

Emerging Technologies

WHITE PAPER

THE SAN DIEGO ASSOCIATION OF GOVERNMENTS

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Introduction

The pace of technology is moving more rapidly than anyone could have predicted. In the early 20th century, it took nearly 75 years for technologies such as the telephone and household stove to reach market penetration (Figure 1). Today, consumer electronics are being adopted by the market at a far quicker rate. As of 2016, 95 percent of U.S. adults (age 18 and over) owned a cell phone, and smartphone ownership reached 77 percent¹.

Technology is influencing every aspect of our lives, including how we travel. The rapid adoption of the smartphone in the U.S. market has enabled transportation innovation such as on-demand mobility services like Uber and Lyft. Additionally, nearly every major auto manufacturer is racing toward production of autonomous vehicles (AVs), anticipating having AVs commercially available as early as 2019. Conservative estimates for AV adoption forecast 90 percent market penetration within the next 50 years.

Technology Adoption in the U.S.

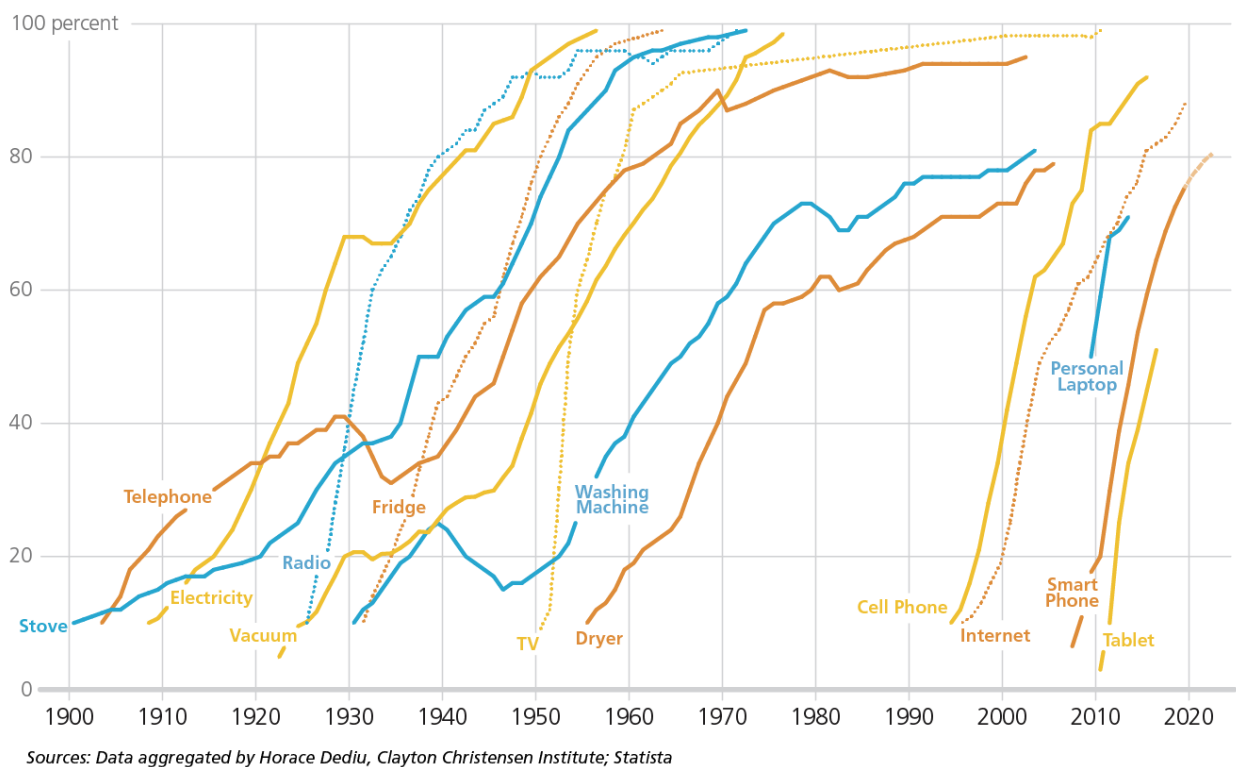


Figure 1. Technology adoption has rapidly increased over the last several decades

The objective of this white paper is to present technological and societal trends that have the potential to radically change how the region's transportation system is used in the future, and to outline potential policy considerations that will enable the region to harness the benefits and reduce the potential negative impacts of these trends. This paper presents research that demonstrates how many of these technological advancements have the potential to improve safety, mobility, and efficiency. However, without proactive planning and policy interventions, these technologies could move the region away from its objectives by increasing sprawl, vehicle miles traveled (VMT), and greenhouse gas emissions (GHG), and by limiting access for disadvantaged communities.

This white paper contains three sections:

1. **Technology and Societal Trends Impacting Transportation:** This section explores the rapid change in the transportation sector brought about by advancements in Information and Communications Technology (ICT) and vehicle technologies that have made way for several key mobility trends:
 - a. Mobility as a Service
 - b. Zero Emission, Autonomous, and Connected Vehicles
 - c. Smart Cities and Transportation Systems

Although each trend is described separately, they are interrelated and their combined impact is significant, so it is critical to consider how they work together. For example, ICT is the backbone for Mobility as a Service (MaaS) and Smart Cities, which both rely on better connectivity and Big Data. Shared vehicle fleets that are electric and automated offer significant opportunities for mobility, safety, and sustainability. Smart Cities and Intelligent Transportation Systems (ITS) provide the connected infrastructure that ultimately support the efficiency of a shared, electric, and autonomous transportation future.

2. **Policy Considerations:** This section explores the planning, policy, and investment considerations that can leverage these trends in support of the region's policy objectives. Technology is rapidly changing transportation, so policies and infrastructure investments will need to keep pace, requiring new ways of conducting business in partnership with the private sector.
3. **Look Ahead:** This section explores technologies that are still under development, but relevant to the future of transportation. While not a focus of this paper, it is important to monitor how these technologies are progressing. As more research and data becomes available, these technologies may be considered in future updates of San Diego Forward: The Regional Plan.

Technology and Societal Trends Impacting Transportation

In recent years, nothing has had a more profound impact on transportation than advancements in ICT. The expansion of the Internet and improvements in computing and wireless communications have made virtual activities a viable alternative to many physical activities, which has changed travel demand patterns. On one hand, ICT reduces certain types of trips by enabling an increase in telework and social engagement online and by providing access to remote services like online education and healthcare. On the other hand, ICT has led to a significant increase in online retail activity, which may reduce some types of shopping-related trips, but induces other types of trips – mainly freight and delivery. According to a recent survey, 51 percent of Americans prefer to shop online². In response to this shift in preference, traditional brick and mortar retailers are transitioning to an online presence, offering free shipping and next-day delivery to meet the growing demands of their customers. High volumes of goods and expedited delivery can lead to an increase in traffic volumes if done without consolidation and, by 2045, it is expected that freight volume will increase by more than 40 percent³. As such, new models for the delivery of goods are emerging. For example, Walmart partnered with Uber for delivery of goods, and Amazon Flex hires independent contractors to deliver packages in their personal vehicles⁴. Similarly, food delivery services with online storefronts are contributing to changes in travel demand. Third-party delivery platforms like Instacart, GrubHub, PostMates, and UberEATS allow grocery stores and restaurants to increase their distribution. As demand for online goods and services continues to grow, companies are contemplating entirely new production and delivery methods that could improve logistics like drones, delivery robots, and 3-D printing, which are described in the “Look Ahead” section of this paper.

ICT also has provided a platform for the sharing economy to flourish, with innovative companies such as Airbnb and TaskRabbit fundamentally transforming the way consumers discover and purchase services. This is most notable in the transportation sector, where innovation is resulting in new shared mobility services that are rapidly adopted in the market. In cities across the world it is possible to rent shared cars, shared bikes, or shared rides from individuals on demand through a mobile application. These innovative shared mobility services are providing communities with more travel choices, and their popularity is beginning to challenge long-held beliefs about the need to own a vehicle to have personal mobility. The degree to which sharing a ride will trump individual ownership awaits to be seen, but this paper considers the trend toward a future where mobility is consumed as a service.

Perhaps the greatest impact that ICT will have on the future of transportation is the Internet of Things (IoT). IoT is a term that refers to a network of ordinary objects, like household appliances, cars, street lights, and traffic signals (Figure 2), that are embedded with Internet-connected electronics, sensors, or software that can capture, exchange, and receive data.⁵ The rapidly increasing number of connected devices and systems presents significant opportunities for transportation. Data and connectivity enable Smart Cities and intelligent transportation systems that offer a host of benefits such as reliability, operational efficiency, cost-effectiveness, safety, and improved asset-management and planning, all of which is discussed in the “Smart Cities and Transportation Systems” section of this paper.

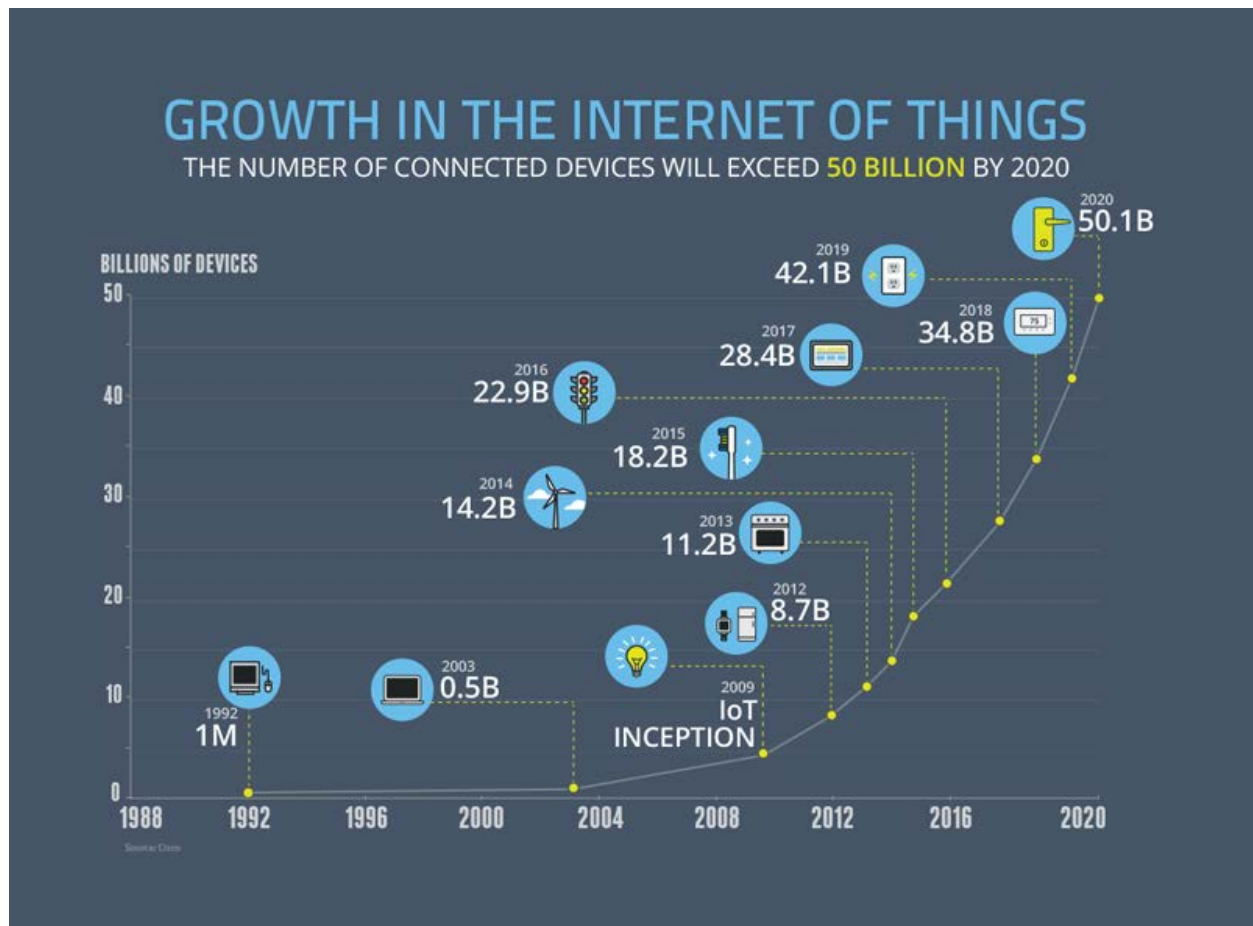


Figure 2. The IoT Explosion (Source: NCTA)

Mobility as a Service

Mobility as a Service (MaaS) is the idea of providing people with on-demand access to a wide range of public and private shared mobility services.⁶ MaaS enables a transition from the current paradigm, where vehicle ownership is all but required to enable people to freely move about their community, to a new mobility paradigm, where people have access to an array of transportation services, and where access can be purchased as needed, is competitive with the private automobile, and provides more convenient, efficient, and potentially less expensive travel options. Proponents of MaaS imagine an ecosystem where public and private operators cooperate and where consumers have access to information that enables preferential choice. Rather than having to locate, book, and pay for each mode of transportation separately, MaaS proponents have developed mobile applications that aggregate data from service providers to enable users to plan and book door-to-door trips using a single application that provides the best transportation option based on real-time conditions and user preferences (i.e., time, convenience, cost) (Figure 3).

Mobility as a Service (MaaS)



Figure 3. Mobility as a Service provides an integrated platform for trip planning and booking across modes

While shared mobility, which includes transit, carpool, and vanpool, is not a new concept, technology has allowed for explosive growth and variance in business models in recent years, blurring the line between public and private transportation.

On-Demand Rideshare

On-demand rideshare services allow users to request a ride in real time using a mobile application. These services link passengers with available drivers based on trip origin and destination, identify the quickest route, and facilitate trip payment. On-demand rideshare generally falls under two categories: dynamic carpooling and ridehailing.

Dynamic Carpooling is an application-enabled service that conveniently matches drivers and passengers in real time, filling empty seats and reducing congestion and auto emissions. Dynamic carpooling applications facilitate cost sharing among travelers, but prohibit drivers from making a profit. Examples of dynamic carpool services that are becoming popular in California are Scoop and Waze Carpool.

Ridehailing services (e.g., Lyft and Uber) allow users to request rides from a hired driver. They are distinctly different from taxis in that they must be “e-hailed.” In California, these services are classified as Transportation Network Companies (TNCs). Ridehailing service offerings are changing rapidly (Figure 4). In the San Diego region, passengers can hail discounted shared rides (commonly referred to as “pooled” rides), solo rides, and luxury vehicle rides. Shuttle style services, where the user walks to a particular corner or to a popular route to hail a discounted ride, are available in other markets (e.g., Lyft Shuttle), and to some extent mimic services traditionally provided by public transit agencies. Uber and Lyft also have introduced monthly subscription services that function similarly to monthly transit passes in some markets.

In just a few years, ridehailing services have established operations in more than 700 cities across the U.S., with Lyft providing about 1 million rides per day and Uber providing over 5.5 million rides per day. Overall, TNCs provide service to over 80 percent of the U.S. population and deliver over 6 million rides per day.⁷ In comparison, Americans take about 27.7 million transit trips per day.⁸ However, to date there is insufficient evidence to indicate how widely available and equitable ridehailing services really are. More data is needed, particularly from the service providers, and ongoing pilot efforts to ensure these services are made available across all dimensions of a community's population are being expanded to help inform policy development to align these services with the regional goals.

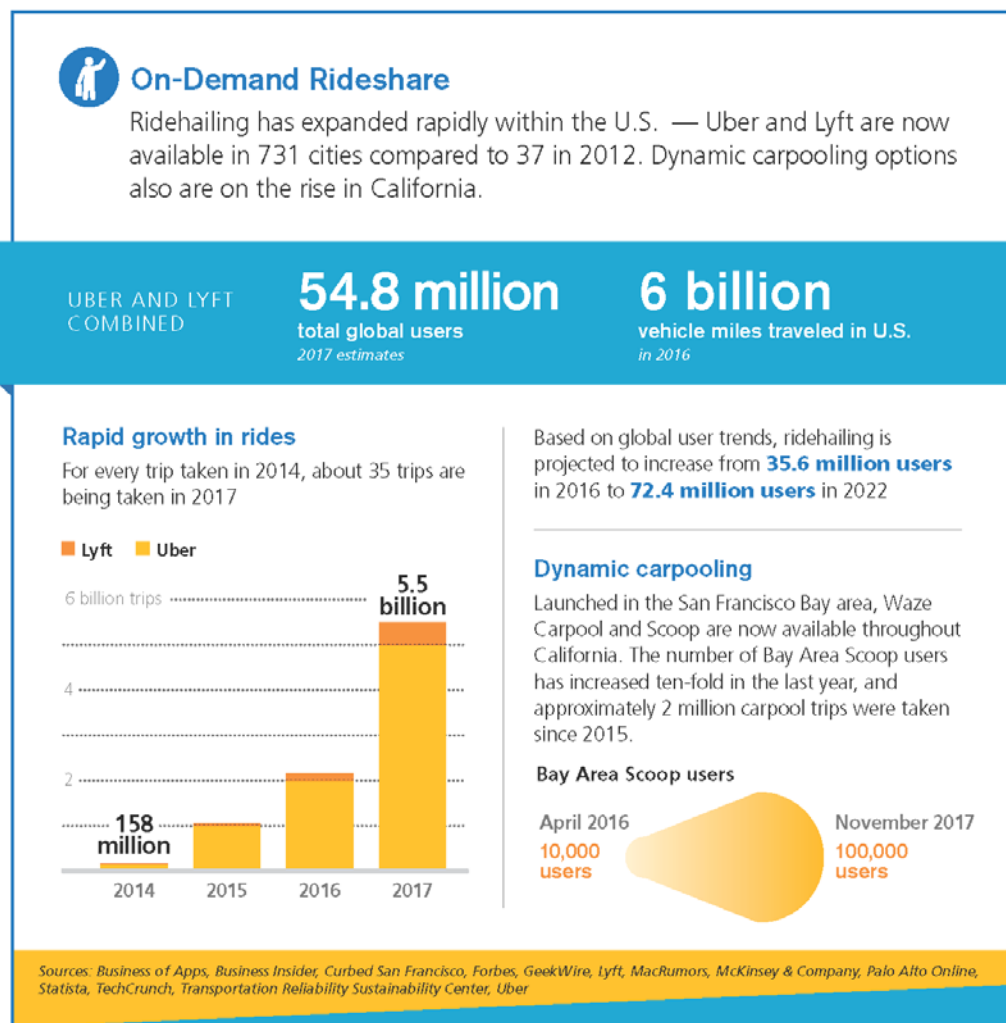


Figure 4. On-demand ridesharing is growing rapidly in the U.S.

Bikeshare

Bikeshare systems provide fleets of bikes to be rented for a short period before they are returned to the system. Providers use technology to automate locking/unlocking, collect payment, and identify the location of bikes. Technological improvements have led to dockless bikeshare systems that allow members to park and lock a bike wherever they want within a designated zone. Early dockless bikeshare providers include Ofo, LimeBike, Spin, and JUMP. Dockless bikeshare is expanding rapidly due to the minimal amount of capital investment required to launch a system. In the San Diego region, dockless bikeshare services are operating in several jurisdictions, with more planning to launch dockless bikeshare in 2018.

Electric bikeshare

Electric bikeshare systems are in the early stages of development. Park City, Utah launched the first all-electric station-based bikeshare system in July 2017, and the first dockless e-bike system became available in Washington, D.C. in September 2017. Similarly, electric scooter sharing services are gaining popularity in Europe, and can make it easier for people to travel more quickly when topography is challenging and parking is scarce.

Scout in San Francisco is the only scootershare service operating in the U.S., and its users ride about 50,000 miles per month.⁹

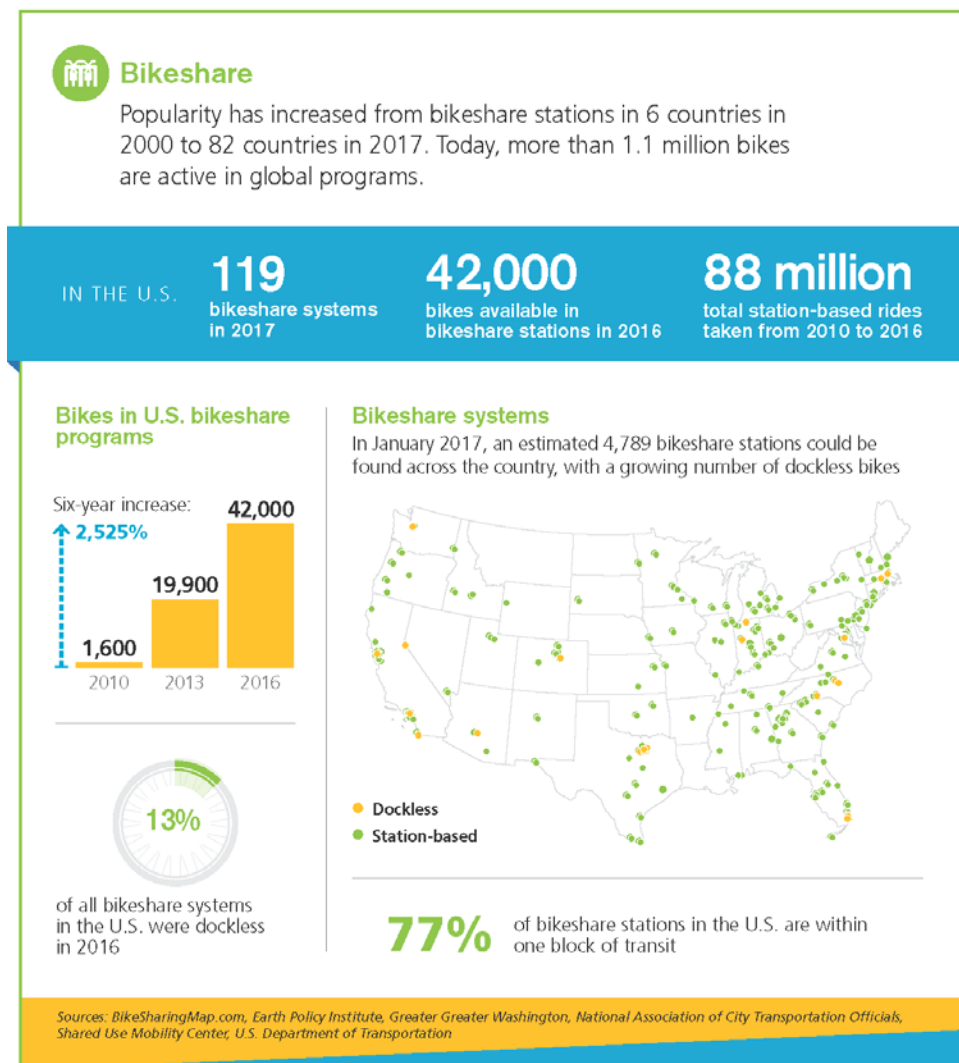


Figure 5. Technological improvements are spurring the growth of bikeshare programs nationwide

Carshare

Carshare provides short-term vehicle rentals that are accessed via a mobile application. Rental rates generally include insurance, parking, and fuel or vehicle charging costs (Figure 6). Round-trip carshare services allow users to reserve and return a vehicle to the same designated parking spot (e.g., Zipcar). Alternatively, one-way carshare allow users to pick up a vehicle from one designated parking spot and return it to another designated carshare parking spot. Free-floating carshare services such as car2Go, ReachNow, and WaiveCar allow users to pick up and park a vehicle anywhere within a designated service area. Peer-to-peer carshare services such as Maven, Croove, Getaround, and Turo allow private vehicle owners to rent their car by the hour or day to others within their community; adding another mode to the supply side of the transportation system.

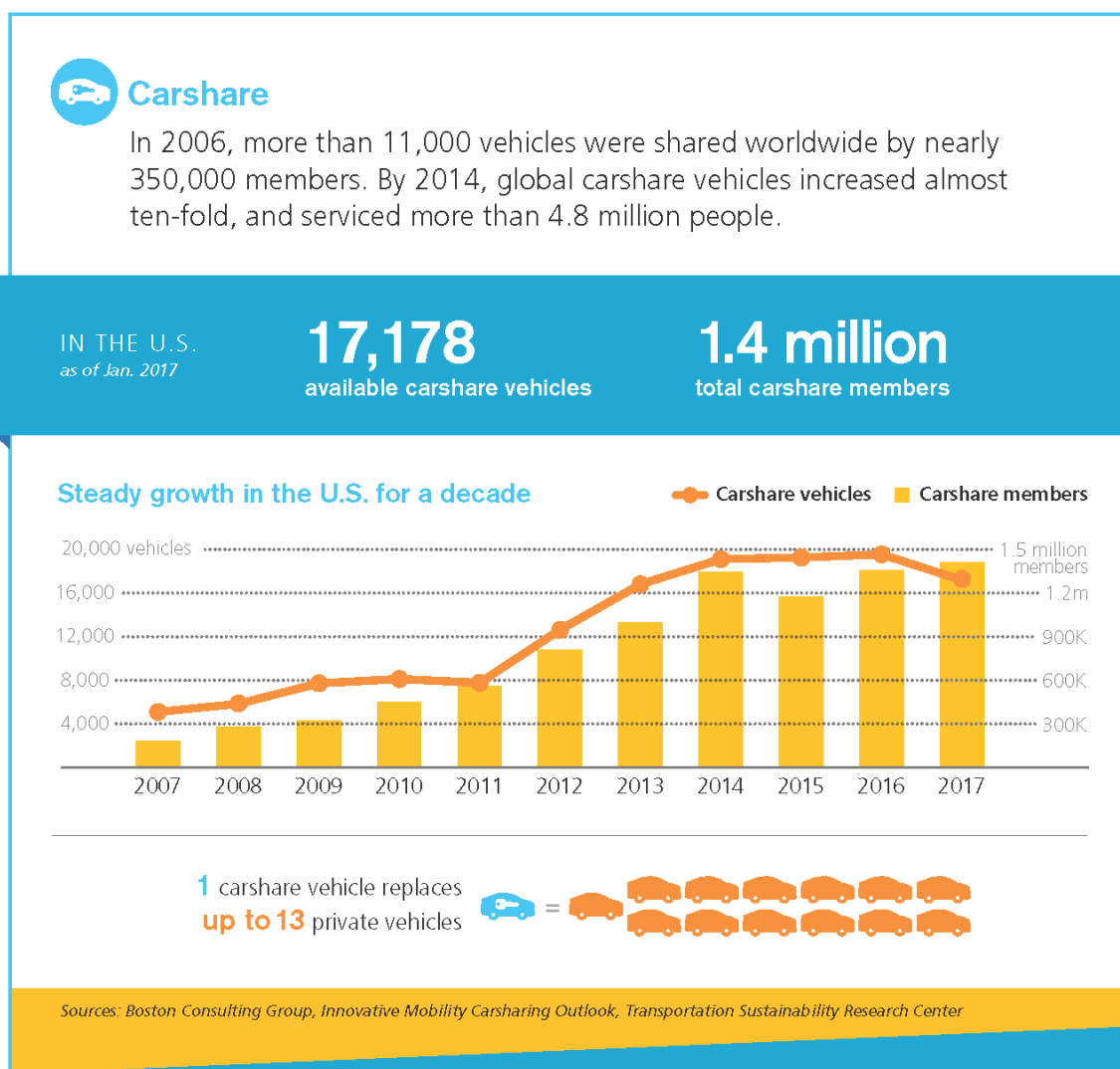


Figure 6. Carshare growth is helping to replace personal vehicle use

Carshare providers are being encouraged to electrify their fleets in order to support cities with their sustainability goals. For example, BlueLA is an all-electric carshare service, consisting of one self-service kiosk and five parking spots, each with an electric charger, where members collect and drop off vehicles.¹⁰

Carshare growth has slowed recently, which may be the result of competition with other shared modes of transportation. In San Diego, Daimler shuttered their car2Go carsharing service, citing regulatory challenges and competition from other shared modes, namely ridehailing services. As a result, carshare service operators are looking for ways to increase the use of vehicles, which is leading to innovative dual-use service models. For example, Green Commuter, a Los Angeles-based operator, offers a fleet of electric vehicles to be used for commuter vanpooling during commute hours, and then reserved as carshare vehicles or used as corporate fleet vehicles during the off-peak period. Alternatively, Zipcar is now targeting commuters by offering monthly leases, which come with free maintenance, gas, and parking, on its fleet of shared vehicles for weekly access between 5 a.m. Monday and 7 p.m. Friday.

Public transit

Public transit, the original shared mobility service, is the backbone of MaaS. High-frequency transit continues to be the most efficient way to move many people along popular routes from common origins and destinations. Other shared mobility services can complement public transit by serving different trip types and needs. Recent research conducted by the American Public Transportation Association (APTA) shows that the more people use shared modes of transportation, the more likely they are to use public transit, own fewer cars, and spend less on transportation overall.¹¹

Public transit systems across the country are experiencing a technological revolution that is resulting in improved operations and user experience. Leading agencies are using ICT to improve fare collection, scheduling, and routing of transit services. Agencies can track the location of their buses and trains, as well as how many people are riding a particular route and bus in real time. This information can be utilized to better predict how many buses will be needed on given routes at different times of the day, and can control when they arrive at a stop so that fewer are too late or too early. Real-time information enabled by ICT also improves the user experience by providing riders with accurate information to support trip planning and trip reliability (Figure 7).

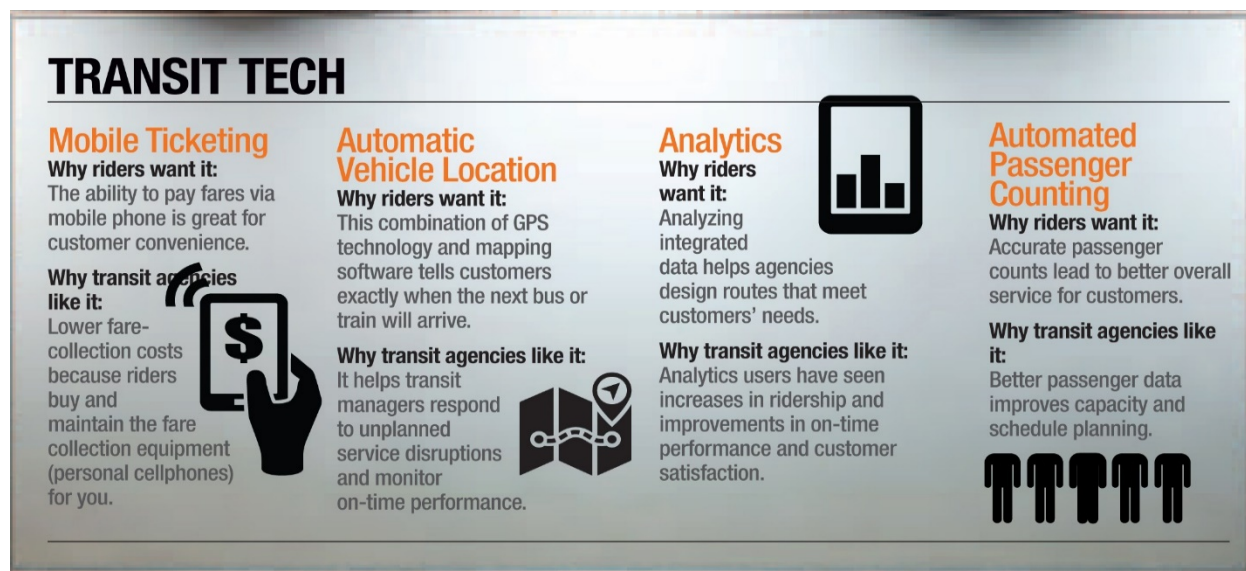


Figure 7. Technology improves transit operations and the customer experience
(Source: Government Technology)

The spectrum of public transportation vehicles and features also is changing as a result of technology – for example, the implementation of demand-responsive transit with smaller vehicles along less-traveled routes where high-frequency transit isn’t warranted or is too costly to operate.

Microtransit

Microtransit is an on-demand shuttle service that carries between 5 and 12 passengers and typically operates along a dynamically generated route or within a designated zone (Figure 8). Microtransit services vary in their business models. Chariot, a privately-owned and operated service of Ford Smart Mobility, is focused on commuters and currently serves the cities of Columbus, Seattle, San Francisco, Austin, and New York. Via, on the other hand, is an example of an innovative mobility service provider that directly partners with public agencies to plan and implement on-demand, transit services within a community. Other companies offer technology solutions, such as vehicle routing; fleet management; and booking services that enable government agencies or private fleet operators to enhance their existing transit services.

Some microtransit service providers are fulfilling short-distance trips within smaller service areas with Neighborhood Electric Vehicles. The Free Ride Everywhere Downtown (FRED) in San Diego uses six-passenger Polaris Gem zero-emission vehicles (ZEVs) that can be hailed using a mobile application or by waving down a vehicle within the fleet’s operating area. FRED typically is used to fulfill trips under two miles, and now services almost 400 riders a day. FRED recently was granted renewed funding to grow its fleet to 30 by 2020.¹²

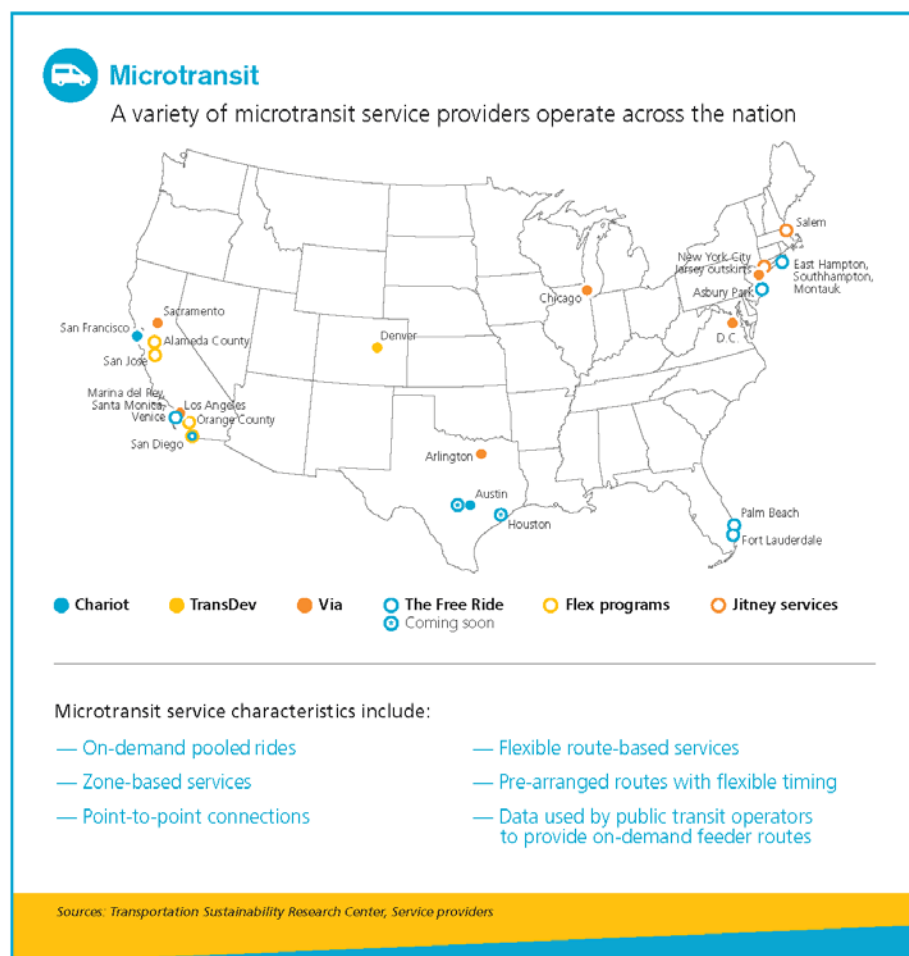


Figure 8. Microtransit services are becoming more common and supplementing traditional transit.

MaaS in Action

Whim is the most comprehensive MaaS platform in use today in the City of Helsinki in Finland, which aims to make automobile ownership unnecessary by 2025.¹³ Launched in 2016 by MaaS Global, the Whim application facilitates trip planning and payment across all shared modes of public and private transportation within the city (i.e., transit, taxis, carshare, and bikeshare). Users of the application can enter a destination to select and pay for the best mode or combination of modes to cover the door-to-door journey. Users can prepay as part of a monthly subscription (like a monthly transit pass) or can pay as they go using a bank account linked to the service.

Transit agencies and cities of all sizes across the U.S. are exploring MaaS as a way to enhance public transit and reduce drive-alone trips. LA Metro owns and operates a bikeshare system that can be accessed with their transit fare card, TAP, creating a seamless transition from transit to bike. LA Metro also partnered with Via to provide on-demand microtransit service that will connect commuters to and from select Metro stations. The City of Centennial in Colorado partnered with Xerox and Lyft to provide commuters with an integrated application to book a free Lyft ride to light rail stations. The Dallas Area Rapid Transit's GoPass Mobility on Demand Sandbox Project will fully integrate ride-sharing services into its GoPass ticketing app. SANDAG has developed a Regional Mobility Hub Implementation Strategy, which illustrates how MaaS can be implemented in the San Diego region to support transit investments and improve mobility in a variety of community settings (Figure 9). SANDAG also partnered with Waze Carpool and Uber to enhance traditional Transportation Demand Management (TDM) programs through on-demand services.



Figure 9. SANDAG Mobility Hub Concept

This influx of public-private partnerships and the convergence of shared mobility services makes MaaS more of a reality. Some estimates project that MaaS could reduce auto sales by more than 30 percent by 2030,¹⁴ and many major auto manufacturers are pivoting to become mobility service providers. Ford Smart Mobility LLC was developed in 2016 to expand Ford's business model and invest in microtransit service (Chariot), carshare service (GoDrive), bikeshare (GoBike) and a partnership with Lyft to test AVs. General Motors developed the Maven carshare service, invested millions of dollars in Lyft, and has announced plans to deploy thousands of

autonomous electric vehicles for ridesharing. Toyota is at work developing Ha:mo, a MaaS concept that provides shared fleets of small neighborhood electric vehicles for various types of trips in urban environments as a complement to public transit.

MaaS Opportunities and Challenges

Shift from one commute mode to multiple: The surge in application-enabled mobility services has created expectations for more personalized transportation on demand. This may impact mode-specific fare affinity programs, such as monthly transit passes, but provides a significant opportunity for MaaS.

Decreased vehicle ownership: Shared mobility user surveys indicate that access to these services decreases their likelihood of purchasing a vehicle and increases their likelihood of selling a vehicle.

Decreased demand for parking; increased demand for curb space: Fewer privately-owned vehicles means less demand for traditional parking. However, these services are impacting curb space, which conflicts with other modes of transportation in the roadway and creates bottlenecks with passenger pick-up and drop-off. Cities are rethinking how curb space is used and are dedicating areas for pick-up and drop-off zones.

Limited access for the unbanked and those without smartphones: MaaS requires credit/debit for payment and a smartphone for accessing the service, presenting limitations for the unbanked and those without a smartphone. Further, most private mobility service providers are not sharing data about how their services are used, so it is unknown if disadvantaged communities are benefiting from these services.

Shared mobility trips are replacing single-occupant vehicle trips and transit trips: Shared mobility services tend to concentrate in urban areas, and research shows that carshare, bikeshare, and ridehailing replace transit trips in these areas.¹⁵ Recent research indicates that about 60 percent of ridehail trips either would not have otherwise been taken, or were formerly transit, bike, or pedestrian trips.¹⁶ In dense cities like Washington, D.C. and New York City, bikeshare has replaced some transit trips. However, in less dense cities, such as Portland and Denver, bikeshare users reported that 26 percent to 47 percent of their trips would have been car trips.¹⁷

VMT impacts of some shared vehicle services are unclear, and pricing will be an important lever to achieve reductions: Data access restrictions make it challenging to understand the impacts of shared mobility on overall VMT. Studies from the University of California, Davis and the APTA link ridehailing services to declining transit ridership, and to increases in VMT and congestion.¹⁸

Increased comfort with pooled trips: People are growing accustomed to sharing rides with strangers, and do not mind sharing a ride for the right price. This cultural shift could lead to an increase in ridesharing with the right incentives in place. Encouraging more pooled trips will likely require updated pricing mechanisms.

Numerous public-private partnerships across the world are demonstrating how services can come together to support each other, reduce operational costs, and better meet the needs of consumers.

Uncertainty about service provider participation: Mobility service providers have been reluctant to share information beyond their individually branded mobile applications, and the reality of a single platform to locate, book, and pay for trips across multiple branded services remains elusive.

Vehicle Technologies

Vehicle technologies are advancing rapidly, with vehicles becoming increasingly safer, lighter, and more fuel efficient. New and diverse vehicle types are emerging in the market that meet the needs of specific types of trips, such as longer-distance commuting with multiple passengers versus very compact alternatives for solo drivers traveling shorter distances (Figure 10). This section of the paper explores the trend toward vehicles that are zero-emission, autonomous, and connected. These technologies are addressed independently, given their unique applications, market forces, and policy considerations, although their futures are predicted to be intertwined given the synergies and benefits of combined application. For example, electric vehicles, connected vehicles, and AVs can be smaller and lighter, requiring less space for conveyance and storage (parking). This trend enables cities to rethink the way in which the public's right-of-way for streets, sidewalks, and curb space are allocated, and can potentially help to facilitate a more comprehensive implementation of Complete Streets concepts that provide safe space for everyone and every mode.



Figure 10. Ultra-compact electric carshare vehicle (Source: Toyota Global)

Electric and Other Zero-Emission Vehicles

Zero-emission vehicles (ZEVs), like plug-in electric vehicles (PEVs)¹⁹ and hydrogen fuel cell electric vehicles (FCEVs), play a big role in how countries, states, and local governments plan to cut GHG emissions. Technology innovations are underway across all vehicle types from passenger vehicles and vans to buses and trucks.

PEVs have gained the most traction amongst consumers and businesses so far, though it is still a nascent market. Major auto manufacturers released their first electric vehicle models in 2010, and over 70 models are planned by automakers for model year 2020. As of May 2017, almost 300,000 ZEVs, primarily PEVs, were sold in California, comprising nearly half of the total U.S. market and about 30 percent of the expected 2 million vehicles sold globally.²⁰

This growing ZEV market is creating a massive need for new charging infrastructure across the transportation network. Public and private investment is necessary to provide adequate charging and hydrogen-fueling infrastructure. Beyond the infrastructure needs for PEVs, transit operators will need to consider how to address range issues and overcome recharging electric transit buses. One such technology that addresses this issue is inductive charging, where a transit vehicle can recharge batteries by simply remaining over an inductive

charging system at a transit stop or layover facility. Inductive charging will also be critical for AVs, particularly those AVs that are part of a shared rideshare fleet. An example of inductive or wireless charging is QUALCOMM's Halo™ technology (Figure 11).



Figure 11. Static and in road Inductive Charging (Source: QUALCOMM)

Local electric utilities play an essential role in the build-out of ZEV infrastructure to meet the growing demand, as the addition of grid-connected charging stations – whether at homes, businesses, or public sites – must be evaluated prior to operation to ensure that no localized grid impacts occur. Utilities also are at the forefront of vehicle-to-grid integration efforts that could eventually enable electric vehicles to plug in and supply power back to the grid in times of need. Some companies offer solar charging stations combined with energy storage to recharge vehicles using the sun (Figure 12).



Figure 12. Chevy Volt plugged in to a renewable, portable charging station.

Governments at all levels are taking steps to ensure the success of ZEV markets. In California, Governor Jerry Brown set a goal that the state should develop enough ZEV infrastructure to support 1 million vehicles by 2020, and 1.5 million ZEVs by 2025.²¹ California also enacted ZEV regulations that require 15.4 percent of all passenger vehicles sold in California to be zero-emission in 2025.²² In the U.S., a multi-state ZEV Memorandum of Understanding that commits to having 3.3 million ZEVs on the road by 2025 was signed by nine governors (California, Connecticut, Maine, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont).²³ Together, these states represent about 30 percent of all new vehicle sales in the U.S.²⁴ Internationally, India has

committed to having 6 to 7 million electric vehicles on their roads by 2020, and will allow only electric vehicles to be sold by 2030. India is the world's fifth-largest auto market.²⁵ Additionally, governments in many countries, including China, France, Germany, Italy, Japan, Norway, South Korea, Spain, Sweden, the United Kingdom, and the United States, have enacted policies encouraging PEV sales.²⁶

Concurrent with government action, industry is making significant investment in advanced vehicle technologies and associated infrastructure. Vehicle manufacturers have taken notice of government commitments and are positioning themselves as future market leaders in ZEV transportation. Volvo²⁷ has committed to produce only PEVs or hybrid vehicles in 2019. Volkswagen²⁸ has committed \$40 billion by 2022 to PEVs, AVs, and new mobility services. Daimler AG is spending more than \$11 billion to bring at least ten new PEVs to market under its new Mercedes-Benz EQ sub-brand by 2022.²⁹

Autonomous Vehicles

A Level 5 AV (see Figure 14) can perform all functions of driving without intervention from a human. AVs use sensors, cameras, and Global Positioning System (GPS) technology to read information about the surrounding environment and navigate to their destination with limited or no human assistance (Figure 13).

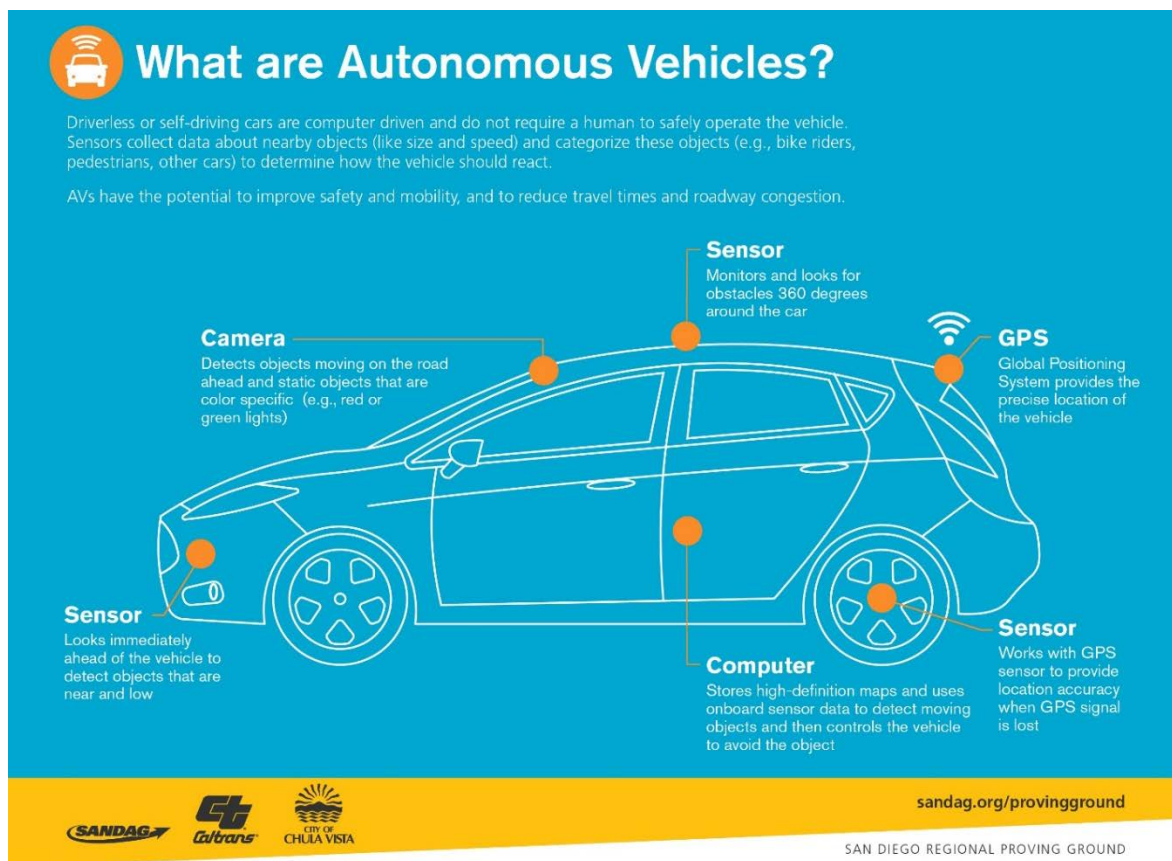


Figure 13. Characteristics of autonomous vehicles

The advent of AVs is being driven by the private sector at a rapid pace. Vehicles with partial automation are already commercially available, and auto manufacturers claim they will have fully-automated vehicles (Level 5 AVs) commercially available as early as 2020 (Figure 14). Conservative estimates for AV adoption show a 10 percent to 20 percent market penetration by 2030, with AVs accounting for 10 percent to 30 percent of VMT.³⁰

Presently, two models of AV adoption are being widely discussed: the shared fleet model (similar to how Uber and Lyft are manifesting) and the private car-ownership model. Both Uber and Lyft are heavily invested in advancing AV testing and deployment in partnership with auto manufacturers and technology companies. The absence of a driver could reduce their operational costs and ultimately bring down the price of trips for consumers. AVs also have applications for transit service providers. The future could bring fully-autonomous shuttles, buses, and other shared services that feed to light rail and commuter rail services, thus increasing access to and use of public transit services, and furthering the likelihood of the MaaS model discussed earlier in this paper.



Figure 14. Levels of vehicle automation

The potential benefits of AVs are numerous. AVs could increase mobility for the elderly, the disabled, and the transit dependent, eliminate many vehicle accidents, improve bike and pedestrian safety, revolutionize delivery services and logistics, and almost eliminate the need for concentrated parking facilities. By some estimates, a partially-automated fleet of vehicles could increase freeway capacity by 10 percent to 25 percent, while estimates for the capacity for a fully-automated automobile fleet range are as high as a five-fold increase.³¹ However, these benefits will not materialize on their own. Without effective planning and policy intervention, AVs are just as likely to lead to an increase in total VMT, exacerbate urban sprawl, and increase energy consumption and GHG emissions.

Federal and state governments are struggling to keep pace with private-sector innovation and develop regulations that will ensure that common safety standards are adopted and uniformly applied in terms of vehicle design and operation on public right-of-way. The federal government has developed voluntary guidance on Automated Driving Systems that was updated in September 2017 and is expected to be updated again later this year, while Congress continues to work toward passing an AV bill.³² Last month, the Federal Transit

Administration unveiled its five-year agenda for researching automation in transit – The Strategic Transit Automation Research (STAR). STAR is intended to encourage public transit agencies and manufacturers to begin researching and piloting automated buses.³³

Across the U.S., states are handling AV regulations differently. California has taken a very proactive role in developing regulations for testing and deployment, while other states have elected to take a hands-off approach and welcome testing and deployment without government intervention. Local and regional agencies are trying to understand how to prepare for AVs and what types of investments they should be making in the transportation system to prepare for the autonomous future. Some infrastructure improvements may be needed to support AVs, although these needs are not yet well understood. For example, faded or inconsistent lane markings, and damaged or inconsistent signage or lights might make it difficult for AVs to navigate. In May 2017, Caltrans issued a policy that will lead to a new state standard that makes roadway lane striping more visible to AVs; going forward, Caltrans will apply a six-inch-wide painted pavement stripe, and will minimize the use of “Botts’ dots.” However, it is not yet well understood if other improvements to roadway infrastructure will be required to ensure that AVs can operate safely and efficiently.

Ultimately, systematic AV deployment will require collaboration across all levels of government and with the private sector. One such effort is the United States Department of Transportation (U.S. DOT) Autonomous Vehicle Proving Ground Program. SANDAG partnered with the City of Chula Vista and Caltrans to be designated as one of ten U.S. DOT Autonomous Vehicle Proving Grounds in the country. The intent of the initiative is to inform and help foster a consistent approach across the nation toward the planning and policy development for AVs, and to do so by collaborating with the private sector to test AV technology and share data and best practices.




Connected Vehicles

Connected vehicles (CVs) can communicate to each other through in-vehicle and wireless technology (Figure 15). CVs communicate position, direction, and speed to give the driver or the vehicle the situational awareness to react to incidents, thus reducing the number of accidents and smoothing traffic flow. CVs also can communicate with smart infrastructure and other connected devices like smartphones or wearable technology, further improving safety across modes and smoothing transportation system operations.



What are Connected Vehicles?

In-vehicle and wireless technology enables connected vehicle (CV) communication:

	vehicle to vehicle (V2V)
	vehicle to infrastructure (V2I)
	vehicle to everything (V2X)

CVs give the car and driver advanced information and warnings to inform safer driving decisions, such as when a car ahead brakes suddenly, or if there is an accident that causes traffic to slow or reroute. CVs can share data about the vehicle with the driver ten times per second, such as if tires are slipping due to water on the road. These wireless communications are shared between vehicles (V2V) to improve road safety.

CVs can receive notifications from vulnerable road users (V2X) – like pedestrians, bike riders, and road workers – to alert drivers to use caution.

CVs also can communicate with traffic control infrastructure (V2I) like traffic signals, ramp meters, toll and parking payment systems, which could improve traffic flow and reduce emissions.

The National Highway Safety Administration reports that, when fully deployed, CVs could address 80% of unimpaired accidents.



Connected Vehicles are not autonomous, however Autonomous Vehicles can be connected.



sandag.org/provingground

SAN DIEGO REGIONAL PROVING GROUND

Figure 15. Characteristics of connected vehicle technology

CV technology is not only about improving operations for cars – it provides benefits across modes. For example, the software company Tome has partnered with Trek Bicycle to create an artificial intelligence-based bicycle-to-vehicle communication system to help drivers get alerts to bicycles ahead in dangerous areas of the road.³⁴ Similarly, pedestrian-to-vehicle communications have been demonstrated by Qualcomm and can provide information about a pedestrian's location to all other travelers on the network, including approaching vehicles (Figure 16). The devices used may include smartphones, and new innovations from IoT being applied to wearable technology such as smart watches, wristbands, glasses, clothing, or others.³⁵



*Figure 16. Information about this blind pedestrian's location is broadcast to approaching vehicles
(Source: Intelligent Transportation Systems Joint Program Office)*

CVs are not AVs, but AVs can be connected and may provide the greatest benefit in terms of safety and operations when they are connected. Cellular technology that enables a vehicle to communicate directly with a wide array of other objects is known as Cellular-vehicle-to-everything (CV2X) technology. CV2X complements other AV sensor technologies and directly connects vehicles to everything—including to each other, to pedestrians and people on bikes, to roadway infrastructure, and to the network.³⁶ A connected AV not only would operate safely independently, but because of the constant communication between vehicles, the roadway, infrastructure, and other entities such as pedestrians and bicycles, it would be able to operate as part of a larger safety ecosystem further discussed in the “Smart Cities and Transportation Systems” section of this paper.

CV technology has unique application for transit and for goods movement. One example of a CV application is platooning, which enables vehicles, including transit buses and trucks, to form “road trains” with decreased following distance; all vehicles in the “train” work cooperatively as a single entity. The future could see smaller transit vehicles linked together, which would enable operators to dynamically adjust system capacity depending on demand.

The U.S. DOT has been working toward vehicle-to-vehicle (V2V) communications with auto manufacturers for over a decade. In 2006, the U.S. DOT joined a partnership of automotive manufacturers, Crash Avoidance Metrics Partnership (CAMP), to develop and test prototype V2V safety applications. CAMP includes Ford, General Motors, Honda, Hyundai-Kai, Volkswagen, Mercedes-Benz, and Toyota.³⁷

Until 2017, the U.S. DOT has been committed to Dedicated Short-Range Communications (DSRC) as the primary mechanism for vehicle safety applications. DSRC is a two-way, short- to medium-range wireless communications mechanism that permits very high levels of data transmission critical in communications-based active safety applications. In 1999, the Federal Communications Commission allocated 75 megahertz of spectrum in the 5.9 gigahertz band for use by ITS vehicle safety and mobility applications.³⁸ Several manufacturers are actively developing and testing vehicle communication devices and CV applications, while others are developing vehicle-to-everything equipment that uses other forms of wireless communications, including WiFi. General Motors was the first to commit to integrating DSRC-based technology into its newer

vehicles.³⁹ Ford's Chief Executive Officer also has declared that all Ford vehicles, beginning with model year 2019, will be equipped with CV2X technology, allowing the cars to communicate with each other and to other devices.⁴⁰

In 2016, the National Highway Traffic Safety Administration issued a Notice of Proposed Rulemaking on V2V communications technology for new light vehicles, which is a major step toward mandating V2V communication systems in vehicles. However, CV infrastructure is not a part of the federal rulemaking, which means that state, regional, and local governments would need to invest and deploy roadside equipment and applications that would make vehicle-to-infrastructure (V2I) communications possible.

Thus far, public funding has been driving CV deployment of DSRC.⁴¹ Several pilot projects have been federally funded through the Connected Vehicles Pilot Deployment Program. In 2016, the U.S. DOT awarded \$45 million to initiate a Design/Build/Test phase of the Connected Vehicle Pilot Deployment Program in three sites: Wyoming, New York City, and Tampa. The Wyoming Department of Transportation's Interstate 80 CV pilot uses V2I and V2V connectivity to send alerts and dynamic traffic guidance to 400 equipped trucks along a busy freight corridor. New York City's Department of Transportation uses V2V and V2I CV technologies to communicate with bus fleets, taxis, delivery trucks, and city vehicles to send out speed warnings and reduce fatalities in high-crash intersections. Tampa's pilot project focuses on using V2V and V2I to improve safety and traffic conditions in Downtown Tampa.⁴²

Vehicle Technology Opportunities and Challenges

Electric vehicle infrastructure is not pacing with demand: More public infrastructure to support PEVs is needed in the near term. To underscore the magnitude, analysts estimate the need for 125,000 to 220,000 publicly accessible PEV charging ports in California by 2020, whereas currently about 12,000 are available. AVs will likely be electric, creating demand for wireless or inductive vehicle-charging infrastructure in the long term.⁴³

Hydrogen powered vehicles will enter the San Diego market: Auto manufacturers will not sell their FCEVs in a metro-area until two to three hydrogen refueling stations are built. San Diego's first commercial hydrogen station opened in late 2016, and a second station is in development. Expect passenger vehicle sales to expand in the next few years and vehicle demonstrations for fuel cell electric trucks and buses to begin in the next decade.

AV and CV technology could improve safety and mobility: 90 percent of accidents are caused by human error. CV/AV technology will dramatically decrease this number, increase roadway capacity, and increase mobility for low-mobility populations. CV2X technology enhances the benefits of autonomous driving by enabling communication across modes and across the transportation network.

AVs could increase VMT and urban sprawl without policy intervention: Policy analysts warn, however, that the ease of travel anticipated with AVs could induce unprecedented demand for vehicle trips and increased VMT. As vehicle fleets become increasingly autonomous, the issue may be exacerbated by the increased ability to use travel time for non-driving tasks, and consumers may be willing to travel longer distances as travel time becomes more productive. Vehicles traveling between trips without occupants is another risk without policy that encourages higher occupancy.

Shared AV fleet models are on the horizon: Interrelationships exist across ZEVs, MaaS, and AVs, as several automakers have stated their intention to produce electric AVs and have partnered with ridehailing companies to introduce these vehicles into their fleets.

Decrease in parking, ticketing, and gas tax revenue: Public agencies may need to substitute and/or complement traditional revenue sources with use fees. The recently completed California Road Charge Pilot Program demonstrated the viability of a road charge model.

The emergence of electric vehicles, AVs, and CVs will impact vehicle form creating opportunities to rethink roadway design: Smaller, lighter vehicles that can travel closer together create opportunities for highways to handle more vehicles within existing rights-of-way. On local roadways, opportunities include retrofitting roads to accommodate neighborhood electric vehicles and reallocating space so that lanes no longer needed for moving or storing cars can be used for other purposes and modes.

AVs may require changes to infrastructure: AVs rely on clear and consistent pavement delineation and traffic control devices, as well as maintenance in a state of good repair, putting pressure on local and state government to invest in necessary improvements and ongoing maintenance.

Smart Cities and Transportation Systems

Smart Cities are connected cities that use ICT to enhance the quality and performance of public services, such as energy and transportation, in order to reduce resource consumption and increase responsiveness and overall efficiency of operations (Figure 17). The use of technology itself does not make a city smart – rather, it is how the city uses data to improve planning, investment, and operational decisions and to engage more directly with the public. For example, mobile applications can allow citizens to report issues to local agencies for quick response. Sensors on transit vehicles can monitor where vehicles are and when maintenance is required. Real-time data can improve transit trip planning and lead to increases in customer satisfaction. Data collected from sensors also can be used to improve traffic monitoring and help to optimize traffic flows to prevent roadways from becoming too congested. Smart Intersections combine advances in ICT to increase capacity, improve safety, and reduce fuel consumption and emissions. Strategies can include corridor signal timing coordination, predictive/adaptive arterial signal timing, and multi-modal intelligent traffic signal systems (Figure 18).

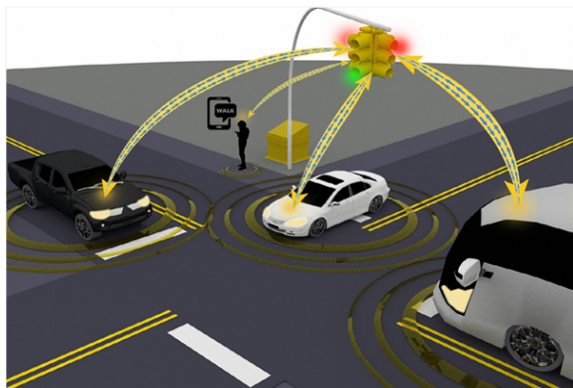


Figure. 17
Source: Volpe



Source: Bicycle Dutch



Figure 18. Make-up of a Smart City, Hitachi

In December 2015, the U.S. DOT issued a “Smart City Challenge” that asked mid-sized cities to develop ideas for an integrated transportation system that would use data, applications, and technology to more effectively and efficiently move people and goods while reducing costs. Seven finalists were selected to work in partnership with the federal government and the private sector to develop and implement Smart City demonstration projects using emerging transportation technologies to address their most pressing transportation problems.⁴⁴

Beyond the Smart Cities Challenge, local jurisdictions are beginning to recognize the need for a strategy, and are rethinking traditional planning efforts to better account for the impact of technology. Cities also are experimenting with different Smart City concepts through pilot projects and demonstrations that can help guide planning and policy development. For example, the City of Chula Vista recently has developed a Smart City Strategic Action Plan. This, combined with its federal designation as an Autonomous Vehicle Proving Ground in partnership with SANDAG and Caltrans, positions the city as a living laboratory to confirm that technology works and provides a public benefit.

Transportation System Management and Operations

At the state and regional level, the concept of Transportation System Management and Operations (TSMO) is becoming the focus of transportation planning. For many decades, the development and operation of transportation systems has been considered in terms of physical infrastructure. The solution to congestion and capacity issues has been to expand or build new facilities. This is not likely the optimal strategy for the future, as transportation financing becomes more constrained, and as technological infrastructure and Big Data are better facilitating new approaches to address capacity issues. TSMO is a regional application of the Smart Cities concept, and applies technological solutions to roadway infrastructure to better plan, operate, and maintain the system. TSMO uses IoT and data analytics to improve performance and manage demand for the overall transportation system. TSMO incorporates both transportation system management and TDM solutions to dynamically influence the entire trip chain, from mode choice to route choice – even the cost of the trip and parking (Figure 19).

Active Demand Management	Active Traffic Management	Active Parking Management
Dynamic Ridesharing	Dynamic Lane Use Control	Dynamically Priced Parking
On-Demand Transit	Dynamic Speed Limits	Dynamic Parking Reservation
Dynamic Pricing	Queue Warning	Dynamic Way-Finding
Predictive Traveler Information	Adaptive Ramp Metering	Dynamic Parking Capacity

Figure 19. TSMO uses technology to manage the entire trip process (Source: FHWA)

Although new technology and increased data collection offer opportunities for safer and more efficient cities and transportation systems, it also creates new types of vulnerabilities. In 2015, DHL and Cisco Systems estimated there to be 15 billion connected objects globally. By 2020, it is anticipated that more than 50 billion Internet-connected devices will be installed.⁴⁵ As more data is collected and shared, significant efforts and resources will be required to address data security concerns raised by reliance on increasingly complex and interdependent systems.⁴⁶

Smart Cities and Transportation Systems Challenges and Opportunities

Increased use of Big Data for planning: Companies such as Google and Amazon are increasingly integrating Big Data into their businesses' planning and marketing processes, allowing them to better market goods and services. Public agencies also have integrated Big Data into their management systems, in particular for preventive maintenance, incident detection, and engagement.⁴⁷

Limited funding for major capital projects: Due to limited funding for new infrastructure and a growing trend toward increasing sustainability, agencies are focusing on maximizing their existing investments and preserving the system through the use of technology and powerful data analytic tools. Investing in smart transportation systems may be a more effective, adaptable, and sustainable investment approach than capacity-increasing projects.

New role for public agencies in the collection and distribution of data: The private market has and is expected to continue capturing and aggregating data from smartphones and telematics. Agencies are reconsidering their role as providers of transportation information and are taking on new roles as data distributors and/or procurers,⁴⁸ and as such, workforce development and capacity building are challenges that local agencies will need to address to yield the full benefits offered by advanced technology.

Increased connectivity and data sharing: The population of the U.S. sends out 2.6 million gigabytes of Internet data per minute, and 90 percent of the data in the world was created in the last two years.⁴⁹ Data-as-a-service companies provide services to customers in exchange for their customer's data, and customers have and are expected to continue to agree to this exchange.

Cybersecurity concerns: Increased connectivity and data-sharing raises concerns about the security of private information and increases the risk of cybersecurity threats.

Continued need for prioritization of smart infrastructure to achieve congestion and safety goals: Smart infrastructure can route cars off of a freeway when there is an accident, or can implement congestion pricing or other pricing mechanisms that will be crucial to mitigating congestion externalities from AVs, additional freight delivery, and ridehailing services.

Shift to network thinking demands inter-agency coordination: Nationally, including within the San Diego region, the trend for all tools and systems is to shift from concentrating on isolated roadway systems to focusing on multi-modal performance management from a full transportation network perspective. This requires coordination and cooperation with agency partners.

Regional consistency and collaboration is critical to the success of Smart Cities and Transportation: Cooperation across systems and among managers and operators results in services that are seamless compared to the stove-piped systems of today, enhancing the effectiveness across the region, and the user experience and sharing resources and capabilities that heretofore were not possible.

Policy Considerations

While there is a great deal of uncertainty about how these technology trends will evolve, there is no doubt that they have the potential to provide great benefits for the San Diego region. However, there also are potential risks without proactive planning, policy interventions, and investment decisions that can guide the integration of technology and new mobility services toward an equitable and sustainable transportation future. The scenarios that follow frame the conversation by describing two possible approaches and their respective outcomes, followed by policy and investment considerations that can prepare the region to take advantage of the opportunities and minimize the unintended consequences of a passive approach.

Seizing the Opportunity	A Passive Approach
Shared mobility services are integrated with public transit, moving more people with fewer cars. Mobility hubs are thriving and more people choose not to drive or own a car because shared mobility services, including public transit, are convenient, affordable, and comfortable. Vehicle automation allows commuters to make productive use of time that otherwise would have been spent driving.	Roadways become more congested due to an increase in private automobile trips. Automated vehicles are not connected or shared, increasing VMT with zero-occupancy vehicles on roadways between rides.
Vehicles are electric, autonomous, and connected, significantly improving safety while reducing congestion and GHG emissions. There is adequate public charging infrastructure to support shared electric fleets.	The lack of charging infrastructure prohibits the rapid expansion of electric vehicles, and inefficient AV fleets run on fossil fuels, increasing GHG emissions.
The region leverages the trend toward IoT and maximizes existing capital investments through implementation of Smart Cities, TSMO, and CV infrastructure, potentially reducing the need in the long term for capacity-increasing capital projects.	Shared mobility services are not well-integrated and compete with public transit; public transit is slow to adapt to technology trends and societal needs. This impacts ridership and fare box revenues, resulting in service reductions and difficulty supporting the transportation needs of low-mobility populations. Shared mobility services struggle to succeed and become less affordable, less accessible, and less desirable.

Seizing the Opportunity	A Passive Approach
<p>Telecommunications effectively reduces vehicle travel for work and personal trips. Although online shopping has increased, the delivery of goods and services is optimized in a connected and autonomous environment.</p> <p>Autonomous fleets of shared mobility services enhance mobility for all, including seniors, low-income individuals, the disabled, and those without access to a privately-owned vehicle.</p> <p>Complete streets projects become easier to implement with less right-of-way needed for cars. Roads are safer for pedestrians and cyclists, and shared mobility services have designated pick-up and drop-off zones. Requiring less space for parking allows for more opportunities for productive uses of space, such as housing.</p>	<p>Complete streets projects become more difficult to implement. Ridehailing vehicles double-park, blocking cyclists, endangering pedestrians, and creating bottlenecks. More space is required to accommodate cars and less space is available for housing, commercial uses, and public spaces.</p> <p>The increase in online retail activity continues to generate inefficient goods movement activity, leading to freight-related congestion that impacts major corridors and local streets and roads.</p>
<p>Smart Cities infrastructure is widely deployed. Public services are data-driven, enhancing communities and enabling mobility to be consumed as a service through MaaS platforms that facilitate easy trip-planning, routing, and payment. Data generated from the transportation system and mobility services significantly improve transportation planning and decision-making.</p>	<p>Data infrastructure and management capabilities do not provide for connectivity between cars, infrastructure, and information systems; public services are not adapted. The lack of data-sharing hinders mobility hub effectiveness and limits data-driven planning, decision-making, and service delivery.</p>

The San Diego region has been a leader in piloting and deploying innovative transportation services and infrastructure that leverage technology to improve the management of and to reduce the demand on the system. By continuing this legacy of action, the region can prepare for a transformative future where everyone benefits from improved mobility choices. The following policy and investment considerations are intended to help guide discussion by policymakers as they take steps toward shaping the future of mobility for the region.

Policy and Investment Considerations

Develop staff expertise, tools, and resources for data governance and management. Standardize data-sharing processes and promote open data policies across the region. Design and build data infrastructure so that new services can more easily integrate.

Develop a coordinated Smart Cities roadmap for the region that identifies high-priority transportation applications and accelerates their deployment through an implementation strategy that leverages existing regional services and planned infrastructure investments.

Invest in Smart Cities demonstration projects that enhance data management and sharing capabilities, and operational coordination across jurisdictional boundaries; consider new service delivery models that make more effective use of public resources, and that enable cities to adapt to their unique circumstances. Develop and prioritize projects that promote coordination and integration with traffic system management and operations and that enhance service delivery.

Invest in mobility hub demonstration projects and supportive policies that improve access for all, ensure equity, and promote safety across modes. Encourage and prioritize projects (e.g., transportation system management and demand management, pedestrian, bicycle, and smart growth efforts) that support Mobility Hub implementation to promote integration with public transit and seamlessly connect people between shared modes.

Build upon current ITS strategic planning efforts and the San Diego Autonomous Vehicle Proving Ground to test and validate advanced traffic signal management systems, including accelerating the deployment of CV applications for fleet operations including public transit, emergency response, and freight operations.

Consider pricing mechanisms to increase system efficiency; support a shift toward shared modes of travel and thus reduce drive-alone trips and VMT.

Leverage the San Diego Regional Proving Ground as a test-bed for innovative pilots and public -private partnerships that support shared, electric, connected, and autonomous mobility, and Smart Cities initiatives. Foster innovation and mobility partnerships that provide the greatest public benefit.

Enhance regional modeling tools to better account for the impact of technology on transportation demand, congestion, system management, and access.

Develop technical resources and tools that support local government agencies with planning and preparing for technology and new mobility services. Encourage information sharing, coordination, and capacity building on Smart Cities initiatives through existing regional advisory bodies such as the San Diego Regional Engineers Council. Revisit and update existing toolboxes, policies, design guidelines, and resources, such as the Regional Complete Streets Policy and the Regional Parking Management Toolbox, to better integrate technology with new mobility services. Develop a Regional Smart Cities (Deployment) Toolbox with a focus on transportation infrastructure and applications.

Encourage unsolicited proposals and respond with procurements that incentivize the provision of equitable and accessible mobility services.

Look Ahead

As described in the previous sections, advances in ICT are revolutionizing how transportation is provided and managed. Although much ground was covered in this paper, other technologies on the horizon could dramatically impact both personal travel and goods movement in the future. While there is not sufficient data or research available on these technologies today, this section was developed to capture emerging technologies that could be considered in future updates of San Diego Forward: The Regional Plan.

Hyperloop

Hyperloop is a tube through which a pod could travel at very high speeds using electromagnets and vacuum technology. Routes have been proposed across the globe, including one between San Diego and Los Angeles that would take less than 13 minutes. A number of start-ups are working on the development of the Hyperloop and are optimistic about its deployment, although skeptics think it is unsafe and cost-prohibitive.⁵⁰

3-D Printing

3-D printing is the process of making a solid object from a digital file autonomously. The logistics industry is set to be disrupted by this technology, which could reverse globalization trends and reduce the need for production far from distribution.

Augmented Reality

Potential applications of Augmented Reality (AR) in the transportation sector are numerous. AR currently is being used in connected and automated vehicle testing facilities, allowing for more specific scenario testing at a reduced cost. AR applications enhance the ability to provide education and healthcare from a remote location, and could be used as a travel-demand mitigation tool by reducing the need for travel to physical locations. Commercial applications in the retail industry also are on the horizon, allowing marketers to provide customers with a better understanding of their product before purchase.

Delivery Robots

Courier network services, such as GrubHub, Caviar, and Postmates, are researching ways to automate delivery through sidewalk robots. Companies such as Starship and Marble have developed prototypes, and some have been released on San Francisco streets, although they now are restricted to certain zones of the city.

Drones and Flying Cars

Drones are flying robots that use GPS and sensors to fly autonomously. While use-cases for drones vary widely, transportation and logistics companies, such as Amazon and Airbus, have taken interest in them as a way to transport goods. Airbus Helicopters is testing a drone parcel-delivery service on the campus of the National University of Singapore. While there are environmental gains from improved first/last mile and drayage delivery of goods, many question the appropriateness and safety of this delivery method.

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