confronted with traffic issues such as work zones or inclement weather. CARMA is based on open-source software and an agile development process to facilitate collaboration, research, and testing in CDA among the participating agencies, academia, and industry to rapidly advance automation on the Nation's transportation system.[137]

DOT ATCMTD Award: Texas Connected Freight Corridors

The Texas Connected Freight Corridors project is Texas' largest deployment of CV technology, using it to enable safe and efficient goods movement through key freight corridors in the Texas Triangle. With a focus on the freight community, the deployment strives to achieve a technology-ready sector that can easily integrate data from connected vehicle applications, as well as immediate improvement in safety and mobility for trucks operating on Interstates in Texas.

The Texas Connected Freight Corridors project will deploy CV technologies in more than 1,000 trucks and agency fleet vehicles that will be able to transmit data and receive warnings from these applications. Using a mix of communication technologies, advanced safety and congestion management systems will be applied to improve traveler information, asset condition assessment, and system performance. The deployment is expected to be operational in 2022.

The National Highway Traffic Safety Administration (NHTSA) is working toward requiring certain vehicles to be equipped with V2V communication technology with the capability to send and receive basic safety messages between vehicles.[138]

Another service enabled by vehicle connectivity is vehicle platooning. V2V communications combined with driver assistance systems such as adaptive cruise control and automated emergency braking allow vehicles to safely follow each other much more closely than in conventional driving. This ability to follow closer can increase the capacity of highways, and, for large trucks, enable significant fuel savings due to reductions in aerodynamic drag. Initial deployments of truck platooning systems are happening today and the DOT continues to study the impacts and opportunities related to truck platooning. Truck platooning uses vehicle-to-vehicle communications

[135] ATCMTD Grant 2020 Program Report (US DOT Draft)
[136] https://www.its.dot.gov/pilots/
[137] https://highways.dot.gov/research/operations/Cooperative-Driving-Automation
[138] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/v2v_pria_12-12-16_clean.pdf

technology to allow trucks to follow each other more closely—at about one second apart—and travel in a more coordinated fashion. Benefits include increased throughput, improved fuel economy, and lower operating costs.[139] There is also the potential for more advanced leader-follower platooning in which the follow truck may potentially operate driverless while the lead truck is driven normally. This technology, while still in research and development, has the potential to address driver shortages as freight movements continue to grow.

Emerging state-of-the-art technologies and systems, such as CVs, will help usher in an era of improved safety, mobility, and system efficiency, and provide real-time data to support transportation planning and system operations.

Work Zone Technology

Work zones play a key role in the process of maintaining and upgrading our Nation's roadways. Unfortunately, daily changes in traffic patterns, narrowed rights-of-way, and construction activities associated with work zones often create a combination of factors resulting in crashes, injuries, and fatalities. These crashes also cause excessive delays, especially given the constrained driving environment. Work zone incidents affect everyone. In addition to vehicular crashes and fatalities, the leading causes of death in the road and bridge construction sector are runovers, backovers, and falls. Simply put, drivers, passengers, and construction workers are all at risk in work zones. Transportation agencies across the country are using technology to make travel through and around work zones safer and more efficient.

The Minnesota Department of Transportation is implementing a work zone technology application that uses real-time work zone activity information to improve situational awareness for operators and notifications for the public.[140] Pennsylvania's Automated Work Zone Speed Enforcement (AWZSE) program uses vehicle-mounted systems to detect and record motorists exceeding posted work zone speed limits using electronic speed timing devices.[141] AWZSE systems are only operational in active work zones where workers are present.

The next trend in transportation data is the availability of real-time work zone data. Through the Work Zone Data Exchange Specification,[142] DOT has facilitated the development of a work zone data format that enables infrastructure owners and operators to make harmonized work zone data available for transportation applications. The intent is to make travel on public roads safer and more efficient through ubiquitous access to data on work zone activity. Specifically, the project aims to get data on work zones into vehicles to help ADS and human drivers navigate more safely. The development has been facilitated by DOT, but stakeholders are developing the actual standards and specification.

Future Considerations

This is an exciting time in transportation, with many technological advancements underway that will improve the future transportation system. Transportation contributes to prosperity by enabling access to opportunities. New technologies can enhance that access, but there are many potential barriers and benefits to consider. These include understanding required capabilities for high-tech system operations and maintenance; identifying impacts on system performance, including accessibility, mobility, and safety for all system users; identifying impacts on the transportation workforce; and anticipating future policy, regulatory, and legislative needs.

Technology innovation has led to the emergence of on-demand and shared transportation services that will have a major impact on the movement of goods and people. Their market penetrations are

[139] FHWA Research and Technology Program (2017). Partially Automated Truck Platooning Demonstration Video. https://highways.dot.gov/research/
[140] https://www.dot.state.mn.us/guidestar/1996_2000/smart_work_zone/workzone.pdf
[141] https://workzonecameras.penndot.gov/
[142] https://www.transportation.gov/av/data/wzdx

accumulating, especially within urban areas. In addition, it seems likely that electrification, connectivity and vehicle automation will cause similar or perhaps even greater transformations. Given the sizeable research and investments being made in transformative transportation technologies by the public and private sectors, their introduction to transportation systems will most certainly continue. However, the potential for these innovations to produce improvements in safety, mobility, and system performance implies that their rollout strategies will require careful consideration.

Transformative Technologies – Transit

Transportation and emerging technologies are inextricably linked. Throughout history, the need for new transportation modes has driven the development of new technologies; new technologies have in turn created new transportation modes. A desire to go to the moon fueled the development of booster rocketry, and the development of the airplane created air travel. Shared surface transportation evolved from horse-drawn coaches to train travel, taxis, bus and heavy rail systems, and shared services such as Lyft, Uber, and Via. Now, the ubiquitous and powerful mobile phone is at the center of enhanced traveler expectations for real-time information about a ride. New bus technologies such as low- and no-emission systems are transforming traditionally diesel-dependent public transportation fleets, reducing carbon emissions and addressing climate change goals.

KEY TAKEAWAYS

- FTA invested more than $30 million over four years for demonstration projects that explore new technologies and approaches that integrate public and private mobility services to increase service hours, geographic coverage, and accessibility.
- Smartphone-based Mobility as a Service (MaaS) technology helps millions of people plan and pay for trips, evaluate transportation options, identify vehicle locations and arrival times, and enjoy seamless, less stressful travel.
- More travel options through Transportation Network Companies (TNCs) and a wide array of shared-use mobility modes such as car, bike, and scooter sharing.
- Improved safety through development of collision avoidance technologies, railroad worker communication and alert systems, and operator visibility enhancements to improve the safety of pedestrians and other roadway users.
- Enhancing public transit operational effectiveness and efficiency through new technologies such as unmanned aerial systems, artificial intelligence, and robotics for asset management.

The new data generated by sensors and other technologies are enabling the use of artificial intelligence, machine learning, robotics, modeling, and simulation in ways that, today, might seem as far out as the Jetsons did in the 1960s. Safety for pedestrians, riders, bicyclists, and transit workers can expand while reducing fatalities and injuries through new safety technologies such as detection systems using radar, camera- and loudspeaker-equipped aerial drones, buried sensors, video analytics, and railway worker tracking systems. Soon, new multimodal payment systems enabled by a smart phone or a smart watch could expand contactless fare systems. Finally, the need to transform public transportation due to issues associated with the coronavirus disease 2019 (COVID-19) pandemic is prompting new uses for many of these technologies to address contact tracing, sanitation and decontamination of rolling and rail stock, and real-time routing to address crowding issues on shared transportation systems.

Transit is confronting changing demographics, economics, and consumer choices. Many millennials and members of Generation Z prefer to live in cities, are less likely to own personal vehicles compared with the general population, and choose to take transit. On the other hand, "gig economy" workers with changing work hours and locations may make transit service planning more difficult, and the increase in telework reduces demands for transportation, especially fixed-route systems. America's aging population requires senior transportation services that meets the needs of older adults and people with disabilities. Rural communities' mobility needs continue to be challenging. A lack of coordinated transportation options in frontier and Tribal communities can lead to isolation. Many people rely on public transportation to travel to work, to school, to visit friends/family, to be entertained, or to access health services, making it a lifeline to economic vitality and independent living.

Before discussing specific technologies, it is important to note how people's mobility expectations are changing: as consumer preferences shift, services must shift to accommodate their needs. New technologies are often the key to providing new services.

Changing Mobility Dynamics in Public Transportation

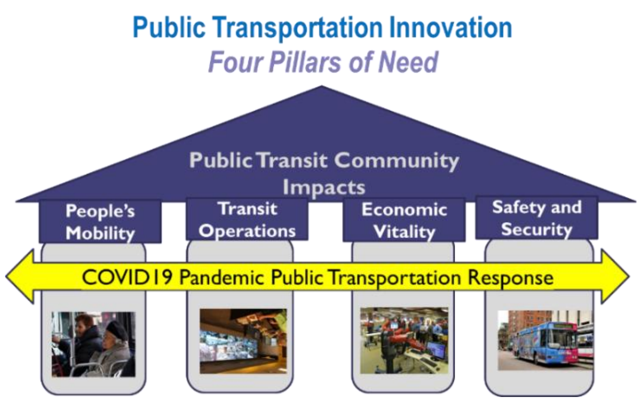
The past decade has brought challenges and opportunities for public transportation. Changing technologies, public policies, demographics, and consumer preferences have led to disruptions and transformations in public transportation as travelers across the United States began adopting a wide array of new mobility options and tools. Smartphone-based Mobility as a Service (MaaS) technology helps millions of people plan and pay for trips, evaluate transportation options, identify vehicle locations and arrival times, and enjoy seamless, less stressful travel. More travel options have become available, including services provided by Transportation Network Companies (TNCs) and a wide array of shared-use mobility modes such as car, bike, and scooter sharing. In many communities, transit agencies have incorporated MaaS technology into their operations and partner with TNC and shared-use mobility services to expand geographic coverage and hours of service.

Federal Transit Administration Research and Development Investments in New and Emerging Technologies

The Federal Transit Administration's (FTA) research mission is to advance public transportation by accelerating innovation. The FTA statutory research program supports innovations in promising emerging technologies to solve challenging issues facing public transportation. FTA fields research to meet public transit needs in four areas, as shown in *Exhibit 12-7*.

Emerging technologies and solutions using those technologies are categorized in three of the four areas of need: people's mobility, transit operations, and safety and security.

Exhibit 12-7 ■ The Four Pillars of Public Transportation Innovation



Source: FTA Technology Database.

Improving People's Mobility

In recent years, FTA has invested more than $30 million in grants for programs such as Mobility on Demand (MOD), Integrated Mobility Innovation (IMI), and Accelerating Innovative Mobility (AIM). Through these grants, transit agencies across the United States are experimenting with new technologies and approaches that integrate public and private mobility services to increase service hours, geographic coverage, and accessibility.

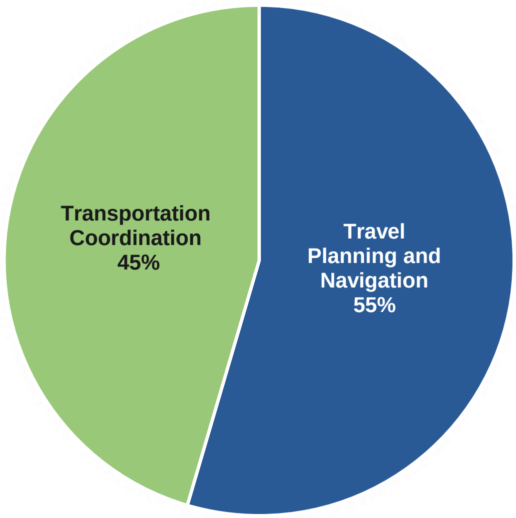
Major types of technologies that can expand mobility for travelers include transportation coordination technology and travel planning and navigation technology. *Exhibits 12-8, 12-9,* and *12-10* describe the 11 mobility innovation and technologies being demonstrated and evaluated under FTA-funded programs in the Spring of 2020.

Exhibit 12-8 ■ Mobility Innovation Technology Demonstrations

Technology Project Title	Project Sponsor	Technology Category	Technology Status
MOD Sandbox: Mobility Platform	City of Phoenix	Travel Planning and Navigation Technology to Improve Mobility	Demonstration Started
MOD Sandbox: Bay Area Fair Value Commuting Demonstration Project	City of Palo Alto	Travel Planning and Navigation Technology to Improve Mobility	Demonstration Started
MOD Sandbox: Integrated Carpool to Transit	San Francisco Bay Area Rapid Transit	Transportation Coordination Technology to Improve Mobility	Evaluation Completed
MOD Sandbox: Paratransit Mobility on Demand Demonstration	Pinellas Suncoast Transit Authority, Inc.	Transportation Coordination Technology to Improve Mobility	Demonstration Started
MOD Sandbox: Integrated Fare Systems–From Transit Fare to Bike Share	Chicago Transit Authority	Travel Planning and Navigation Technology to Improve Mobility	Demonstration Started
MOD Sandbox: Open Trip Planner Share Use Mobility	Tri-County Metropolitan Transportation District	Transportation Coordination Technology to Improve Mobility	Demonstration Started
MOD Sandbox: First and Last Mile Solution	Dallas Area Rapid Transit	Travel Planning and Navigation Technology to Improve Mobility	Demonstration Started
MOD Sandbox: Flexible Trip Planner Project	Vermont Agency of Transportation	Travel Planning and Navigation Technology to Improve Mobility	Evaluation Completed
Atlanta Region TMC Platform for One Click, Phase II	Atlanta Regional Commission	Transportation Coordination Technology to Improve Mobility	Deployment planning grants
Travel Management Coordination Center (TMCC) of Southern Wisconsin	Greater Wisconsin Agency on Aging Resources, Inc.	Transportation Coordination Technology to Improve Mobility	Deployment planning grants
Guided Augmented Independence Travel Aid (GAIT-Aid)	Design Interactive, Inc.	Travel Planning and Navigation Technology to Improve Mobility	Project Started

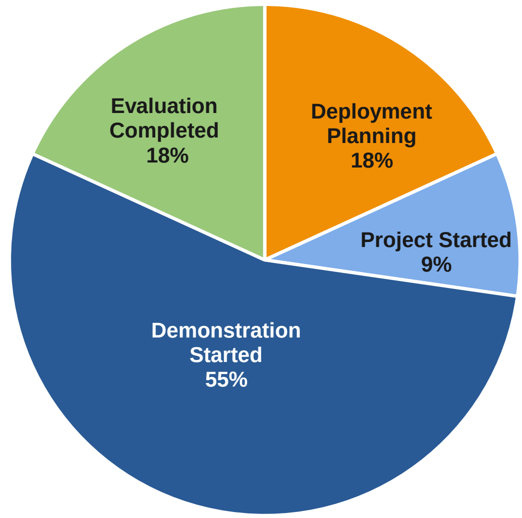
Source: FTA Technology Database.

Exhibit 12-9 ■ Mobility Technology Categories



Source: FTA Technology Database.

Exhibit 12-10 ■ Mobility Technology Deployment Status, March 2020



Source: FTA Technology Database.

Transportation Coordination Technology

FTA is investing in transportation coordination technology grants, supporting mobile apps, open trip planners, and call centers, to help organizations provide seamless travel across different types of transportation modes and services. Examples include:

- The Greater Wisconsin Agency on Aging established a Travel Management Coordination Center (TMCC) to provide access to healthcare and coordinate human services transportation for older adults, veterans, persons with disabilities, individuals with lower incomes, and other transit-dependent user groups. The TMCC sought to demonstrate how emerging cloud- and mobile-based technologies can eliminate barriers to coordinating transportation for human services.
- Bay Area Rapid Transit (BART) in San Francisco, California, piloted an integrated carpool-to-transit program in which participants were guaranteed a parking space at BART stations if they carpool, verified through a third-party app and enforced through the license plate list that the app provider delivered to BART each day.

Travel Planning and Navigation Technology

FTA is sponsoring research in trip payment, planning, and navigation technologies to help individuals, including people with disabilities, overcome barriers to using transit. Examples include:

- Design Interactive, Inc. is using Small Business Innovative Research (SBIR) funds to develop its Guided Augmented Independence Travel Aid (GAIT-Aid) software, which customizes trip planning and navigation for persons with mild cognitive impairments.
- The Vermont Agency on Transportation developed an online trip planner for people in rural portions of the State. The tool allows individuals to plan their trip using fixed-route public transit and connections to flexible transit options such as dial-a-ride, hail-and-ride, and deviated-fixed modes.

Ensuring Everyone's Safety

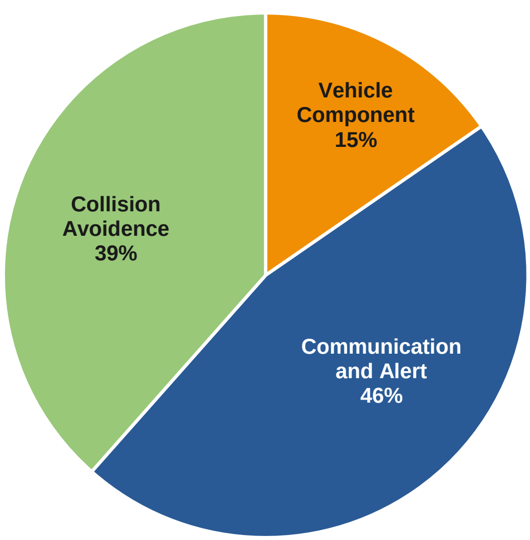
Public transportation is one of the safest modes of travel. Transit averages less than two fatalities per 100 million passenger miles traveled for Fixed-Route Bus, Heavy Rail, and Light Rail. However, certain types of safety events continue to pose challenges, such as bus collisions at intersections with vehicles and pedestrians, track worker injuries and fatalities, and suicides at rail stations. FTA is addressing these issues by investing in vehicle component, collision avoidance, and worker communication and alert technologies. *Exhibits 12-11, 12-12,* and *12-13* describe the 13 safety technologies being demonstrated and evaluated under FTA-funded programs in the Spring of 2020.

Exhibit 12-11 ■ Safety Technology Demonstrations

Technology Project Title	Project Sponsor	Technology Category	Technology Status
Demonstration and Commercialization of LRV Bumper for Enhanced Safety in Shared Right-of-Way Street Environments	Applied Research Associates, Inc.	Vehicle Component Technology to Improve Safety	Project Started
Wayside Worker Protection Demonstration	Metropolitan Atlanta Rapid Transit Authority	Communication and Alert Technology to Improve Safety	Demonstration Started
Driver Assist System (DAS) Technology to support Robust, Flexible Bus-on-Shoulder (BOS) and Narrow-Lane Operations for Robust Transit Service under All Operating Conditions	Minnesota Valley Transit Authority	Collision Avoidance Technology to Improve Safety	Evaluation Completed
Connected Vehicle Infrastructure-Urban Bus Operational Safety Platform	Battelle Memorial Institute	Collision Avoidance Technology to Improve Safety	Evaluation Completed
Innovative Platform Track Intrusion Detection System (PTIDS) Technology: A Demonstration on Los Angeles Metro Rail System	Los Angeles County Metropolitan Transportation Authority	Communication and Alert Technology to Improve Safety	Demonstration Started
Pierce Transit Collision Avoidance and Warning Research and Demonstration Project	Pierce Transit	Collision Avoidance Technology to Improve Safety	Demonstration Started
Transit Bus Mirror Configuration Research and Development	NY Metropolitan Transit Authority	Vehicle Component Technology to Improve Safety	Demonstration Started
CTA Operations Control Center Safety Enhancements Project	Chicago Transit Authority	Communication and Alert Technology to Improve Safety	Demonstration Started
Enhanced Employee Protection Warning System Including Roadway Worker Protection	Sacramento Regional Transit District	Communication and Alert Technology to Improve Safety	Demonstration Started
Fixed Location Train Detection and Worker Warning System	Maryland Department of Transportation	Communication and Alert Technology to Improve Safety	Demonstration Started
Collision Avoidance and Mitigation Technologies on LA Metro Bus Service Pilot	LA County Metropolitan Transportation Authority	Collision Avoidance Technology to Improve Safety	Project Started
Track Inspector Location Awareness with Enhanced Transit Worker Protection Pilot	Washington Metropolitan Area Transit Authority	Communication and Alert Technology to Improve Safety	Demonstration Started
Pedestrian and Cyclist Detection Devices for Buses	Novateur	Collision Avoidance Technology to Improve Safety	Demonstration Started

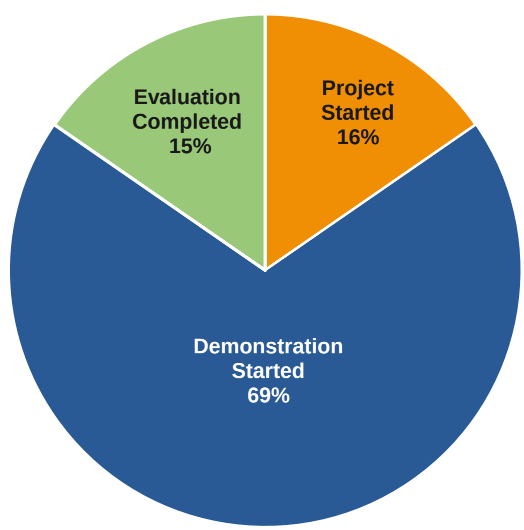
Source: FTA Technology Database.

Exhibit 12-12 ■ Safety Technology Categories



Source: FTA Technology Database.

Exhibit 12-13 ■ Safety Technology Deployment Status, March 2020



Source: FTA Technology Database.

Safer Vehicle Component Technology

FTA is investing in innovative bus and rail designs and materials that may help operators avoid collisions or reduce damage from accidents. Examples include:

- The Sacramento Regional Transit District is demonstrating a light rail vehicle crash-energy-management bumper system to reduce collision damage between light rail vehicles and autos. The bumper has an improved geometric profile and a segmented design that actuates at lower forces in the common collision scenario of corner impacts with automobiles. The technology is designed to prevent light rail vehicles from crashing on top of smaller vehicles.
- The New York Metropolitan Transportation Authority is designing a safer bus mirror that improves visibility for bus operators and decreases the possibility of collision with pedestrians due to blind spots.

Collision Avoidance Technology

FTA and its project sponsors are demonstrating vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technology to help operators avoid accidents or warn drivers before a collision occurs. Examples include:

- The Los Angeles County Metropolitan Transportation Authority (LA Metro) will deploy smart cameras and interior display modules on buses that alert the driver both visually and audibly if a pedestrian or cyclist is in the driver's blind spot. LA Metro will also deploy a technology for fleet managers that tracks the location of vehicles and reports all warnings.
- The Novateur Corporation is designing a cyclist collision warning system for buses. The system will use sensors to measure the dynamics of pedestrians and cyclists near the bus and assess the risk of collision by combining this information with data on the movement of the bus and other environmental variables.

Worker Communication and Alert Systems

FTA is funding the development of technology to improve communication between workers, train operators, and control centers. Improved communication will create and safer conditions for track workers and the technology can alert workers when a train is approaching. Examples include:

- The Chicago Transit Authority is enhancing its Control Center's "QuicTrac" train tracking tool by 1) improving the tool's ability to alert others when the signal system loses train detection; 2) adding an overlay of the Worker Ahead wayside system on the QuicTrac display; and 3) including detection of red signal violations by a train.
- The Maryland Transit Administration has deployed the ZoneGuard system, an electronic roadway worker protection system that will continuously monitor the locations of light rail vehicles and roadway workers to warn roadway workers of approaching vehicles.

Bus Compartment Redesigns

FTA is investing in both new bus components and retrofits to improve safety for operators, travelers, pedestrians, and bicyclists. New technologies will increase operator visibility to improve the safety of pedestrians and other roadway users (e.g., minimizing bus operator blind spots). Advanced communication technologies will increase passenger accessibility for positive interactions between operators and passengers, including assisting passengers in need of special assistance. Improved ergonomics can reduce bus operator work-related health issues and injuries, and can improve operational efficiency by better locating instrument and control interfaces.

Enhanced ventilation systems can filter out contaminants and improve air quality inside vehicles. Advanced driver assistance technologies will help drivers detect people out of their line of sight and avoid collisions. Safety shields will protect bus operators from assault and infection. New sanitation methods could streamline bus maintenance and reduce depot time. Automated bus movement in maintenance depots can reduce worker exposure to infectious materials in buses, and robotic systems can clean rolling stock safely.

Improving Transit Operations

Public transit continues to use technologies to improve transit operations. For example, the percentage of transit vehicles running on alternative fuels or propulsion (i.e., compressed natural gas or battery electric vehicles) increased from 27 percent in 2012 to 32 percent in 2018.[143]

FTA's research and demonstration projects use technology to enhance public transportation operations across all aspects of system services, from the design of buses to the maintenance and management of important transit assets and ensuring a state of good repair. Key areas of focus include enhancing public transit operational effectiveness and efficiency through new technologies such as unmanned aerial systems, artificial intelligence, and robotics. FTA is also exploring new energy technologies and innovative bus designs in partnership with the Department of Energy. *Exhibits 12-14, 12-15*, and *12-16* display the 12 transit operations technologies being demonstrated and evaluated under FTA-funded projects in the Spring of 2020.

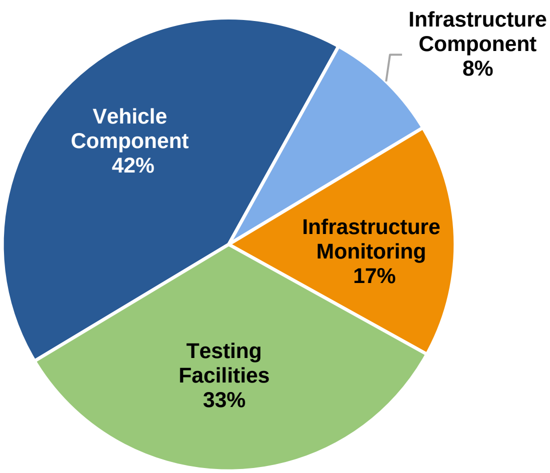
Exhibit 12-14 ■ Infrastructure Technology Demonstrations

Technology Project Title	Project Sponsor	Technology Category	Technology Status
Development of Bus Exportable Power System for Emergency Response	Center for Transportation and the Environment, Inc.	Vehicle Component Technology	Evaluation Completed
Resilient Concrete Crosstie and Fastening System Designs for Light Rail, Heavy Rail, and Commuter Rail Transit Infrastructure	University of Illinois	Infrastructure Component Technology	Evaluation Completed
Integrated Wheel/Rail Characterization and Safety through Advanced Monitoring and Analytics	New York Metropolitan Transportation Authority	Infrastructure Monitoring Technology	Evaluation Completed
Low or No (LoNo) Emission Component Assessment Program, Auburn University	Auburn University	Testing Facilities	Project Started
Low or No (LoNo) Emission Component Assessment Program, The Ohio State University	The Ohio State University	Testing Facilities	Project Started
Low or No (LoNo) Emission Bus Testing Centers, Auburn University	Auburn University	Testing Facilities	Project Started
Low or No (LoNo) Emission Bus Testing Centers, The Ohio State University	The Ohio State University	Testing Facilities	Project Started
MARTA Track Inspection and Asset Management Research and Demonstration	Metropolitan Area Rapid Transit Authority (MARTA)	Infrastructure Monitoring Technology	Demonstration Started
Thermoelectric Generation Demo	Center for Transportation and the Environment, Inc.	Vehicle Component Technology	Evaluation Completed
Reduced Engine Idle Load System	Center for Transportation and the Environment, Inc.	Vehicle Component Technology	Evaluation Completed
UTA Paratransit Accessory Electrification	Center for Transportation and the Environment, Inc.	Vehicle Component Technology	Evaluation Completed
Hybrid Beltless Alternator Retrofit	Maryland Department of Transportation	Vehicle Component Technology	Evaluation Completed

Source: FTA Technology Database.

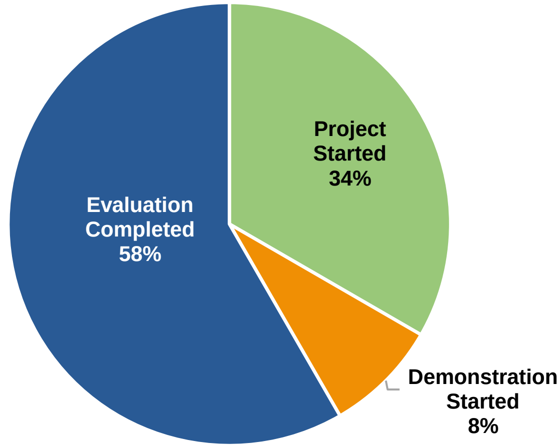
[143] FTA Quarterly Performance Report, January 2020

Exhibit 12-15 ■ Infrastructure Technology Categories



Source: FTA Technology Database.

Exhibit 12-16 ■ Infrastructure Technology Deployment Status, March 2020



Source: FTA Technology Database.

Resilient Vehicle and Infrastructure Components

FTA has sponsored research on innovative vehicle designs and components, including batteries, power systems, and materials that may increase energy efficiency, reduce emissions, and improve resilience during emergencies.

The Center for Transportation and the Environment, a nonprofit organization that receives FTA funding, has demonstrated a Bus Exportable Power Supply (BEPS) System that will give hybrid buses the capability to act as on-demand mobile electrical power generators during emergencies.

- The Center for Transportation and the Environment and the Utah Transit Administration have tested a high-voltage battery for paratransit vehicles that will recharge during travel and power the vehicle's heating, ventilation, and air conditioning (HVAC) system.
- The Maryland Department of Transportation retrofitted buses with a "Hybrid Beltless Alternator" system that can use power from rooftop hybrid batteries.
- The University of Illinois studied resilient rail concrete crosstie and fastening system designs and developed a prototype concrete cross tie that is designed to be more resilient to wear and tear and have a longer useful life.

Infrastructure Monitoring for State of Good Repair

FTA is investing in technology that can automate and improve transit agencies' ability to monitor track conditions to maintain track in a state of good repair and reduce potentially hazardous in-person inspections. Examples include:

- The New York Metropolitan Transit Authority is researching integrated wheel/rail safety characterization through a portfolio of advanced monitoring and analytics technologies.
- The Metropolitan Atlanta Rapid Transit Authority is demonstrating autonomous track inspection systems equipment that can be attached to revenue service rail vehicles, allowing them to identify track anomalies that can potentially lead to a track failure and monitor rail car vehicle performance as it interacts with the track.

In addition, FTA plans to study the deployment of unmanned aerial systems for monitoring infrastructure conditions. FTA is assessing techniques to monitor the health of transit assets using advanced sensors, and plans to research innovative construction techniques, nano-technology applications, and uses of artificial intelligence to enhance public transportation systems.

What Lies Ahead for Public Transportation in 2020 and Beyond

Many of the same technological, demographic, and economic forces that shaped the transportation world in the 2010s will continue to affect the design and provision of transit in the next decade.

Transit will also be affected by new and emerging issues such as the COVID-19 pandemic, which will require technological solutions for effective adaptation. The COVID-19 pandemic had a significant impact on public transportation. Many agencies cut or reduced services and laid off workers. For all agencies maintaining any level of service, the danger of infection required a new focus on sanitation, decontamination, social distancing, and taking any other measures necessary to reducing exposure to the virus. Sadly, some bus and rail workers died from COVID-19, highlighting the need to find more ways to keep everyone safe. Agencies are working on cost-effective and less personnel-dependent methods to sanitize public transit systems. Researchers are investigating new ways to reduce COVID-19 infection in vehicles with the use of ultraviolet light or special high-efficiency particulate air (HEPA) filtration. To reduce crowding or exposure, new communication methods to share real-time information on passenger loads are in development, and agencies are expanding and improving contactless fare options. Transit agencies are also investigating new service models such as providing food delivery services for youth and high-risk populations, transporting biohazard items, and providing dedicated routes for essential workers.

As more data are available to travelers, they can make informed decisions about ride sources, and agencies can optimize travel through transit routing and scheduling. Strategies to improve data governance, standardization, and interoperability are increasingly important as the transit industry operates in a more data-driven environment.

As public and private partnership for shared mobility services mature, new technologies that facilitate multimodal and contactless payment are emerging. These systems will require continued vigilance to ensure the security of consumer information and a strong focus on all aspects of data management and cybersecurity.