San Diego
FORWARD

EMERGING TECHNOLOGIES
WHITE PAPER

SEPTEMBER 2023

SANDAG

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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 20121, 97% of Americans owned a cell phone, and the share of Americans that own smartphones experienced an increase of 81% in less than 10 years[1] This rapid adoption of technology has transformed transportation over the last decade enabling the proliferation of on-demand mobility services like Uber, Lyft, bike and scootershare, and fueling growth in e-commerce and the delivery of goods.

Technology Adoption in the U.S.

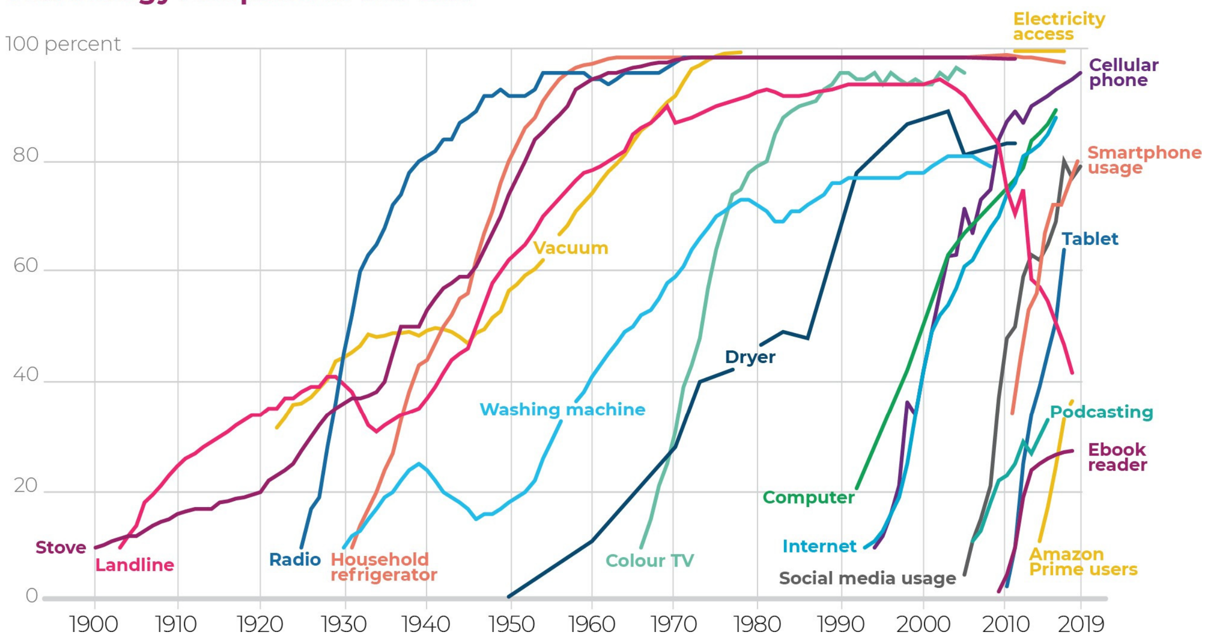


Figure 1: Technology adoption has rapidly increased over the last several decades (Sources: Comin and Hobijn (2004) and others OurWorldInData.org/technology-adoption/)

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 policy considerations that will enable the region to harness the benefits and reduce negative aspects of these trends. The SANDAG 5 Big Moves and the Vision for the 2025 Regional Plan capitalizes on technology to advance a transportation future that is fast, fair, and clean. However, without forward thinking planning and policy interventions, these technologies could move the region away from its objectives.

Although all Big Moves coexist and depend on each other to advance the future of transportation in San Diego, the Next Operating System (Next OS) will be the key move for Emerging Technologies. Next OS is a regional digital platform that will use data to make the transportation system smart and allow MaaS to become a reality. The Next OS is not a single piece of technology, but rather a set of multiple technologies that are connected to provide greater value to the traveling public as well as transportation operators, planners, and policymakers. New technologies provide unique opportunities to create data-driven feedback loops that will continually better transportation offerings. The holistic analysis of data that Next OS can provide is crucial for effective planning, agency collaboration, and performance monitoring will ultimately enhance a user-centric network that will utilize a wide variety of emerging technologies that will be seamlessly integrated.

This white paper contains two 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 (MaaS)

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 MaaS and Smart Cities, which both rely on better connectivity and "Big Data." Shared vehicle fleets that are electric, connected, and automated offer significant opportunities for mobility, safety, and sustainability. Smart Cities and intelligent transportation systems (ITS) provide the connected infrastructure, which ultimately supports 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 goals. 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. It is important to understand technology development and commercialization timeline so that planning and policy can keep pace. The appendix of this white paper includes a technology maturity matrix based on the best information available today.

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 have changed travel demand patterns. On one hand, ICT is reducing certain types of trips by enabling 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 e-commerce, which may reduce some types of shopping related trips, but induces other types of trips – mainly freight and delivery. According to the U.S. Census Bureau, e-commerce sales accounted for 15% of all sales in 2023, up 1% from 2022[2]. 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%[3].

New models for the delivery of goods are emerging. For example, Walmart partnered with Instacart for delivery, and Amazon Flex hires independent contractors to deliver packages in their personal vehicles[4]. Similarly, online food delivery is also contributing to changes in travel demand. Third-party delivery platforms like GrubHub 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.

ICT has also provided a platform for the sharing economy to flourish, with innovative companies such as Airbnb 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 being rapidly adopted in the market. In cities across the world, it is possible to rent shared cars, shared bikes, shared scooters, or shared rides 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 attain personal mobility. The degree to which sharing a ride will trump individual automobile ownership awaits to be seen, but this paper contemplates the trend toward a future where mobility is used 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, streetlights, and traffic signals, which 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 present significant opportunities for transportation. Data and connectivity enable Smart Cities and ITS that offer a host of benefits such as reliability, operational efficiency, cost effectiveness, safety, and improved asset-management and planning, all of which are discussed in the "Smart Cities and Transportation Systems" section of this paper.

Mobility as a Service

Mobility as a Service (MaaS) enables a transition from the current paradigm, where vehicle ownership is all but required, to a new mobility paradigm, where people have access to an array of transportation services, and mobility can be purchased as needed[6] This new model would be competitive with the private automobile providing convenient options for all trip types without the cost and burden of car ownership. Proponents of MaaS imagine an ecosystem where public and private operators cooperate and where consumers have access to all options in a single application. Rather than having to locate, book, and pay for each mode of transportation separately, an integrated mobile application aggregates and coordinates data from all service providers so users can simply plan and book door-to-door trips based on real-time conditions and user preferences (e.g., time, convenience, cost) (Figure 2). While shared mobility is not a new concept (e.g., transit, carpool, vanpool), technology has allowed for an explosive growth and variance in business models, blurring the line between public and private transportation.

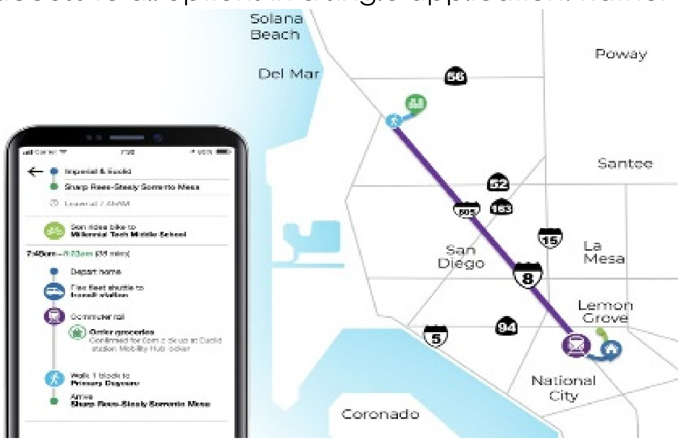


Figure 2: MaaS provides an integrated platform for trip planning and booking across models.

The SANDAG vision for the 2025 Regional Plan leverages advancements in technology and innovation to improve the efficiency and resiliency of the transportation system. A part of this new vision, SANDAG anticipates the deployment of Flexible Fleets which are on-demand, shared mobility services that provide a spectrum of mobility options and vehicles for all types of trips, reducing the need to own a car (Figure 3). Flexible Fleets provide a last-mile connection or fulfill a complete trip.

Micromobility
Small, low-speed vehicles like bikes, scooters, and other rideables

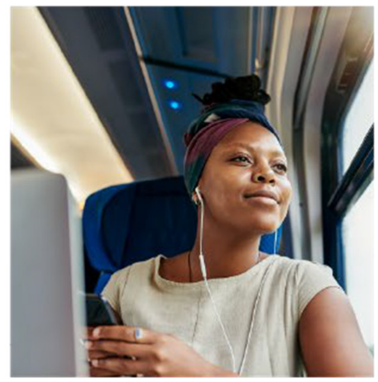
Ridehailing and carshare
On-demand rides that can be requested from a driver or as a short-term vehicle rental

Rideshare
Shared rides between passengers with similar origins and destinations

Microtransit
On-demand shuttle services that provide shared trips from door-to-door

Last mile delivery
Delivery of a range of goods using novel approaches like e-bikes, drones, and automated vehicles

Figure 3: Flexible Fleets



Public transit

Public transit, the original shared mobility service, is the backbone of MaaS. High-frequency transit continues to be the workhorse and 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. 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[7].

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 in real-time. This information can be utilized to better predict how many transit vehicles, or the size of transit vehicle needed on given routes at different times of the day to meet demand. 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 4). The post-COVID-19 environment is proving the importance of the flexibility that technology and new service models provide.

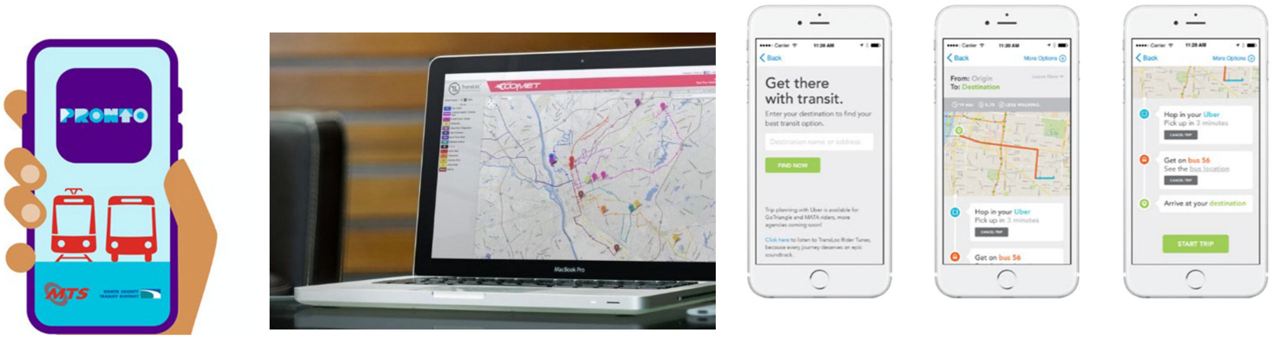


Figure 4: Technology improves transit operations and the customer experience. (Sources: TransLoc, San Diego Metropolitan Transit System)

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 is not warranted or is too costly to operate (Figure 5). Several transit operators are exploring the integration of on-demand transit services, or microtransit, to help serve areas that are hard to reach through traditional fixed-route services and reach new markets of riders.

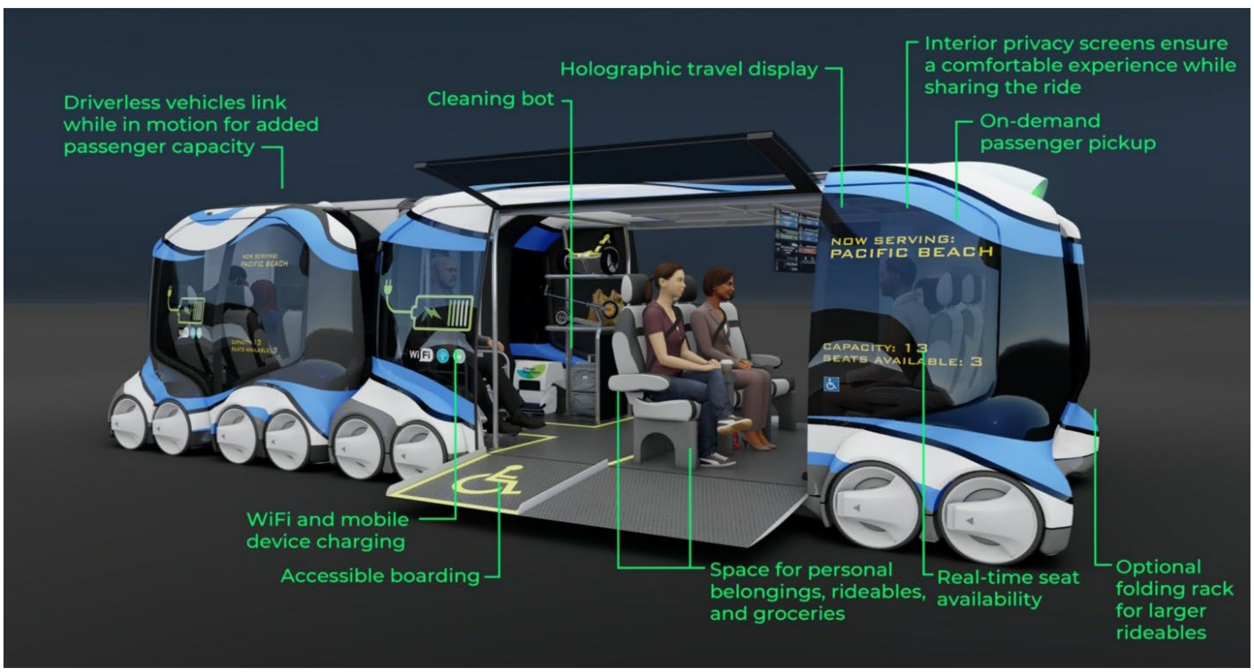


Figure 5: Smaller, right-sized vehicles will integrate with bus and rail service to provide on-demand trips.





Micromobility

Micromobility services utilize small, low-speed vehicles to provide a healthy and sustainable alternative to driving. Micromobility devices can be personally owned or part of a shared fleet and can include bikes, scooters, and other rideables. Micromobility services are generally best suited for short trips around a community. Although, electric-operated services make it much easier to travel longer distances and tackle challenging terrain. The most commonly used shared micromobility services are bikeshare and scootershare. The National Association of City Transportation Officials (NACTO) estimates that people took 112 million trips on shared bikes and scooters in 2021, an 18% increase above pre-pandemic levels (Figure 6)[8].

Shared moped scooters have been operating in Europe for years, companies like Scoot and Revel now offer on-demand access to shared electric mopeds in some U.S. cities. Monthly subscription-based options like Zebra provide the reliability of a personally owned moped without any maintenance hassle. In the future, we anticipate micromobility services may evolve to include autonomous single-user pods, hoverboards, and more.

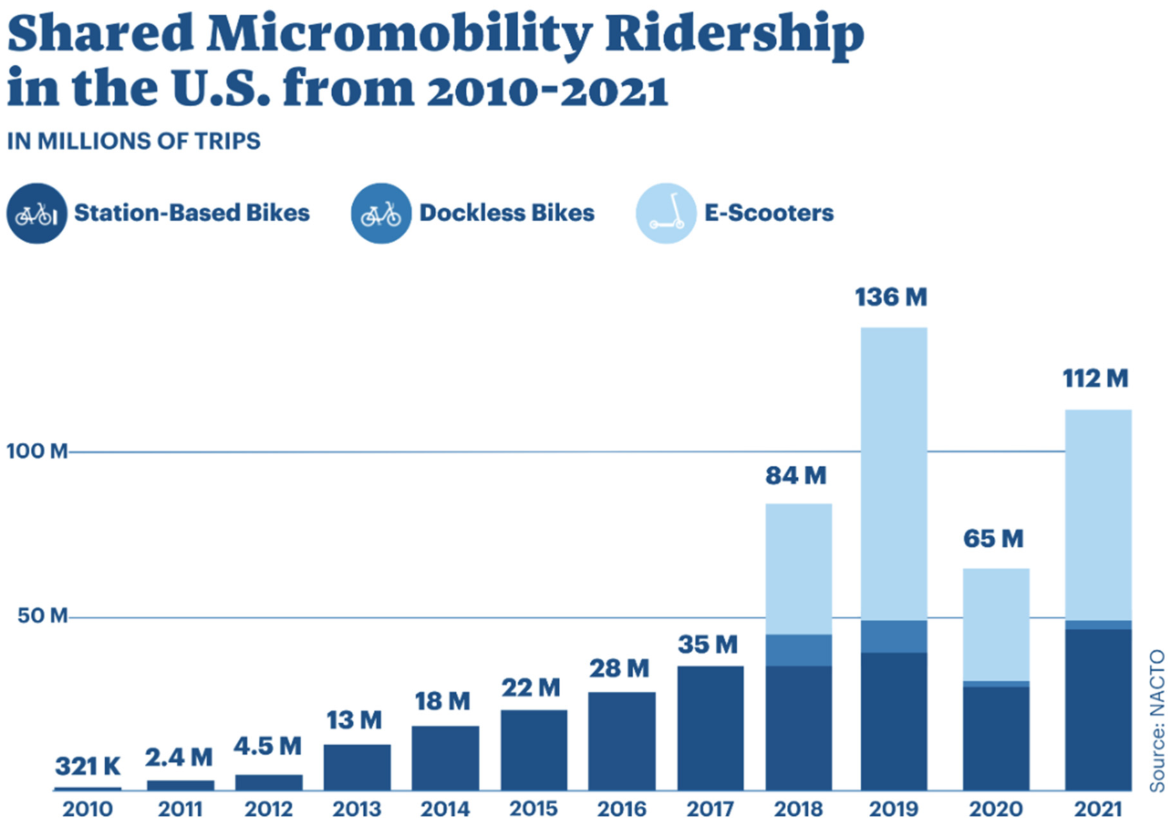


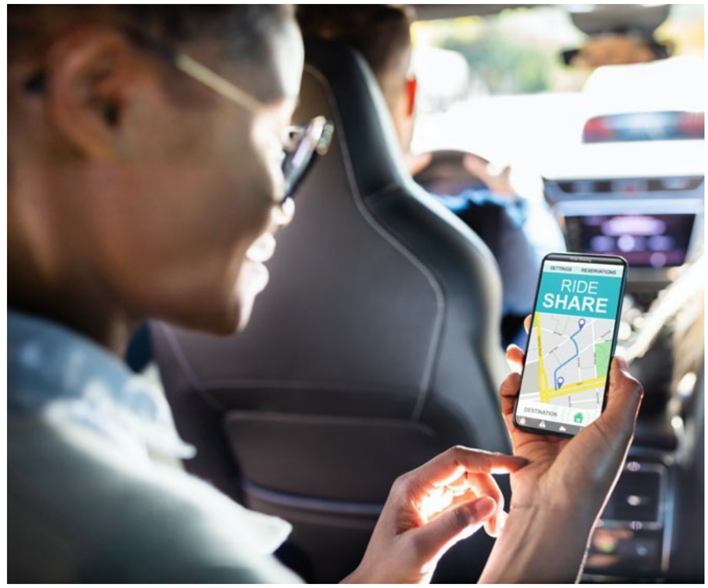
Figure 6: Shared micromobility ridership growth from 2010 – 2019 (Source: NACTO[9])

Personally Owned Electric Bikes and Rideables

While bikeshare companies, such as JUMP, introduced San Diego and other U.S. cities to electric-assist cycling, there has been a remarkable increase in personally owned electric bike (e-bike) activity during the COVID-19 pandemic as people have sought ways to increase the cycling "reach" of recreational trips. E-bike sales boomed in 2020, with manufacturers struggling to keep up with demand. E-bike owners have been found to bike more frequently and for longer distances than conventional cyclists[10]. A scoping review of recent research conducted between 2017 and 2019 across 42 studies examining the impact of e-bike use on other travel modes revealed that the proportion of car trips substituted after people bought e-bikes ranged from 20% to as high as 86%[11] E-bike adoption can contribute at some level to reducing vehicle miles traveled (VMT) and greenhouse gas (GHG) emissions while making physical activity much more approachable, particularly to seniors or health patients needing exercise as prescribed as a necessary part of disease recovery.

Electric rideables, also known as personal transporters, offer people a convenient way to travel locally at speeds of up to 16 mph. Vehicle options include electric skateboards, one-wheeled boards, and self-balancing unicycles. The compact nature of the devices makes them easier to carry aboard transit or stow away at home, work, or school. However, dedicated infrastructure is needed to support safe operations of new electrified modes.

Ridehail



Ridehail services allow users to request a ride in real-time using a mobile application. The service links passengers with available drivers based on trip origin and destination, identifying the quickest route, and facilitating trip payment.

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 7). In the San Diego region, passengers can hail discounted shared rides (commonly referred to as "pooled" rides), solo rides, luxury vehicle rides, or a shuttle style service where the user walks to a particular corner and is dropped at a spot nearby their destination. Uber and Lyft have also introduced monthly subscription services in some markets, which function similarly to monthly transit passes.

In less than a decade, Uber established operations in 10,000 cities globally providing over 18.7 million rides per day in 2019 However, to date, there's insufficient evidence to indicate how widely available and equitable ridehailing services really are. To better understand the impact of TNCs on California cities, SANDAG partnered with the Southern California Association of Governments (SCAG), Metropolitan Transportation Commission (MTC), and San Francisco County Transportation Authority (SFCTA) to conduct a travel survey of TNC users in 2019. The study found that TNC trips make up an average of 1% of all trips occurring in the three regions studied. In the San Diego region, almost 70% of users reported being white indicating less adoption of TNC users by minority groups, particularly those of Black and Asian ethnicity. However, higher TNC use was reported by low-income users in the San Diego region suggesting that ridehailing services are filling a gap in the transportation system.

Ridehail

Ridehailing has expanded rapidly within the U.S. — Uber and Lyft are now available in over 900 cities compared to 37 in 2012.

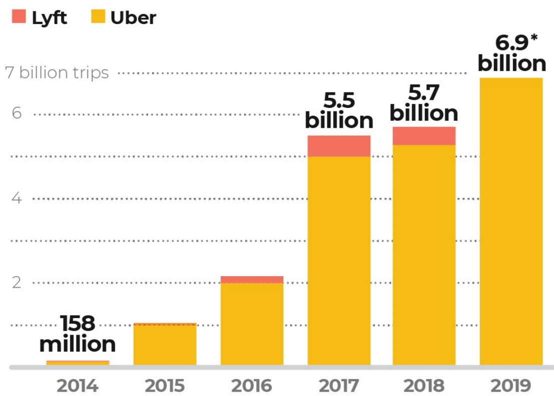
UBER AND LYFT COMBINED

103 million global users
2019 estimates

4.3 billion miles in California
as of 2018

Rapid growth in rides

For every trip taken in 2014, about 44 trips were taken in 2019



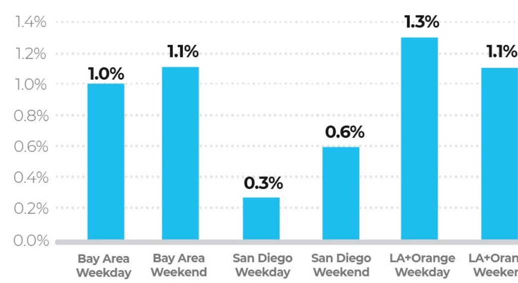
** Trip data for Lyft was not available in 2019*

Based on global user trends, ridehailing is projected to increase from **35.6 million users** in 2016 to **72.4 million users** in 2022

Ridehailing in California

Ridehailing is widely available in California. The 2019 Transportation Study found that ridehailing trips account for approximately 1% of all trips happening in the San Diego, Los Angeles, and Bay Area regions.

TNC Mode Share



Sources: Business of Apps, Business Insider, CA Air Resources Board, Curbed San Francisco, Forbes, GeekWire, Lyft, MacRumors, McKinsey & Company, Palo Alto Online, Statista, TechCrunch, Transportation Reliability Sustainability Center, Uber

Figure 7: *On-demand ridesharing is growing rapidly in the United States*

Carshare

ZipCar, a popular Carshare service.

Carshare provides access to vehicles as short-term rentals 24 hours a day, seven days a week. Vehicles can be found within a specified service area, at transit stations, or other locations, and are accessible through a smartphone app or the provider's website. Rental rates generally include insurance, parking, and fuel or vehicle charging costs. Different carshare models exist. 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 allows users to pick up a vehicle from one designated parking location and return it to another designated carshare parking spot. Depending on a city's carshare regulations, parking locations may be on or off-street (e.g., Zipcar, Gig). Free-floating carshare services allow members to pick up and park a vehicle anywhere within a designated service area. Lastly, peer-to-peer carshare services such as 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. In San Diego, Daimler shuttered their car2Go carsharing service and only roundtrip and peer-to-peer carshare services are available in the region via Zipcar, Getaround, and Turo.

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[12] Community CarShare in Sacramento is a free, membership-based service that residents can use to run errands, travel to appointments, and take local trips. Residents can use the zero-emission vehicles free of charge for up to 3 hours per day.

Globally, the carsharing market is much more popular in Asia and Europe although the market in the United States has grown steadily since 2006 with well over 5.6 million carshare members as of July 2023[13]. Most recently, several carshare providers have faced increasing competition from other shared modes like on-demand rideshare and shared micromobility, which has resulted in several companies scaling back their operations in major cities throughout the United States, favoring markets abroad. 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 on its fleet of shared vehicles for weekly access between 5 a.m. Monday and 7 p.m. Friday, which come with free maintenance, gas, and parking.

Carshare

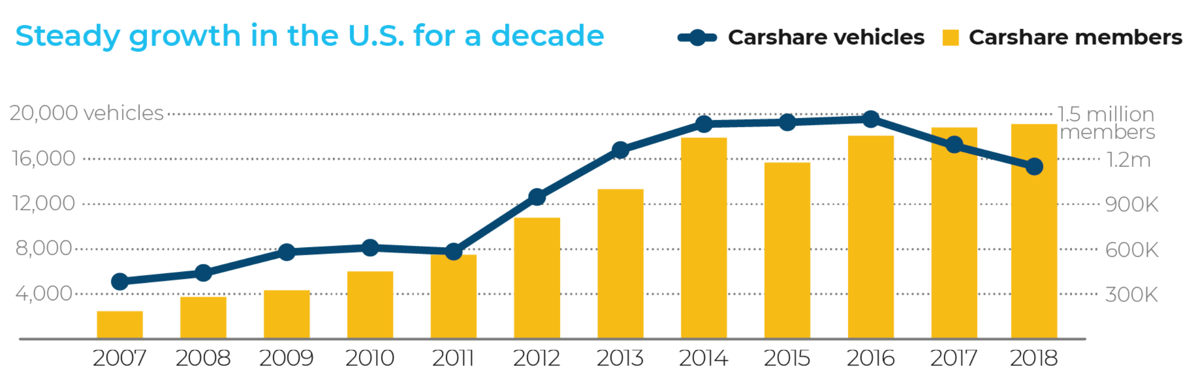
In 2006, more than 11,000 vehicles were shared worldwide by nearly 350,000 members. By 2018, carsharing was operating in 47 countries, 6 continents with approximately 32 million members.

IN THE U.S.
as of January 2018

15,224
available carshare vehicles

1.44 million
total carshare members

Steady growth in the U.S. for a decade



1 carshare vehicle replaces
up to 13 private vehicles

Sources: Boston Consulting Group, Innovative Mobility Carsharing Outlook, Transportation Sustainability Research Center

Rideshare

Rideshare services link drivers and passengers that are traveling in a similar direction and can share the ride in a vehicle. Traditional rideshare programs include carpool and vanpool services that rely on acquaintance-based or organization- based ridematching. These types of services focus on ridesharing among commuters to reduce congestion during peak travel hours and reduce parking demands at employer sites.

In FY 2019, SANDAG's Regional Vanpool Program contributed to VMT reduction of approximately 93 million miles.

Figure 8: Carshare growth is helping to replace personal vehicle use.

In recent years, technology has enabled the use of app-enabled rideshare services like dynamic carpooling and pooled ridehailing or TNC services. This technology enables passengers to conveniently and readily match with a driver headed to a similar destination at any time of the day, helping to expand the ridesharing marking beyond traditional commute trips. **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.

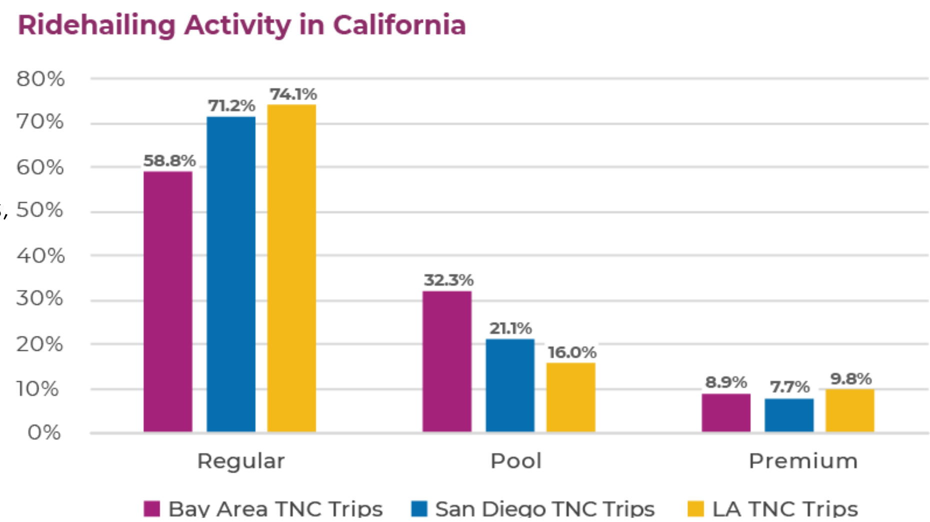


Figure 9: *2019 Pooled trips account for a small portion of TNC trips ridehailing trends in the San Diego, Bay Area, and Los Angeles*

In 2017, TNC companies Uber and Lyft started providing shared rides, otherwise known as pooled ridehailing. **Pooled ridehailing** services, like uberPOOL and Lyft Shared, match multiple passengers with similar origins and destinations with the same driver. To incentivize pooled ridehailing, TNC services offer shared rides at discounted rate compared to the cost of a regular ridehailing trip. While recent research has indicated that ridehailing has led to increased congestion, VMT, and greenhouse gas emissions in major metropolitan areas, this form of ridehailing may lead to increased vehicle occupancies that may mitigate some of the negative impacts of ridehailing trips[14] The 2019 Transportation Study found that opportunities exist to increase the rideshare market in the San Diego region with just over 20% of all ridehailing trips taken using the pooled ridehailing option (Figure 9).

Microtransit

Concept Microtransit shuttle

One new mobility option that is being widely integrated into public transportation systems is 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 defined service area. This technology-enabled service allows users to reserve a ride ahead of time or on-demand and may be ideal for ex-urban and suburban settings where there is not sufficient demand for a fixed-route service. In communities across the globe, microtransit has successfully replaced underperforming transit routes with a convenient option that provides a high level of service to users.

Microtransit services vary in their business models and offer different solutions based on need. TransLoc, a subsidiary of Ford Mobility, offers on- demand technology software to optimize existing transit services to enhance vehicle routing; fleet management; and on-demand reservations. Via, on the other hand, is an example of a mobility service provider that directly partners with public agencies to plan and implement a turnkey on-demand solution within a community. Via partners with cities, organizations, and transit agencies to integrate their on-demand technology and directly operates a fleet of microtransit vehicles. This enables agencies that do not already have a fleet of existing vehicles to test and pilot on- demand pilots in their communities.

Carlsbad Connector was a microtransit pilot deployed by the City of Carlsbad, North County Transit District, and SANDAG to provide on- demand connections between Carlsbad-Palomar employment center and the COASTER rail service.

In August 2019, SANDAG partnered with the North County Transit District and the City of Carlsbad to pilot the first microtransit pilot of its kind in the region. The Carlsbad Connector offered an on-demand shuttle connection for commuters traveling between the Carlsbad Poinsettia COASTER station and the Carlsbad Palomar employment center. The pilot provided weekday shuttle service for commuters between August 2019 and July 2020. The pilot was placed on hold during the pandemic due to low ridership, but the service is expected to return in the future as employees return to work.

Today, there are more than 100 microtransit deployments across 35 states in America[15] In 2021, Arlington, Texas expanded its microtransit to city-wide service with 70 vehicles.

The City of Austin put forward the first transit ballot measure in the nation to specifically fund m icrotransit and expand its microtransit 15 neighborhoods.

A study by Frost & Sullivan predicts that microtransit shuttles will account for 50% of the global shared mobility market by 2030[16] Although much of this growth is focused on Europe and China, significant growth is predicted in the United States as well.

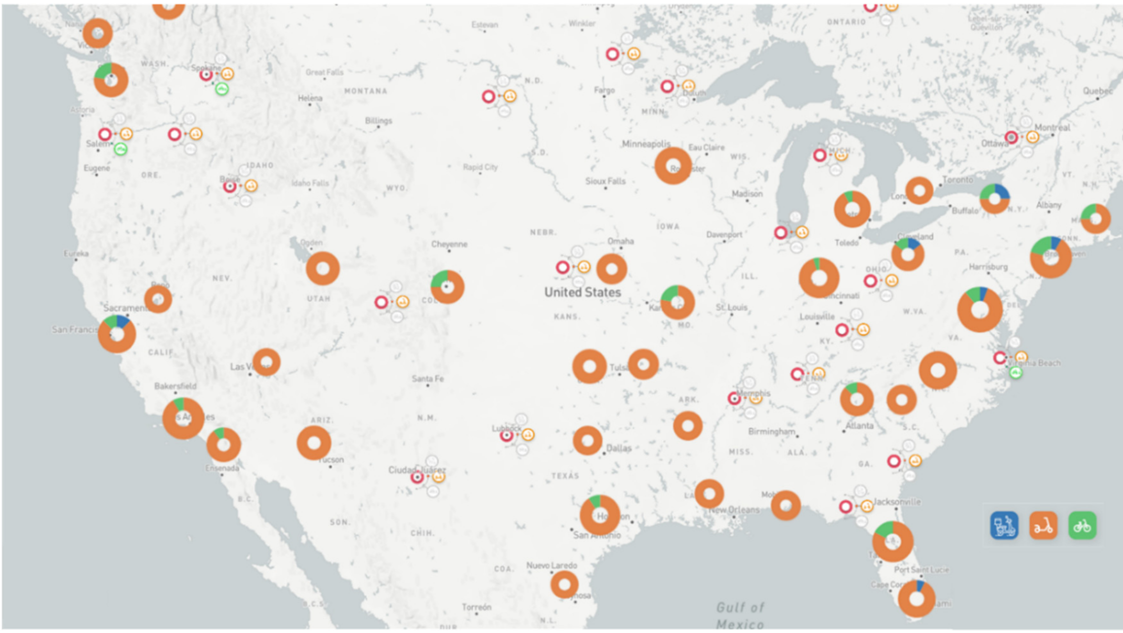
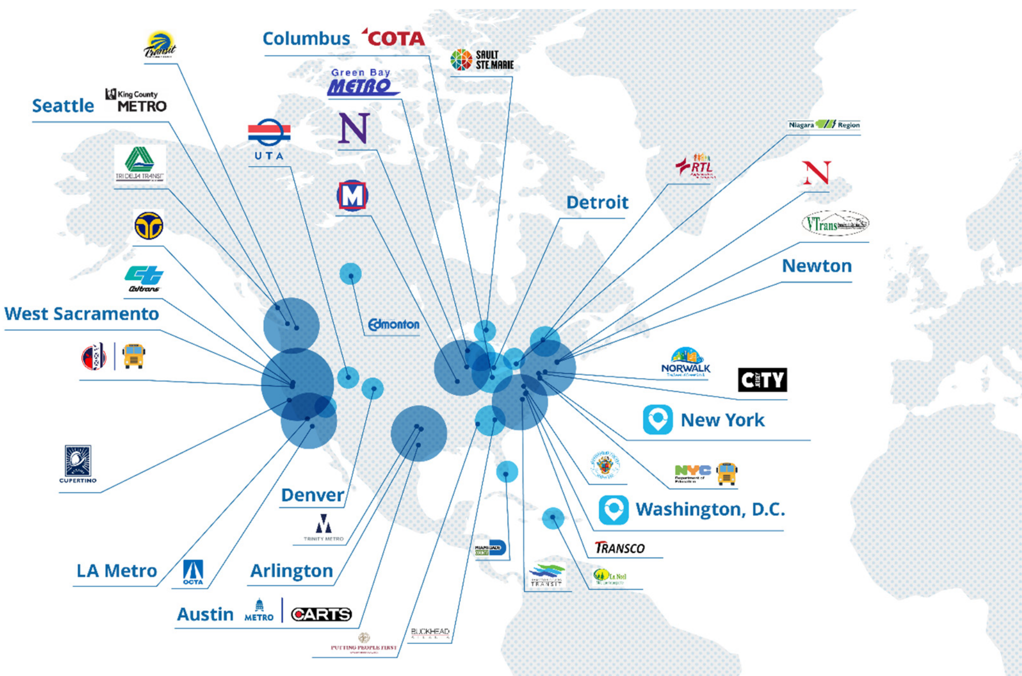
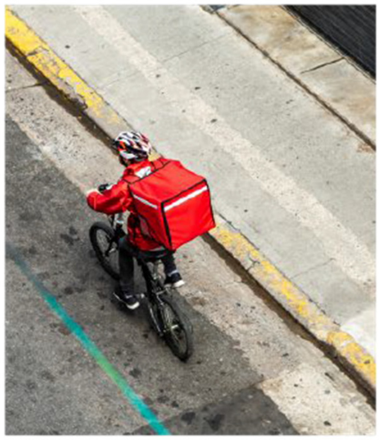


Figure 10: Microtransit (below[17]) comprises some of the shared mobility service pilots (above[18]) being deployed across the United States.





Neighborhood Electric Vehicles

Legislation was passed by the California Legislature (SB 1151) in 2018 to allow for small-scale shared Neighborhood Electric Vehicles (NEV) in San Diego County. This in turn has led a push by San Diego to implement these vehicles in various neighborhoods in the County including downtown San Diego, Pacific Beach, and Oceanside run by a company called Circuit. Some microtransit service providers are fulfilling short-distance trips within smaller service areas using six-passenger Polaris GEM neighborhood electric vehicles (NEVs) that can be hailed using a mobile app or by waving down a vehicle within the fleet's operating area. In 2019, the City of Oceanside partnered with Ford X to launch HOOT Rides, a NEV shuttle proof of concept. The all-electric shuttles served a three-mile service area around providing residents and visitors with an affordable and convenient connection to the nearby Oceanside Transit Center and community events such as the Sunset Market Street fair. The Free Ride Everywhere Downtown (FRED) has been operated by Circuit in San Diego since 2016. FRED is typically used to fulfill trips under two miles and reported serving over 150,000 riders per year in 2019. Another service operated by Circuit is the "Beach Bug" which began operations in the summer of 2023 serving Pacific Beach with a connection to the Balboa Avenue Transit Center. The Beach Bug is free during the pilot period and will continue to be free for rides to or from the Balboa Avenue Transit Center, while other users can expect to pay 2.50$[19]. A recent case study reported that nearly one in three respondents used FRED to connect to public transit[20]. Most recently, in September 2023, Circuit began operating a NEV named FRANC (Free Ride Around National City) in National City serving locations including Kimball Park, the Arts Center, and other locations[21].

The NEVs run on city streets and complete trips of up to three miles in San Diego. Although Neighborhood Electric Vehicles are a key part of Flexible Fleets, as they offer an alternative that fits between micromobility devices, public transportation, and ride-hailing services, NEV electric vehicles stand to benefit in tandem with electric vehicle technology and increasing availability of charging infrastructure. Furthermore, pilot programs that popularize their use may increase sales to private buyers for personal use, which reduces greenhouse gas emissions.

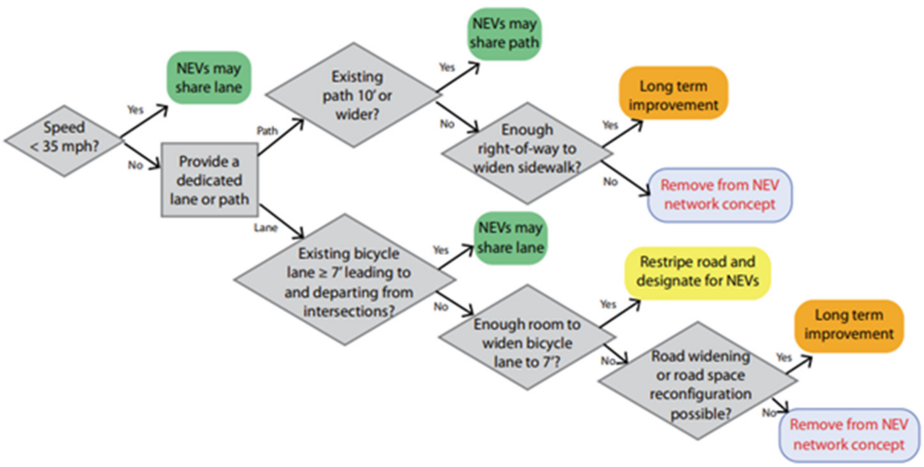


Figure 11: Workflow for Generalized NEV Plan Network Development Process.

(Source: Coachella Valley Council of Governments[22])

Neighborhood Electric Vehicles also present a challenge as there is not much information on how to incorporate this mode of transportation into existing and future infrastructure. These vehicles are larger than bicycles, but slower than cars, NEVs occupy a unique position on the road. NEVs are street legal, however the California Vehicle Code Section 21250-21266 limits them to roads with speeds less than 35 mph and they are prohibited from crossing state highways, except where adequate facilities exist, which may be a barrier for adoption as this creates uncertainty where individuals can and cannot operate NEVs. Next OS could be used to gather, store, and analyze data to creating a routing mechanism specifically for NEV users and planners that would promote safe, effective, and sustainable routes for public agency and private user NEVs to utilize.

Last Mile Delivery

Last mile delivery refers to the direct connection between regional freight distribution centers and local destinations such as households, package delivery lockers, among other locations. About 80% of Americans now shop online and customers have come to expect prompt delivery times and high-quality service[23] Growth in e-commerce has led to an increased demand on companies that provide last mile delivery services. Third-party delivery platforms like GrubHub, PostMates, and Uber Eats enable grocery stores and restaurants to increase their distribution by delivering goods in smaller vehicles or on bikes to a customer's home, work, or smart locker. Some last mile delivery services can consolidate trips by carrying passengers and goods at the same time.

Companies are also integrating the use of autonomous solutions like delivery bots, autonomous vehicles, and aerial vehicles as a cost-effective and low-emission option. Ford recently tested autonomous pizza delivery with Domino's Pizza and is now testing package delivery with a bot named Digit. Robotics company, Nuro, offers autonomous grocery delivery service in Houston, Texas, and recently received the required permits to operate in the state of California.

The U.S. Census Bureau of the Department of Commerce estimates that the e-commerce retail market has steadily grown between 10 – 15% annually. This growth in e-commerce has led to increased demand for last mile delivery services, in particular the use of autonomous solutions like drones as a cost-effective and low-emission option.

Advanced Air Mobility

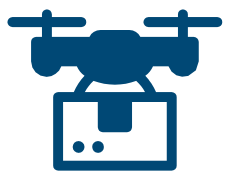
Advanced air mobility (AAM), sometimes called Urban Air Mobility (UAM), consists of an alternative transportation mode that uses vertical space within urban environments for emergency management, passenger mobility, and cargo delivery[24]AAM vehicles use GPS and sensors to fly autonomously, providing a new transportation option in both rural and urban environments. This industry is rapidly growing with well over 70 manufacturers worldwide including Boeing, Airbus, and Bell Helicopters developing corresponding product lines. NASA's Urban Air Mobility Market Study indicates that over a $1 billion investment has been made in the advanced air mobility industry as of 2018, resulting in a market that may likely be commercially viable as early as 2028. Market research firms estimate that the autonomous last mile delivery market in the U.S. is projected to grow at an annual rate of almost 23%, valued at $4.2 billion by 2030[25]. UCSD received a $5.8 million grant from NASA that is directed at creating computational design tools to provide to companies to make more efficient air taxi designs[26]. Although AAM is not yet common for passenger transport, some industry players have already been utilizing helicopters for "ridesharing" such as Blade, in pilot locations with primary offerings between downtown Manhattan, JFK, and select other locations in New York City area at certain times[27]. Companies such as Archer Aviation[28], Joby[29], and Lilium[30] are developing eVTOLs, electric Vertical Take-off Landing aircraft, which will form an integral part of AAM. As AAM matures, MaaS will almost certainly incorporate AAM offerings into their multimodal repertoire in order to remain competitive and provide superior service.

While use cases for drones vary widely, transportation and logistics companies, such as Amazon, Walmart, and UPS, have taken interest in AAM as a cost-effective and sustainable way to transport goods. In 2019, FedEx launched a small package, small drone delivery pilot program for last mile delivery in Tennessee. Walmart recently announced a partnership with Flytrex to deliver grocery and household essential items using automated drones. Many of these innovations also are happening in our region. As part of the Federal Aviation Administration's Integrated Pilot Program, the City of San Diego partnered with the Chula Vista Police Department to use drones to respond to 911 calls and provide situational awareness for arriving police officers. The City of San Diego also partnered with Uber Eats and local medical organizations to test delivery of food and medical supplies.

A key regulatory consideration that will be front and center for AAM is the siting of take-off/landing areas, known as vertiports. Contentious criteria include concerns over noise, safety, security, interference with FAA managed civil aviation and ease of eventual leveragability for MaaS. The development of Mobility Hubs offers an opportunity for AAM considerations to be included early in the planning process, even if actual production AAM operations are still several years away. A planning process that is forward looking and includes proposed land use which accounts for preliminary siting criteria for proposed vertiports could return dividends as AAM develops. AAM has the possibility to provide an alternative mode of transportation that will alleviate roadway congestion, but only if adequate resources are allocated to ensure that AAM is considered in planning processes, and not crowded out by other services at Mobility Hubs.

San Diego's Next OS could help further develop this technology by standardizing data regarding trips frequency, types, and concentrations to meet public demand, but public-private data sharing would be key in establishing an operational datahub for this emerging mode. This type of travel has the potential to alleviate intercity congestion, but it is currently relegated mostly to package delivery in rural areas[31]. AAM will create a new data set of transportation characteristics that can provide insights for agencies, owners, and users. Data such as on-time arrival/departure, reservations, or real-time tracking are all avenues in which Next OS could be coordinated with AAM. Even prior to passenger travel using AAM, package delivery can be coordinated and analyzed using Next OS to understand peculiarities that impact service and key characteristics that facilitate the development of best practices. Current developments in AAM are largely in the private sector. As noted above, the formation of public-private partnerships will help protect the important regulatory, equity-ensuring and harmonization role of the public sector in the AAM expansion process.

The growth of e-commerce has led to **increased demand** on last mile delivery



The autonomous delivery industry is projected to be valued at **$40 billion** by 2030

The autonomous delivery market is growing rapidly at an annual rate of **24%**

Advanced air mobility is estimated to be commercially viable by **2028**

MaaS in Action

SANDAG Oceanside Mobility Hub Concept portrays a MaaS landscape.

The influx of public-private partnerships (P3s) and the convergence of shared mobility services make MaaS more of a reality. Some estimates project that MaaS could reduce auto sales by more than 30% by 2030 and many major auto manufacturers are pivoting to become mobility service providers[32] Ford Mobility LLC was developed in 2016 to expand Ford's business model and to invest in new mobility and technology. In recent years, Ford has acquired several technology companies that will enable MaaS offerings such as on-demand technology provided by TransLoc, Autonomic's transportation mobility cloud platform, and a partnership with autonomous vehicle technology provider Argo AI. Hyundai also recently announced Strategy 2025, a new roadmap to guide the company's transition to becoming a smart mobility provider. Hyundai's roadmap includes plans for a wide range of products beyond vehicle manufacturing such as UAVs, robotics, and last-mile delivery.

MaaS Opportunities and Challenges

Shift from one commute mode to multiple: The surge in app-enabled mobility services has created expectations for more personalized transportation on demand. This growing comfort with using different modes of transportation for different types of trips provides a significant opportunity for MaaS. However, a fully integrated transportation system will require operators to share information with one another and with users which is not occurring widely today.

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. Cities are rethinking how curb space is used and considering opportunities for using data and technology to manage the curb flexibly to meet changing demands for both passengers and commercial deliveries throughout the day and night.

Limited access for the unbanked, those without smartphones and people with disabilities: MaaS requires credit/debit for payment and a smartphone for accessing the service, which presents limitations for the unbanked and those without a smartphone. Not all privately operated mobility services offer accessible vehicles for people with disabilities. 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. Opportunities exist to provide accessible trip planning kiosks in mobility hubs to make MaaS available to everyone. Public- private partnerships can bring more accessible mobility on demand services to people with disabilities.

Shared mobility trips are replacing other types of trips: Shared mobility services tend to concentrate in urban areas, and research shows that these services can replace transit, bike, and pedestrian trips, and they can induce demand for trips that would not have been taken if the service wasn't available. The SANDAG 2019 Transportation Study found that almost 8% of TNC trips in the San Diego region would not have occurred if TNCs were not readily available, and TNC trips are largely replacing trips that would have occurred using active transportation and taxis. The study also found that the ridehailing services in the Los Angeles and Bay Area are replacing trips that would have otherwise been taken on transit.

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, as well as increases in VMT and congestion[33] The 2019 Transportation Study found that ridehailing services are rarely used to connect to transit services and could be contributing to higher VMT in the region. Data from TNC drivers in the San Diego region implies that over 40% of their VMT is attributed to deadheading, the period of time in which there are no passengers in the vehicles[34]

Transition to zero emission vehicles (EVs): As MaaS continues to build momentum, the use of EVs for all motorized mobility services will be necessary to reduce GHG emissions. To address this, the California Air Resources Board has established the Clean Miles Standard to reduce GHGs from TNCs and transition to 100% EVs by 2030.

Pricing policies and mechanisms should be updated and integrated: People are growing accustomed to using shared modes of transportation and are more comfortable sharing a ride for the right price. This cultural shift could lead to an increase in ridesharing with the right incentives and disincentives in place. Encouraging more pooled trips that reduce VMT will require an integrated and dynamic pricing system. Fare policies should maximize road-usage by moving the most people with minimal roadway impact and incorporate strategies to improve equity. This includes providing monetary incentives to transfer to higher-capacity modes at high-demand times.

Numerous P3s: the line between public and private transportation has blurred and across the world, a mix of publicly and privately operated mobility services are demonstrating how providers can come together to better meet the needs of consumers and provide equitable service. Flexible microtransit service is now operating in 35 states in the U.S providing service to areas that are difficult to serve with traditional fixed-route public transit. Auto manufacturers are getting into the mobility business preparing to offer mobility as a service in the future.

Uncertainty about service provider participation: Mobility service providers have been reluctant to share data and integrate into apps along with competitors. Many private mobility providers currently offer a closed-system and encourage customer loyalty, a barrier to seamlessly integrating multiple providers to offer MaaS[35]. The reality of a single platform to locate, book, and pay for trips across multiple branded services remains elusive.

Vehicle Technologies

San Diego's Barrio Logan community and NEV shuttles in Downtown San Diego and Pacific Beach (Sources: San Diego Metropolitan Transit System and Circuit)

Vehicle technologies are rapidly advancing, with vehicles becoming increasingly safer, lighter, and more fuel efficient. New and diverse vehicle types are emerging in the market to meet the needs of specific types of trips, such as longer-distance commuting with multiple passengers. Extremely compact vehicle alternatives are also available to service solo trips, and last mile deliveries over shorter distances. 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 expected to be intertwined given the synergies and benefits of overlapping applications. For example, electric, automated, and connected vehicles can be smaller and lighter, requiring less space for parking. This trend enables cities to rethink the way in which the public's right-of-way for streets, sidewalks, and curb spaces are allocated, and can potentially help to facilitate a more comprehensive implementation of local Complete Corridors that provide safe space for everyone and every mode.

Battery Electric, Plug-in Hybrid and Hydrogen Fuel Cell Vehicles

Zero-emission vehicles (ZEVs), such as battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEV) and hydrogen fuel cell electric vehicles (FCEV), play a significant role in how countries, states, and local governments plan to cut GHG emissions and improve air quality[36]. Technological innovations are underway across all light, medium, and heavy vehicle types from cars and vans to utility vehicles, buses, and trucks.

BEVs and PHEV (together referred to as plug-in electric vehicles [PEV]) have gained the most traction amongst consumers and businesses so far. Major auto manufacturers released their first EV models in 2010, and as of 2023 there are over 115 light duty PEV models available in California[37]. Additionally, ZEV adoption in California has steadily increased, with ZEVs making up approximately 19% of new vehicle sales in 2022, compared to just 8% in 2020[38].This growth in the ZEV market, along with a welcomed expansion of EV infrastructure has led California to be the state with the most ZEVs and electric charging stations. As a result of these new and improving technologies, Veloz reports that in 2023, California was home to over 1.5 million ZEVs, comprising about 42% of the approximately 3.6 million ZEVs nationwide[39] [40].

This growing ZEV market is creating a massive need for new charging infrastructure and hydrogen fueling stations across the transportation network. Governments at all levels are taking steps to ensure the success of ZEV markets[41]. In 2019, the California Air Resources Board called for an increase in ZEVs statewide by issuing the Innovative Clean Transit Regulation, which requires transit agencies in California to transition to 100% Zero Emission Bus (ZEB) fleet by

2040. Beginning in 2029, 100% of new vehicle purchases by California transit agencies must be ZEBs[42 43]. In 2020, Governor Newsom set an additional goal that the state must have 100% of new car (light-duty) sales be ZEVs by 2035[44 45].Regionally, SANDAG and other public agencies have ramped up efforts to increase adoption of ZEVs to exceed the region's fair share of the goals set by the State. According to the California Energy Commission, in 2022, San Diego County had 95,024 ZEVs and 2,827 public EV chargers[46]. Figure 12 shows vehicle and infrastructure progress towards meeting the region's share of the 2025 and 2030 state goals.

SANDAG has implemented an EV charger incentive program, known as CALeVIP, in partnership with the California Energy Commission, San Diego County Air Pollution Control District (APCD), and Center for Sustainable Energy. To complement CALeVIP and further reduce GHG emissions, SANDAG is developing a ZEV incentive program that will enable more people, especially low-income and disadvantaged households, to purchase a ZEV. Combined, these programs support the installation of about 33,000 EV chargers and acquisition of 100,000 EVs by 2035. Also, SANDAG has partnered with SDG&E, APCD, and other regional stakeholders to establish the Accelerate to Zero Emissions Collaboration (A2Z) to reduce barriers to EV adoption, increase private investment, and generally accelerate EV adoption and EV infrastructure deployment within the region.

In the U.S., the multi-state ZEV Memorandum of Understanding was signed by nine governors (California, Connecticut, Maryland, Massachusetts, New York, New Jersey, Oregon, Rhode Island, and Vermont), which commits to having 3.3 million ZEVs on the road by 2025[47]. Together, these states represent about 30% of all new vehicle sales in the U. S.[48]. Additionally, national 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[49].

Concurrent with government action, vehicle manufacturers have taken notice of these commitments and are positioning themselves as future market leaders in electric transportation.

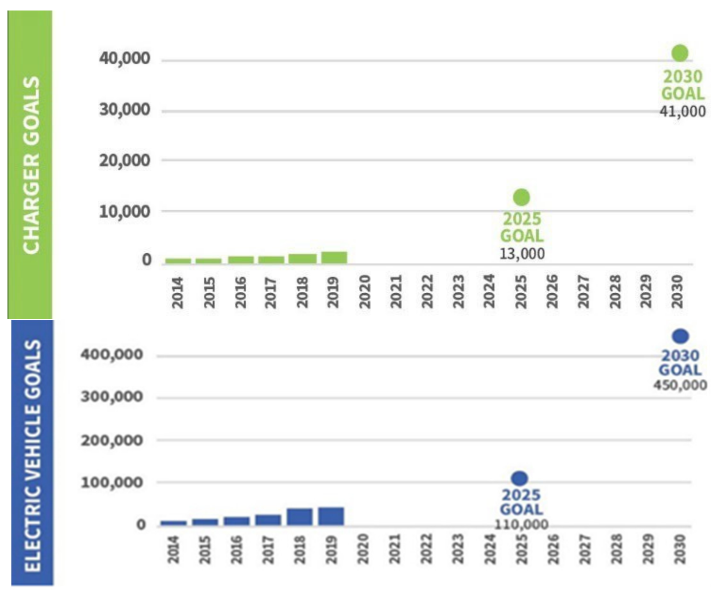


Figure 12*: Electric Vehicle Progress and Charging Station Progress*

Globally, the private industry has invested $985 billion into ZEVs[50]. Most recently, GM announced that it will only sell EVs starting in 2035 and beyond51. Volvo has committed to produce a zero-emission version of each of its models by 203052. Volkswagen has committed more than $200 billion to PEVs, AVs, and new mobility services53. Daimler AG is spending nearly $70 billion to go all-electric by the end of the decade54.

Advances in Zero-Emission Vehicle Charging/Fueling Network

Public and private investment is necessary to provide adequate charging and hydrogen fueling infrastructure. Beyond the infrastructure needs for light-duty ZEVs, transit and goods movement operators will need to consider how to address range issues and provide EV charging or hydrogen fuel for zero-emission transit buses and trucks.

Figure 13: In-Road Inductive Charging and Static Inductive Charging (Sources: Electreon and Momentum Dynamics)

One such technology that addresses this issue is inductive charging, where a vehicle can recharge batteries by aligning an on-board receiver panel over inductive charging system coils embedded in the road or parking spot. Inductive charging will also be critical for AVs, particularly those AVs that are part of a shared fleet. Examples of inductive or wireless charging are Electreon's technology and Momentum Dynamics technology (Figure 13). Electreon has deployed numerous in-road dynamic wireless pilots globally, including an urban transit bus pilot in Tel Aviv and a long-haul goods movement pilot in Sweden[55]. Momentum Dynamics has deployed a static wireless pilot with Link Transit in Washington in stages, beginning with a 200kW inductive charging system at their primary transit center in 2018, and expanding with 300kW of additional inductive charging capacity in 2020 which offers the capability to opportunity charge Link Transit's fleet of 12 BEBs throughout the day while in service[56].

Chevy Volt plugged into a renewable, portable charging station.

Local electric utilities play an essential role in the build-out of ZEV infrastructure to meet the growing demand associated with the addition of grid-connected charging stations, whether at homes, businesses, or public sites. Utilities must work with private and public entities to ensure that no localized grid impacts occur, especially with the push for electrification of medium- and heavy-duty vehicles. As the electric grid transitions away from fossil fuels, utilities must work to ensure clean and renewable energy sources are available to provide a balanced and resilient grid. As battery storage becomes more efficient with the advent of new technologies including Next-Generation Lithium-Ion, Lithium-Sulfur, Aluminum-Ion and Solid State, excess energy produced during the middle of the day can be stored and used during periods when renewables are not available.

Vehicle-to-grid (V2G) integration is one emerging technology that may play a key role in the transition to clean energy and widespread adoption of ZEVs. V2G technology enables EVs to plug in and supply power back to the grid during times where demand outpaces generation. As this technology becomes more widespread, utilities, government, and private sectors will need to collaborate to provide affordable electricity and ensure a resilient grid in the event of natural disasters or emergency even.

Sustainable Alternative Fuels

Since the transition to EVs in the medium and heavy-duty sectors will not happen overnight, low emission fuels known as alternative fuels, are being used as an interim alternative to help reduce GHG emissions. Biofuels, such as renewable compressed natural gas and biodiesel, are one of the largest sources of alternative fuels in use today, and they help the San Diego region drastically lower carbon emissions. Most MTS buses already run on renewable compressed natural gas as the fleet is being transitioned to ZEBs. A local San Diego company, New Leaf Biofuel, devised a process to turn used cooking oil from roughly 2,500 restaurants, hotels, casinos, and other local businesses, into ready-to-use biodiesel fuel. Biodiesel directly displaces diesel fuel usage helping to reduce GHG emissions by 80%[57]

Automated Driver Assistance System

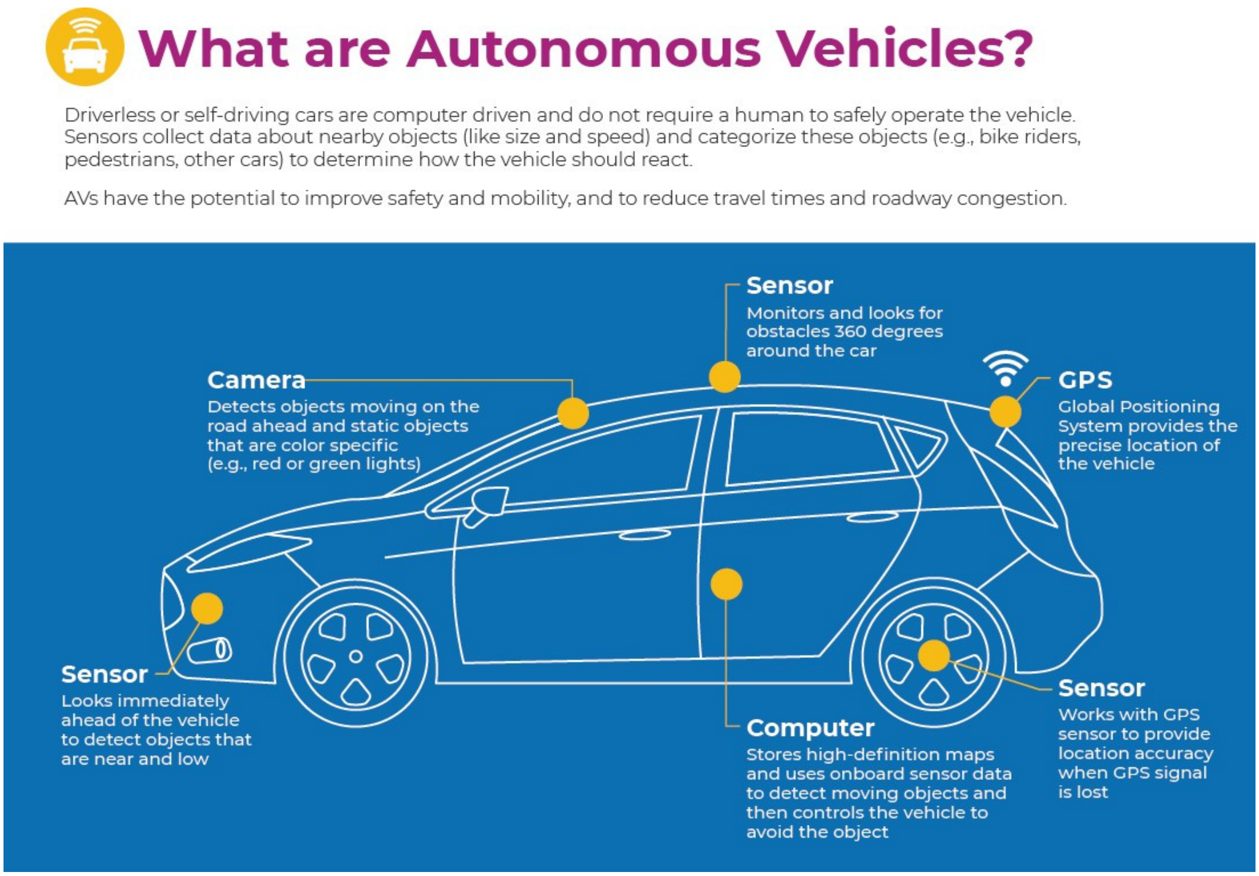


Figure 14: Characteristics of autonomous vehicles

Advanced Driver Assistance Systems (ADAS) features currently available include adaptive cruise control that adjusts to varying speed of traffic on highways, lane departure warning and automated lane keeping, forward collision warning, automated braking and collision avoidance, and even hands-free driving on highways and arterials. Higher-priced vehicle models with these advanced automation features are available today, and we can anticipate continued proliferation into lower-priced models by 2030.

The Society of Automotive Engineers has defined Levels of Automation, which are shown in Figure 15. The industry is rapidly progressing towards commercialization of Levels 2–4.

Vehicles are equipped with sensors, cameras, radar, and lidar along with high-precision GPS and high-definition digitized mapping, which create a 360-degree view of the world around the vehicle (Figure 14). Driver assistance features can cover the spectrum from passive, where the vehicle may alert the driver to an incident (e.g., lane departure warning or forward collision warning), to active, where the vehicle may preempt the driver reaction by actively braking to avoid a collision. The combination of sensing technologies far exceeds the capability of human vision, eliminates blind spots, and reduces reaction times, resulting in enhanced safety, reductions in road fatalities, and protection of vulnerable road users, including pedestrians and bicyclists. Most importantly, we do not have to wait for widespread commercialization of fully autonomous (Level 5) vehicles before these safety benefits become widely available in our drive towards Vision Zero—zero fatalities on our roads. As automation progresses towards Level 5, more effective safety systems will prevent crashes via more adept sensors that provide greater insight into roadway conditions surrounding the vehicle, augmenting the awareness of the driver to make more informed decisions.

There are 40 manufactures possessing a DMV permit for testing AVs on public roads in California. These 40 manufacturers operate 2,015 test vehicles and have 2,932 safety drivers under these permits [58]. Qualcomm has a permit to test with safety drivers in San Diego which currently consists of five test vehicles and 12 safety drivers. Cruise has deployed manually driven vehicles to the San Diego area to gather data and conduct testing, but currently does not have plans to expand AV tech to San Diego[59].

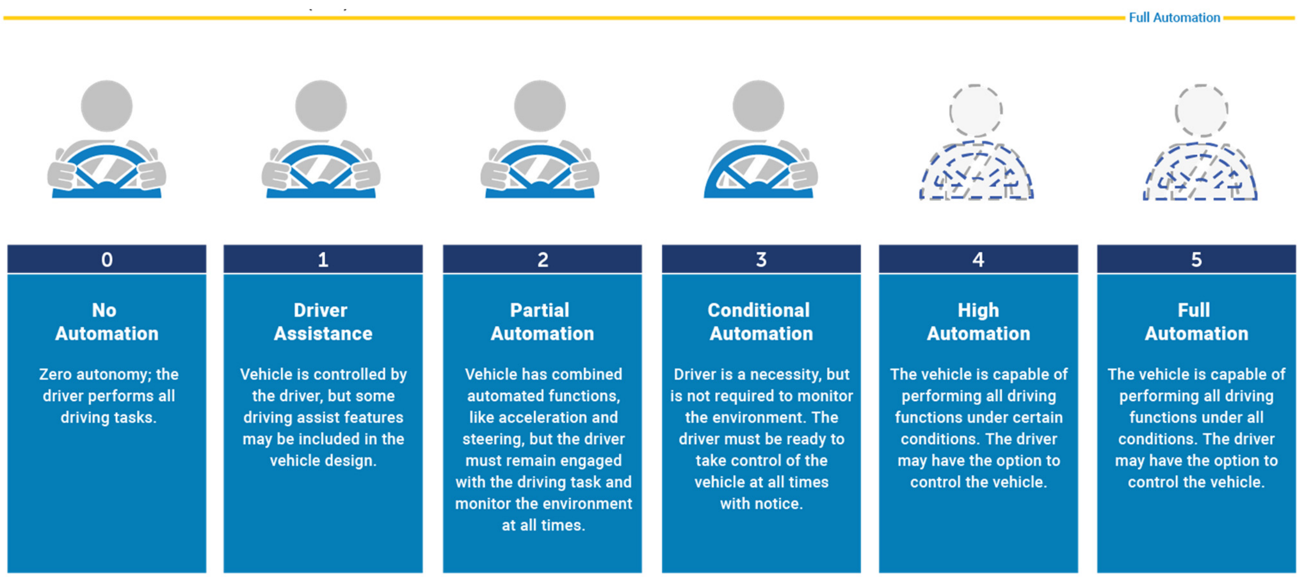
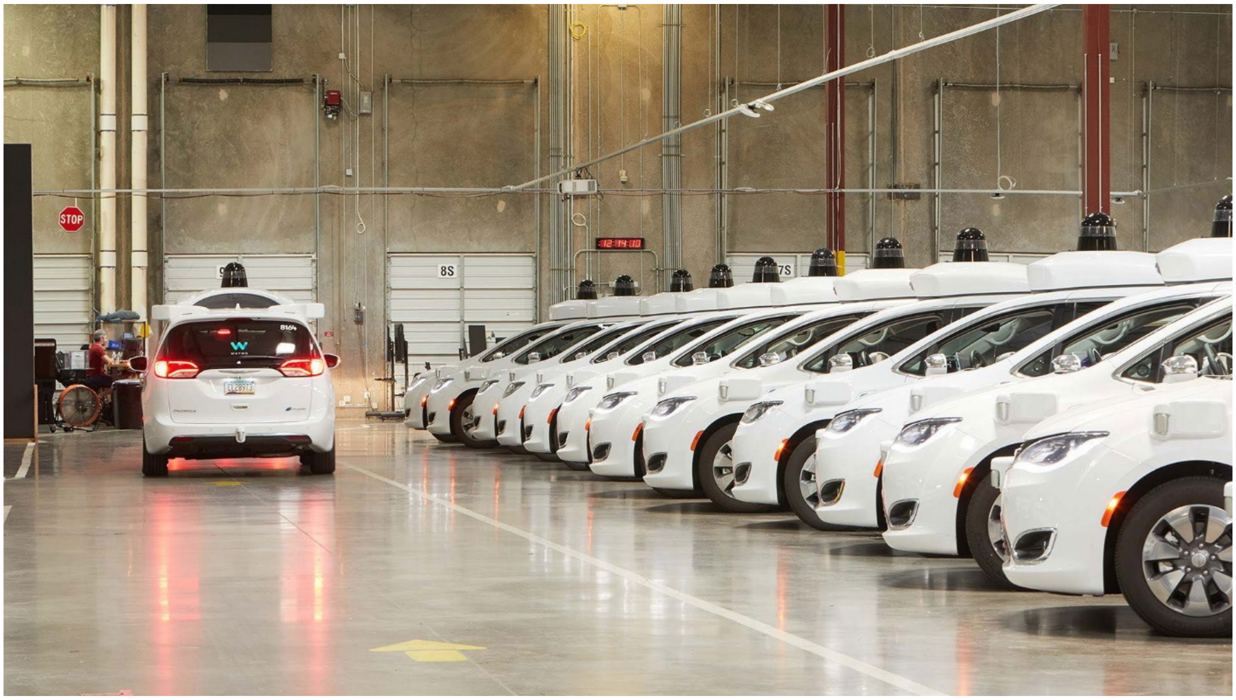


Figure 15: Levels of vehicle automation (Source: NHTSA)

Fully Autonomous Driverless Vehicles

Level 5 vehicles will take much longer to come to market. Several years ago, companies were proclaiming that driverless ridehailing services would be commonplace in urban areas by today. In actuality, we have seen slow progress with a handful of controlled, local pilot projects in a few cities. Waymo is currently leading the charge. After several years of testing an autonomous fleet in Phoenix, Waymo started offering driverless rides to paying passengers in late 2020. In the next ten years, we anticipate slow expansion of controlled driverless ridehail operations and continued investment in detailed mapping and training miles by companies invested in autonomous vehicle (AV) technology like Cruise (GM), Argo.ai (Ford), and Zoox.



Dozens of city employees in Chandler, Arizona, use self-driving vehicles at work in partnership with Waymo, an autonomous vehicle company (Source: Waymo)

In August of 2023, the California Public Utilities Commission (CPUC) approved permits for Cruise and Waymo to begin charging fares. However, only Cruise can charge fares without a safety driver present between the hours of 10 PM and 6 AM. At other times, Cruise is required to have a safety driver present if they wish to charge fares and Waymo is required to always have a safety driver present when they charge fares in their AVs. At any time of the day, the companies can offer free rides in their AVs without a safety driver present. The CPUC enabled further expansion to Los Angeles and Mountain View[60]. However, this authorization is not without controversy. The City of San Francisco has asked the CPUC to pause the implementation of the expansion of AV testing and use within the city. Some city officials have commented on the need for incremental deployment as the AVs have interfered in various situations where the vehicles were not immediately able to extract themselves[61]. In early August of 2023, the DMW halved the number of vehicles Cruise is allowed to have on the street due to a collision with a firetruck[62].

The only permit that has been issued from the DMV for the San Diego area for driverless testing and deployment is held by Mercedes-Benz. They are testing Level 3 autonomous vehicles, which are under its "Drive Pilot" Program. The vehicles are limited to speeds of 40 mph and under and are not allowed to drive passengers[63].

AVs will likely come to market as part of a MaaS model as opposed to individual ownership. Companies like Uber and Lyft are expected to be early adopters because industry analysis shows that the cost of the driver is the dominant operational cost for the ridehail business. Although fully autonomous vehicles are twice as expensive as vehicles with Level 4 ADAS features, these companies could reduce the cost of each ride by as much as three-quarters with autonomous vehicles, turning ridehailing into a profitable enterprise. Lyft lost $911 million in 2018 alone, which raises the question of whether it can survive the years it will take before AV fleets are functional[64].

If guided by good planning and policy, AVs could increase mobility for the elderly, the disabled, and the transit-dependent; revolutionize delivery services and logistics; and almost eliminate the need for concentrated parking facilities. AVs could substantially reduce traffic accidents and vehicle fatalities. According to the National Safety Council, 42,060 people died in car crashes in 2020. The rate of death between 2019–2020 represents the largest jump in 96 years. An estimated 94% of crashes are caused by human error. AVs could significantly reduce the severity and frequency of crashes. By some estimates, as penetration of fully autonomous vehicles increases, freeway capacity could increase by 10% to 25% by 2050, while estimates for the capacity for a full AV fleet (which will take a lot longer) range are as high as a five-fold increase[65]. However, without effective planning and policy intervention, AVs are just as likely to lead to an increase in total VMT, exacerbate urban sprawl, increase energy consumption and GHG emissions, and provide little to no benefit to the disadvantaged communities that should benefit most from this technology.

Safety Considerations

A main concern in the development of full AV implementation is safety, whether that is from cities, manufacturers, regulators, or others. There are many nuanced conditions that occur on roadways and each stakeholder many have different approaches to issues that occur in different situations. In current AV testing, issues have occurred when accidents occur, as first responders have difficulty rerouting the AVs. Autonomous Vehicles tend to be programmed to stop, which can be hazardous to the vehicle, the incident scene, and the first responders. This could be solved through a combination of real-time AV monitoring by some public agency as well as creating a transparent, open system architecture that provides emergency responders the ability to interface with the AV in emergency situations. The phasing in of AV poses this challenge as it necessitates that AVs can interact with human-driven vehicles, which has no easy solution of crash mitigation. An all-AV roadway would be straightforward for AVs, as decision making would be instantaneously shared, but human thought processes cannot be processed and shared in this fashion. Safety will be a persistent factor in the development of AVs and be a major item that all stakeholders will need to address, whether it is software development or infrastructure improvements to support AVs.

Commercial Applications for Autonomous Vehicles

The trucking industry has the potential to be a large part of the AV market share. Trucking has seen a shortage of long-haul truck drivers, which may be able to be addressed using AVs if deemed appropriate by policy makers and regulators. However, this is a controversial topic, as this may threaten trucking jobs, and be blocked by unions. Additionally, some states have restrictions on AV trucking that must be addressed before an impactful roll out could occur. For example, California requires that any AV truck that weights over 10,001 pounds (US truck class 3 and above) have a human operator present. Regardless, testing of AV technology for trucking persists. Aurora is an AV company that operates 30+ trucks on routes between Dallas to Houston and Fort Worth to El Paso. These trucks have cumulatively traveled 455,000 miles, carried 1635 loads, with a 98% on time delivery rate. These trucks still have safeguards with people behind the wheel as of 2023, but the company is looking towards trucking without individuals behind the wheel as soon as 2024.

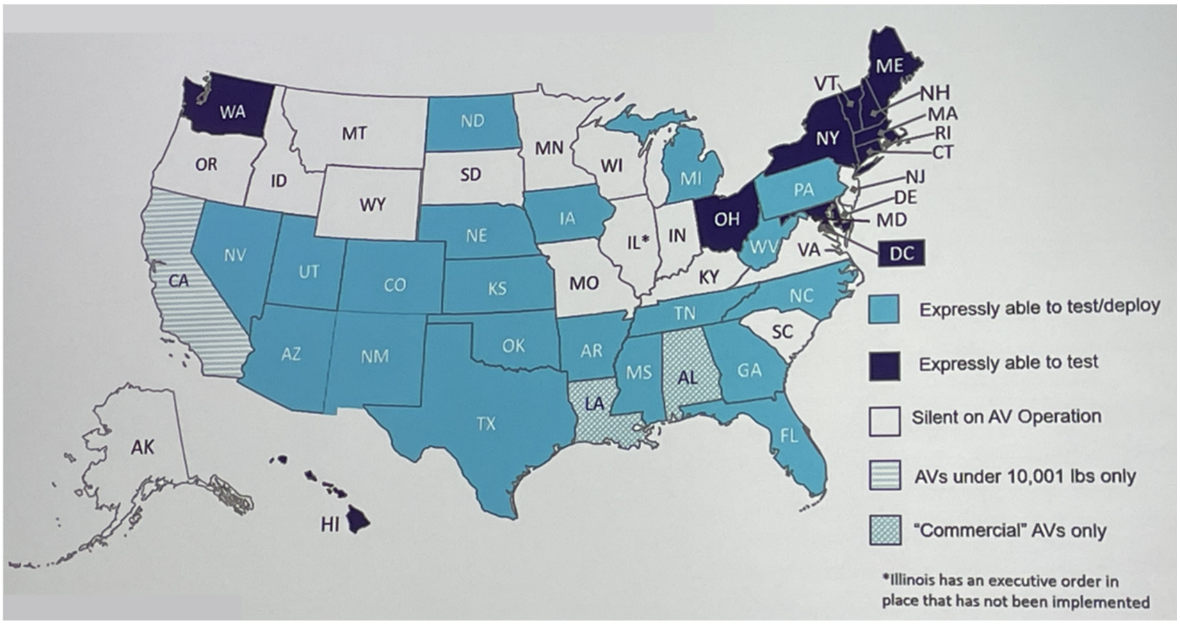
Autonomous Vehicles and Mixed-Use Environments

Figure 16: Treasure Island AV Shuttle

Traffic management will evolve as AV deployment increases as it is possible to confuse the automation of vehicles with the automation of traffic. Traffic management devices will benefit due to the plethora of information that would be able to be communicated between the infrastructure and vehicles. As a centralized data hub, Next OS would be able to store and manage data on AV traffic patterns, best practices, and/or lessons learned enabling companies to utilize the data to improve AV offerings, provide transparency to the public, and allow policy-makers insight into the industry. Traffic management for AVs will have to consider mixed use scenarios where human driven vehicles, cyclists, pedestrians, and other road-users add complexity; this may increase the need for smart infrastructure, even in the short-term. AVs may be limited to managed lanes to prevent any issues in the short-term, but the eventual incorporation of AVs into general traffic lanes may be fraught with issues if traffic management is not incorporated into development.

Cities like San Francisco and Phoenix have piloted autonomous vehicle testing that have demonstrated a proof of concept. The greater Phoenix area has a number of different AV testing grounds and companies involved in AV development and San Francisco currently has an autonomous vehicle programs from companies such as Waymo and Cruise in varied environments from GoMentum Station to Treasure Island[66]. Cities like these can function as models and lead other cities to deploy AVs in a way that is efficient and effective by providing lessons learned. Some European cities have also created self-assessment tools that analyze AV-readiness, which would also direct cities how to take proper steps to begin preparing for a transition to AV. Agencies will benefit from understanding AV capability enabling them to address community needs in an effective manner. Through conducting this outreach, cities must also consider the implications that AVs will have upon their infrastructure, specifically street design, to evolve with their forecasted mobility system. There is no singular roadmap that will lead cities to implement AVs as each jurisdiction will have individual challenges and needs, but early users can create roadmaps for others to follow.

Until a consistent regulatory road map for AV commercialization exists, it is difficult to predict when AVs will come to market. Federal and state governments are struggling to keep pace with private-sector innovation and develop uniform policy that will ensure that common safety standards are adopted and applied in terms of vehicle design and operation in public right-of-way. 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 (raised, non-reflective pavement markers). Ultimately, systematic deployment will require federal guidance, much more collaboration, and a standard approach for AV planning and policy across all levels of government and with the private sector.



US State AV Laws & Regulations as of Summer 2023 (Source: Venable LLP)

A recent meeting of the House Subcommittee of Energy and Commerce met for the expressed purpose to discuss legislation on Autonomous Vehicle developers. Proposed regulations would require submittals of safety assessments, development of a rule-making plan, and updates for federal motor vehicles standards. The legislation is being drafted by Representative Debbie Dingell, a Michigan Democrat and by Representative Bob Latta, an Ohio Republican[67].

Vehicle Telematics and Cloud Connectivity

Vehicles are increasingly getting connected to the cloud, be it for infotainment, on-the-go map updates, or mission-critical over-the-air software or security updates to computing modules in the automotive control systems. One of the earliest such cloud connectivity services was OnStar from GM. Recently, Tesla has been pushing major software updates over the air to their vehicles. Vehicle telematics are also used to monitor the operation of the engine and components and periodically report back to the vehicle manufacturer.

Vehicle telematics can also monitor hard acceleration and braking during vehicle operation as well as speed, miles traveled, fueling, and electric charging. Application of this information have included preemptive vehicle maintenance, as well as insurance rating and discounts, referred to as Usage-Based Insurance, which rewards safe driving by monitoring hard acceleration and braking, sharp cornering, or other unsafe driving behavior. Wejo has developed a platform that can allow cities to utilize telematics data to monitor congestion on roadways to inform planning, operations, and even real-time control of traffic signal timing[68] [69].

Connected Vehicles

Connected vehicles (CVs) can communicate with each other through in-vehicle and wireless technology (Figure 17). 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.

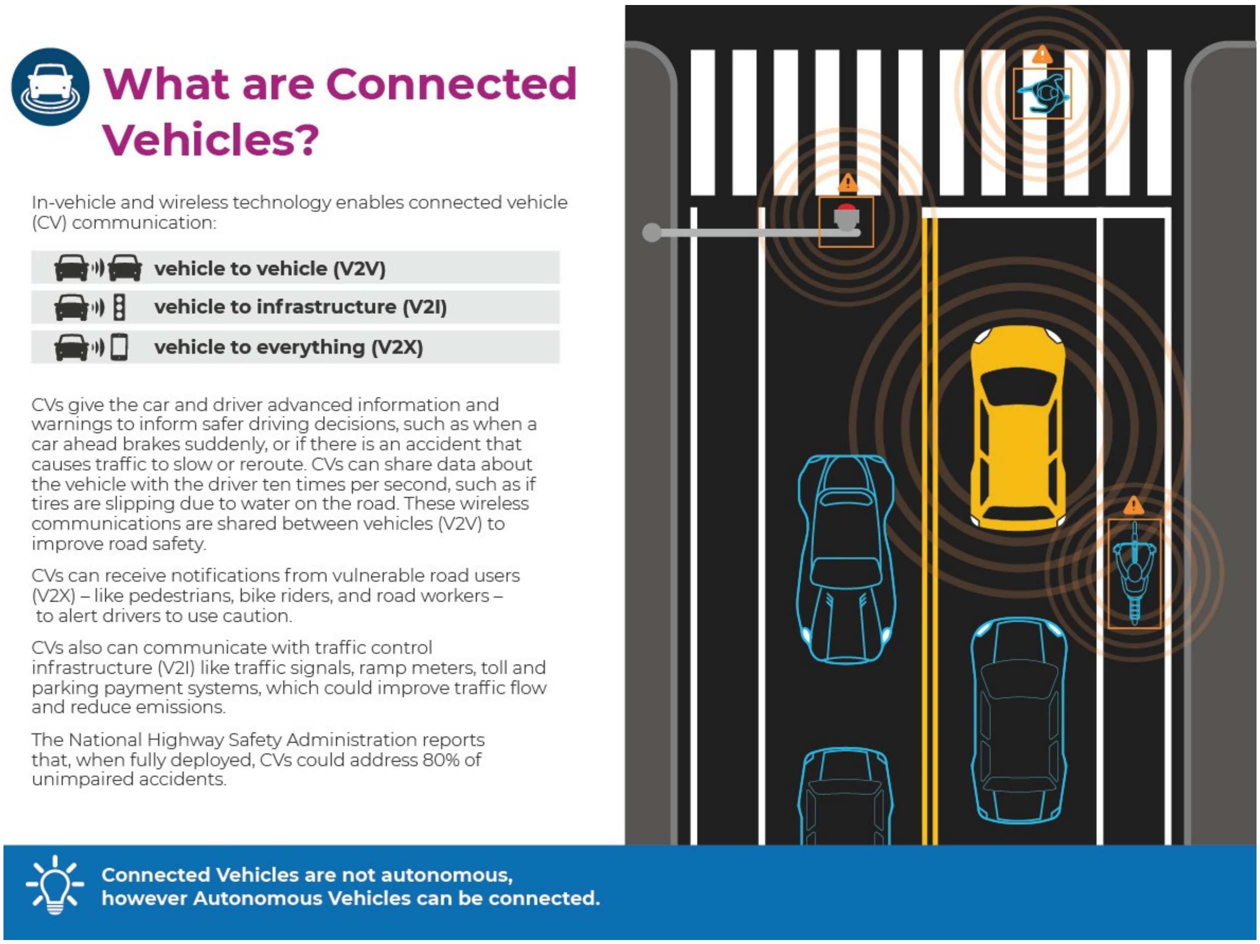


Figure 17: Characteristics of connected vehicle technology

Over the last 20 years, the communications and automotive industry has invested in standardization, research, experiments, pilots, and data collection. All this research is widely available. Nevertheless, commercial adoption of CV technology has lagged as most use cases become valuable only when there is widespread adoption and deployment of connected infrastructure, where investment has been lagging.

By 2030, we anticipate that vehicle-to-infrastructure (V2I) communications will provide congestion relief and greater safety through applications like transit signal priority, freight signal priority, and highway shoulder use. We also anticipate commercialization of truck or transit platooning in this timeframe. CVs enable vehicles to platoon and form “road trains” with decreased following distance. All vehicles in the “train” work cooperatively as one entity. The future could have smaller transit vehicles linked together, which would enable operators to dynamically adjust system capacity to increase or decrease depending on demand. These technologies will enhance efficiency, and by extension reduce GHG emissions by reducing idling and unnecessary acceleration. A variety of additional ADAS (safety) use cases where vehicle-to-everything (V2X) communication supplements on-board sensing in vehicles will also proceed to commercialization. Examples include vehicle-to-bicycle and vehicle-to-pedestrian communication.

Cellular V2X and Evolution of FCC Regulation

Deaths on US highways exceed 43,000 per year. NHSTA highlighted that just two V2X technologies, Intersection Movement Assist and Left Turn Assist, could prevent at least 900 deaths per year[70]. Therefore, creating a connected transportation system has the potential to save many lives, and the federal government has been collaborating with auto manufacturers to advance connected vehicles for many years, but progress has been slow.

Information about this blind pedestrian's location is broadcast to approaching vehicles.
(Source: Intelligent Transportations Systems Joint Program Office

In 1999, the Federal Communications Commission allocated 75 MHz of spectrum in the 5.9 GHz band for use by ITS vehicle safety and mobility applications[71] 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[72] 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 in and deploy roadside equipment and applications that would make vehicle-to- infrastructure (V2I) communications possible. Until 2017, the U.S. DOT had 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 communication mechanism that permits extremely high data transmission critical in communications-based active safety applications.

In November 2020, the FCC ruled to reduce the spectrum allocation for ITS to 30 MHz (from 75 MHz). Systems must now use the newer cellular-vehicle-to-everything (C-V2X) technology and transition away from DSRC within one year. While taking away 45 MHz of spectrum from ITS, the FCC stated that the industry had failed to use the spectrum for any meaningful purpose over 20 years. This decision was made over objections from the U.S. Department of Transportation.

The FCC has enabled state DOTs and OEMs (Original Equipment Manufacturers) to seek waivers for deploying C-V2X on the original DSRC band on the upper 5.9 GHz spectrum, however it only applies to the select few automakers and agencies who petitioned to be able to use this spectrum for CV2X technology. However, this process is dependent on the timely approval of waivers by the FCC enabling C-V2X on DSRC channels to spur industry involvement. If the FCC is not productive in approving waivers, IOOs (Infrastructure Owners and Operators) and OEMs may not feel that there is enough incentive to advance C-V2X. The NW U.S. 33 Corridor Council of Governments in Ohio protested in an FCC filing that after more than $105 million in public/private investments, their project was "having the proverbial rug pulled out from under it, just as it is to go operational.[73] Indeed, hundreds of millions of dollars in public funding have been poured into DSRC pilots with some participation from automakers and communications technology providers. 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[74]

These pilots have demonstrated technology effectiveness and there is now greater enthusiasm that CV technology is moving from pilots to wider adoption. Recent rulings in favor of C-V2X have resulted in greater clarity for the industry and perhaps will continue to lead to a worldwide consensus on the use of C-V2X for ITS.

Vehicle Technology Opportunities and Challenges

Electric vehicle infrastructure is not pacing with demand and policy: More public infrastructure to support PEVs is needed in the near term. To underscore the magnitude, analysts estimate the need for 41,000 publicly accessible electric vehicle charging ports in San Diego County by 2030, whereas currently, about 2,500 are available. AVs will likely be electric, creating demand for wireless or inductive vehicle-charging infrastructure in the long term[75]

Hydrogen-powered vehicles will enter the San Diego market: San Diego's first commercial hydrogen station opened in late 2016, a second station is in development, and three more have been awarded funding in the region. Expect passenger vehicle sales to begin in the next few years and vehicle demonstrations for fuel cell electric trucks and buses to begin in the next decade. Current transit projections show that hydrogen fuel cell buses will be needed to service the longer, more rural routes in the San Diego region.

Shared mobility fleets that are connected, electric, and ultimately autonomous can improve access and mobility for underserved populations: Shared microtransit can provide improved access to underserved populations while reducing VMT and GHG when operated with EVs. In the longer term, these shared microtransit be AVs, which can further reduce the cost of providing mobility.

ADAS and AV technology will improve safety: Ninety-four percent (94%) of accidents are caused by human error. ADAS and eventually AV technology will dramatically decrease this number. ADAS features are being commercially rolled out by automakers today. Level 5 AV will gradually expand its footprint across different cities. Recent research published by Waymo claims that Level 5 AVs will reduce vehicle fatalities to zero.

AVs could increase VMT and urban sprawl without policy intervention: 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 ability to use travel time for non-driving tasks, and consumers may be willing to live farther away, and travel longer distances as travel time becomes more productive. Vehicles traveling between trips without occupants is another risk without policy to discourage these unintended consequences.

CVs can reduce congestion and improve safety: CVs can increase roadway capacity through vehicle-following and platooning. However, the bottleneck may just move from the highway to the off-ramp. Other congestion-reduction mechanisms include transit signal priority, freight signal priority, coordinated shoulder, and ramp use. CVs can complement on-board sensors for increasing the safety benefits of ADAS and AVs. Adoption of CV technology in vehicles and investment in CV infrastructure on roadways remains unpredictable.

Decrease in parking, ticketing, and gas tax revenue: Public agencies will need to substitute and/or complement traditional revenue sources with new innovative sources that are more sustainable long-term to support our infrastructure needs and promote a balanced transportation system. 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.

CVs and AVs may require changes to infrastructure investments: 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 governments to invest in necessary improvements and ongoing maintenance. CV deployments continue to be slowed down because of lack of investments in CV infrastructure, such as intelligent traffic and ramp signals, intelligent highway lane management signs, etc.

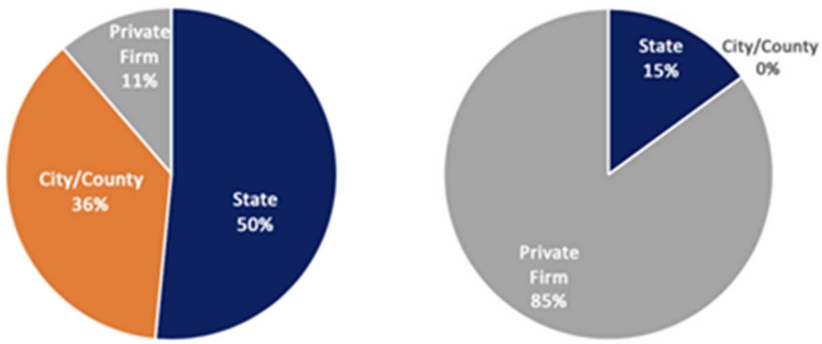
While it is relatively certain C-V2X will take precedent over DSRC, universities and agencies are testing applications of both, sometimes in conjunction with each other. The University of Michigan Transportation Research Institute is conducting research on the issues that come from deployment of DSRC and C-V2X in parallel, adjacent channels with the eventual intent of demonstrating the two methods interoperability. University of Michigan Transportation Research Institute has done both V2I and V2X work that includes curve speed warnings, red light violation warning, and pedestrian in crosswalk warnings, and are continuing to work on further C-V2X technology. Utah Department of Transportation has dual mode Roadside Units (RSUs) that use DSRC and C-V2X. Cirrus, a cloud-based technology developed by Panasonic, has been testing the ability of vehicles to receive Basic Safety Messages (BSMs), that has been tested in various locations throughout the United States including in Utah and the San Diego Regional Proving Ground.

The recent Infrastructure Investment and Jobs Act has enabled V2X installation with a 100% federal share that some DOTs have taken advantage of[76]. Recent cost estimates by ITS America indicate that intersections that are ready for smart capability may only cost 7,000 to 15,000 dollars to equip, but some states requiring full planning, engineering, and procurement phases may raise the cost of smart intersections to 50,000 dollars for IOOs to pay[77]. Intersections that lack appropriate infrastructure to support RSUs may cost an additional 40,000 to 65,000 dollars to enable V2X[78]. (Even then, this price could constitute less than 2% of total cost of a large capital improvement project[79]. ITS America points towards a 10-year nationwide rollout plan that costs some 6.5 billion dollars accounting for signal upgrades, non-intrusive detection systems, the creation of data-backhaul, and interstate variations of the procurement process. On the vehicle side, OBUs (On-Board Units) are incorporated into design of new models and may be added in as an aftermarket part to bridge the gap in connectivity. Some markets, namely China, have incentivized OEMs to deploy OBUs, however this has yet to happen in the United States due to barriers to adoption such as the need of FCC waivers for operating C-V2X and Uu. There is uncertainty regarding the price of OBUs but estimates range from 50 dollars to 300 dollars per OBU[80]. Relative to the overall cost of the transportation network and vehicles, the implementation of RSUs and OBUs do not constitute a significant cost to OEM and IOOs.

A potential early win using C-V2X technology would improve the safety of Vulnerable Road Users (VRUs) through equipping bicycles with OBUs. This would be inexpensive and become widespread faster than vehicles, which require a more time intensive design to incorporate the OBUs or an aftermarket purchase and installation. The bicycle OBUs could feature C-V2X (short range) and Uu (long range) communications. The proliferation of the OBUs can not only decrease accidents involving VRUs, but also increase popularity and become a proof of concept, with high public visibility while vehicle manufacturers incorporate OBUs into upcoming designs.

C-V2X would benefit from a national development plan that would help bring stakeholders and policy makers together that would drive decision making. A potential example for V2X to follow could be found with the National Electric Vehicle Infrastructure program or the ITS4US program. These programs are terrific examples of how public attention can give legitimacy to what may be considered fringe transportation projects due to the relatively new technology. Once a national plan has been established, states could take initiative to use the nationwide framework and alter certain areas to meet their needs without compromising the interoperability of the network.

There are currently projects that are using 5.9 GHz safety band in California to demonstrate proof of concept using C-V2X and DSRC technology. However, DSRC has been sidelined due to the previously mentioned FCC ruling. As such, many projects are transitioning to C-V2X.



UDOT Study Regarding License Holders for DSRC (left) and C-V2X (right)

On August 16, 2023, the FCC granted 17 waivers for state and local DOTs and equipment manufacturers to use C-V2X technology to use 20MHz on the upper end of the 5.9 GHz safety band. This more than doubled the number of agencies and companies operating with an FCC waiver for C-V2X. This was granted due in part that not granting the waivers was determined to be contrary to public interest and impede rapid deployment of technology that has been determined to be suitable for the spectrum. The waivers however require that C-V2X do not create harmful interference for the DSRC incumbents operating in the respective jurisdictions. The decision to grant the waivers is a reassuring step, pending however further decision making from the FCC and USDOT.

As noted previously, regulatory uncertainty is a main concern hindering the deployment of C-V2X. However, some other challenges that IOOs noted included absence of OEM deployment, lack of U.S. DOT leadership engagement on the subject, technology maturity, and interference risks[81]. Specifically, special permission (Freight Signal Priority, Emergency Vehicle Preemption, etc.) security is an issue for V2X as the SCMS (Security Credential Management System) needs more testing to ensure integrity of the communications between vehicle and infrastructure.

San Diego Regional Proving Ground

The San Diego Regional Proving Ground (SDRPG) is one of 10 proving grounds that were designated by USDOT for testing autonomous vehicle technology on public streets and freeways to provide safe testing and insight into big data optimization[82]. Although the USDOT AV proving ground program is no longer active, this area continues to be a key component of AV development and the RPG remains. The roadways part of the SDRPG include SR125, I15, I5, SR905, and surface streets in Chula Vista. Autonomous vehicle (AV) technology can be tested in real-world situations and has been by projects with industry partners looking at pothole detection, wrong way driver information application, a smart lamppost project, and others. Industry partners can enter into agreements with Caltrans to test equipment in the aforementioned areas, however Caltrans will not compensate the industry partners.

Autonomous Vehicle technology is thus tested and bettered through development on San Diego's roads and highways. As AVs still have maturing to reach deployment, testing will be key to ensure a safe and equitable roll out of AVs. San Diego's role as a Proving Ground positions the area to be a key influence on the development of Autonomous Vehicle technology.

Smart Cities and Transportation Systems

Smart Cities use ICT to enhance the quality and performance of public services to reduce resource consumption and operate efficiently (Figure 18). 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 engage more directly with the public. Smart cities and transportation systems are responsive to changing conditions. Unlike major capital projects, smart infrastructure adapts to unpredictable changes over time like new technologies, changing transportation demands, or emergencies like a global pandemic or natural disasters.

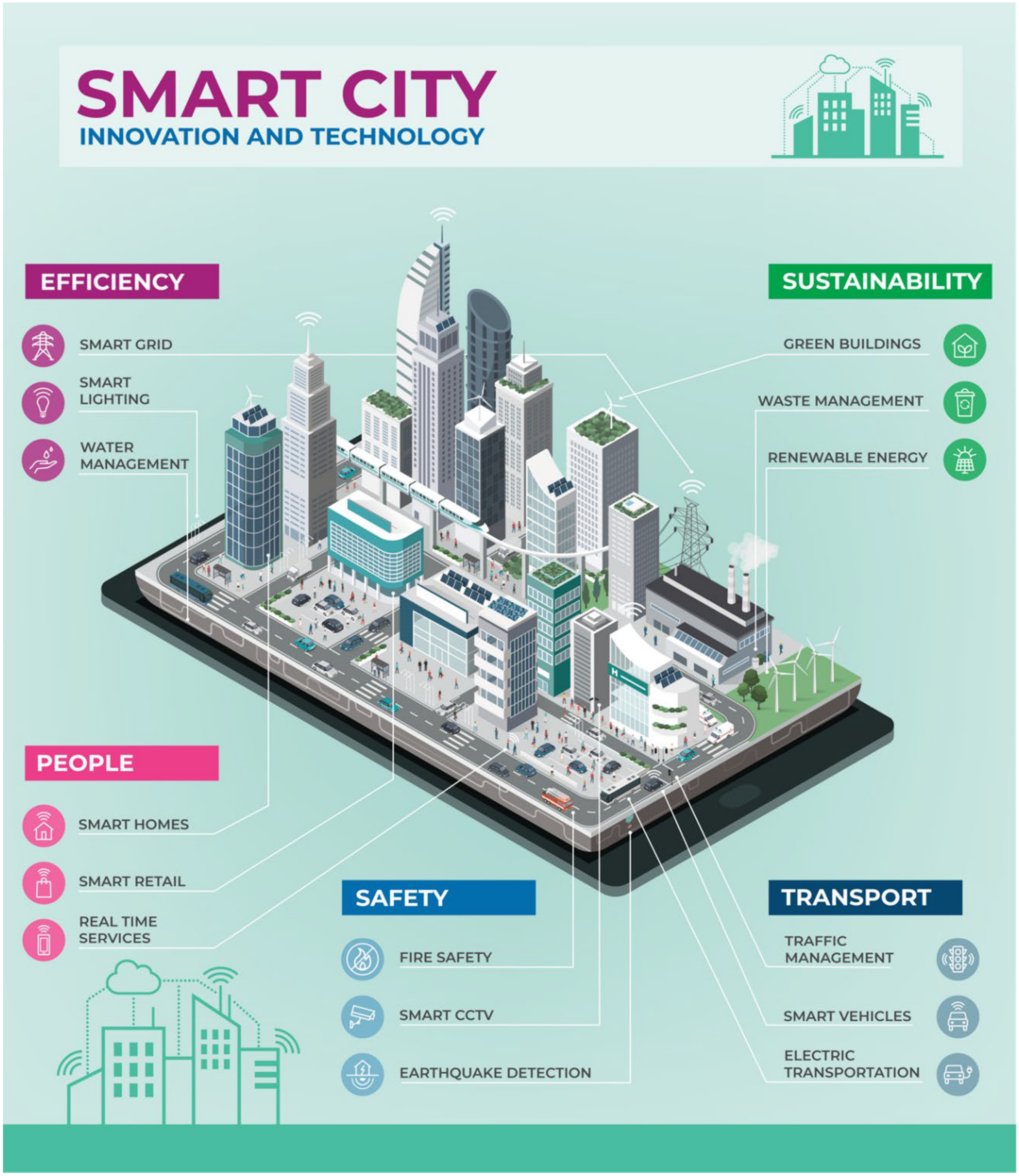


Figure 18: Smart City Concept (Source: elenabs)

In support of Smart Cities, the SANDAG 2021 Regional Plan casts a vision for the Next Operating System. Next OS will be a key functionally for Smart Cities and infrastructure.

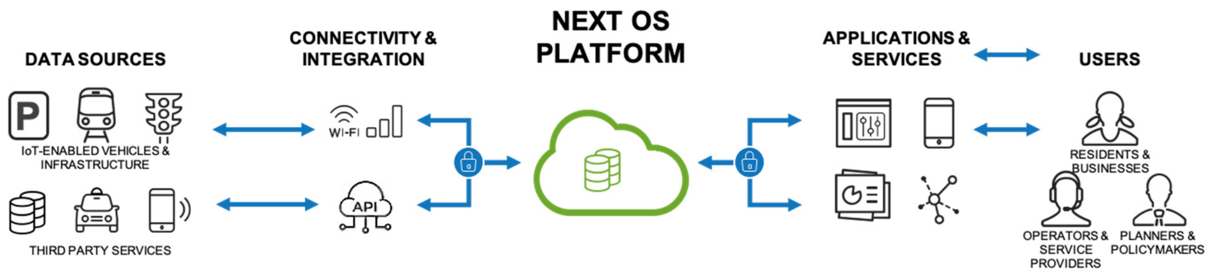


Figure 19: Next OS

The development of the Next OS will jumpstart the vision of Smart Cities by providing the data exchange platform that will support a wide range of smart city and transportation applications. For example, the Next OS will optimize transit and roadways. Data collected from sensors on transit vehicles can monitor where vehicles are and communicate that information to the transit riders, improving the reliability of transit. Sensors can also alert transit operators when vehicle maintenance is required. Data collected from roadway sensors can be used to improve traffic monitoring and operations and detect unsafe conditions to support planning and infrastructure investments. Smart Intersections improve traffic flow and safety for all modes and reduce fuel consumption and emissions (Figure 20).

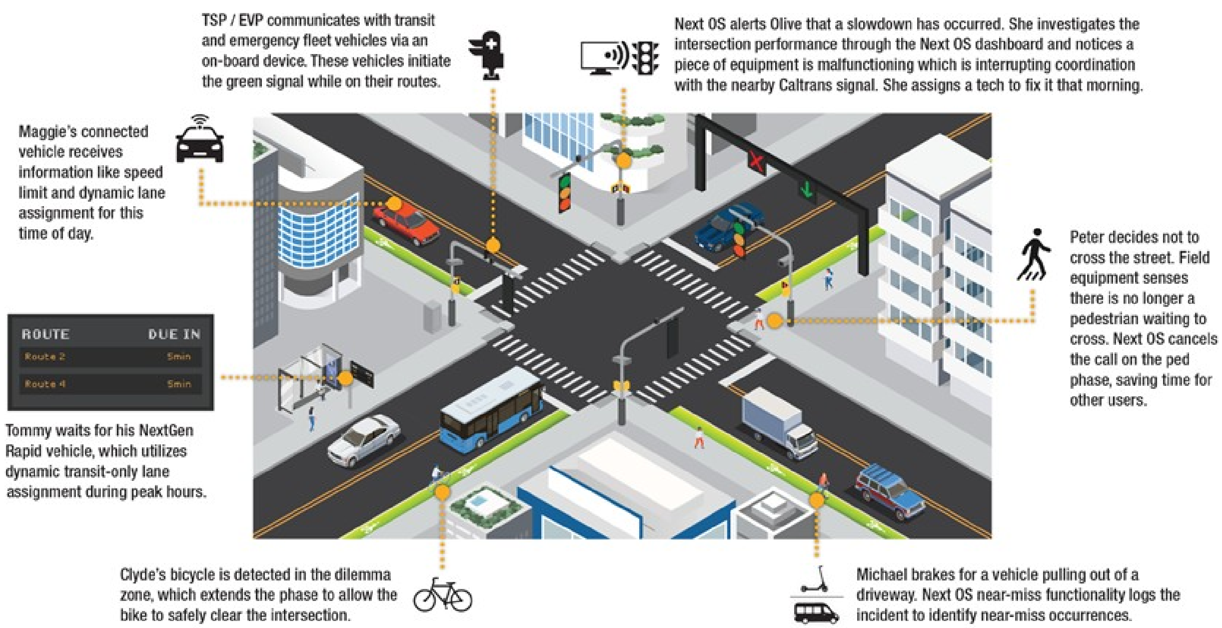


Figure 20: Smart Intersection Systems Concept of Operations

Smart Signals and Smart Intersections

Smart Intersections can begin to take shape with subtle implementations that will bring about Next OS. Infrared sensors, closed circuit television cameras, and in ground loops are examples of existing technology that can all be leveraged to provide far more benefit when enabled with data management, storage, and analysis as Next OS progresses. Advancements in technology, especially AI enabled software, machine learning, and computer vision provide cost-effective solutions at traffic management by complimenting existing technology with innovative performance. An example of CV2X ability for infrastructure could be a Smart Intersections that is enabled with a suite of specific sensors (such as computer vision) or specific routing information from truck data collection preventing overweight or over-height trucks from entering an area through communicating this information to the cab. Bringing traffic signals online with high bandwidth technology and shifting from independent signal timing to advanced traffic management, cities can begin to have an immense amount of control and customization over their infrastructure to provide a responsive network that caters to and cares for the network users. Smart signals also can input precision, real-time data that would then be fed back into Next OS, creating a responsive feedback loop, that when leveraged with innovative technologies, will continually improve functionality.

Traffic signals with "smart" technology currently exist and are manufactured by several companies such as Siemens and Econolite. Smart signals could be employed at new builds while older signals that are within their lifetime could be upgraded to "smart" signal capability. Traffic signals stand to benefit from AI, proliferation of fiber optic, and increasing deployment of more capable intersection controllers, cabinets, and signals, whether they are upgraded or new. Smart signals could incorporate machine learning that uses historical and real-time data to make predictive changes to flow patterns that enhance overall system efficiency. This type of control will be particularly adept addressing non-recurring congestion that allows a rapid response, with little input from the TOC. Smart Signals also proliferate multi-modal transport by increasing sensitivity to all road users. Protected bicycle movements in key active transportation corridors can be achieved through a combination of Smart Signals, equipped with sensors, adjust timing and other movements to allow safer passage to the cyclist, while the Smart Intersection communicates to other signals within the intersection and to other intersections the occurrence. Smart Signals could also provide enhanced movements on rural arterials that may suffer from non-recurring congestion but lack a significant density of signalized intersections for corridor management.

Data that is collected from Smart Intersections and Smart Corridors can enable informed, scientific traffic management that is data-driven through Next OS. The operations of these intersections can then be further refined in a feedback loop that creates harmony among all system users, while optimizing the totality of the network. Information from Smart Intersection and Smart Corridor sensors can be pushed to network users for real-time information regarding signal timing, route length, and historical trends along the corridor, to inform users on delays through 511SD or other private options (Waze, Google Maps, etc.). The same data could be used to make decisions on the necessity of infrastructure improvements. For example, data from Next OS connected intersections could be analyzed to see the benefit of either adding a protected turning movement to a signal or if adding delineators to a bike lane on the roadway will create a safer environment.

Smart Signals may also take shape throughout corridors in the form of smart streetlights. San

Diego has already pioneered this field; San Diego began replacing sodium-vapor streetlights with LEDs that eventually lead to an adaptive control program that enables dimming/brightening of streetlights through wireless control. This was then followed by a GE intelligent cities platform partnership which saw the deployment of additional nodes on the streetlights in 2014 that enabled connection of sensors, who's data is then processed by GE. This is another example of a P3 that has been beneficial to rapid development and deployment of smart infrastructure[83]. Recently, the deployment of smart city sensors had faced push back and a moratorium was issued to the police department from using smart streetlight sensors. The City of San Diego continues to pay interest on the loan from GE that was used to fund the sensors. However, the San Diego Police Department is pushing to use Automated License Plate Readers (ALPRs) that would fulfill some of the functionality that is no longer in place that the smart streetlights had[84].

Curb Management

Curb management is another strategy that will be a key component of the Next OS. Curb management is a concept that reimagines the allocation of valuable curb space. As MaaS continues to evolve and the demand for curb space expands, the development of a curb management system provides an opportunity to use data to flexibly manage how the curb is used at different times of day to meet different needs—passenger pick up and drop off, commercial delivery, flex lanes, parking for micromobility devices, wireless inductive charging, and even food trucks or space for outdoor dining (Figure 21). A white paper on the Next OS Concept was developed to provide more information on transportation use cases proposed in the 2021 Regional Plan[85]

San Diego is familiar with curb management strategies. Not only does the City of San Diego deploy meters for curb management, but the city also piloted a Smart Streetlights program in 2016, partnering with GE for the technology, which has since been purchased by Ubicquia[86]. Initially the system was piloted as a cost saving energy measure by switching to LEDs, which then was augmented by sensors for traffic pattern analysis, but San Diego Police Department used the video/audio capabilities installed on the signals, which created public backlash, leading to the signals and sensors being deactivated and these have since fallen into disrepair[87]. However, the city has recently approved a reactivation of the program that would see new smart signals become operational; this technology could be leveraged to provide smart curb management[88]. Traffic patterns could be monitored and infrastructure improvements and MaaS offerings could be provided intelligently through analysis using Next OS that transition parking lanes to flex zones. Additionally, this type of technology could reduce the need for police personnel to enforce parking time limits. This could potentially increase the turnover rate of parking, which is a principal factor for EV charging. Reliable EV charging opportunities would aid in adoption of EVs as this would target individual's range anxiety. Curb management is critical to ensure overall execution of the 5 Big Moves, as curb space is the cornerstone between movement and destination.

The improvement of existing curb management technology will benefit businesses, communities, and network users by increasing customizability over the current infrastructure. As the MaaS develops, there will be an associated need to incorporate these offerings into the existing infrastructure. The creation and analysis of data regarding curb use patterns will enable precision implementation that address issues that address the varying curb access needs of communities in San Diego.

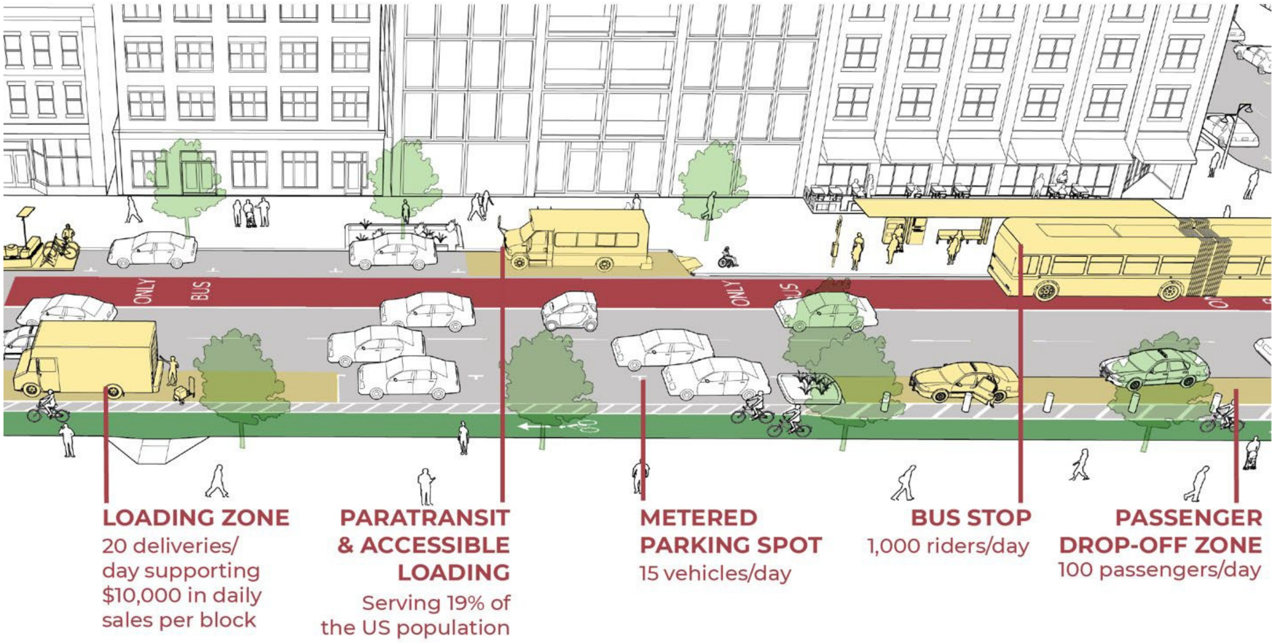


Figure 21: Curbside Management Strategies for Improving Transit Reliability (Source: NACTO)

Parking Management

Parking management differs from curb management as it refers to off-street parking, in this case for parking lots for transit riders. Next OS will ensure the integrity of the service, monitoring traffic into and out of parking lots to create data sets that would enable cost effective value-add service to the lot. Demand pricing could also be undertaken through a system-wide data analysis that could ensure that supply and demand of parking is equal by utilizing Next OS.

Like curb management, parking management could benefit from the smart streetlights program or other more advanced parking monitoring systems. There are numerous streetlights that have yet to be installed that were purchased from GE; these lights could be installed in city lots to monitor parking and provide an opportunity to impact public safety. Public-private partnerships could be made with private parking companies that own, operate, and maintain parking lots and structures to implement similar devices and practices with the eventual goal of incorporating these private parking offerings into the 5 Big Moves, specifically within Next OS.

Additional Smart City Applications

Smart City applications extend beyond transportation and include energy, water and waste management, and public services. For example, just-in-time waste management uses sensors to make waste collection efficient, reducing impact on the environment and transportation. For water management, sensors detect leaks and pollution and identify when maintenance is needed. A smart grid can detect changes in energy consumption and balance supply and demand (Figure 22). Mobile apps, like the City of San Diego's Get It Done app, allow citizens to report issues to the City and get a quick response.

According to Barclays, Smart Cities globally have the potential to generate $20 trillion in economic benefits by 2026. Investment in reliable technology and high-speed connectivity is central to Smart City buildout, which is one reason SANDAG is undertaking the development of a Regional Digital Equity Strategy and Action Plan that will identify and address gaps in high-speed connectivity.

Beyond investing in ICT, becoming a smarter region requires a new operational philosophy that is not constrained by jurisdictional boundaries and legacy governance models. Agencies will need to commit to cooperative operations focused on achieving common objectives regarding user experience, system performance, and policies to operate a complete regional network of smart systems through the Next OS. Most importantly, all agency personnel will need to become a part of this culture of data, and agencies will need to establish and adopt data governance principles and provide data governance training for staff. These principles include establishing processes and methods to ensure accuracy and reliability of data; transparency—communicating to the public how data is used, secured, and protected; and developing privacy impact assessments and access controls.

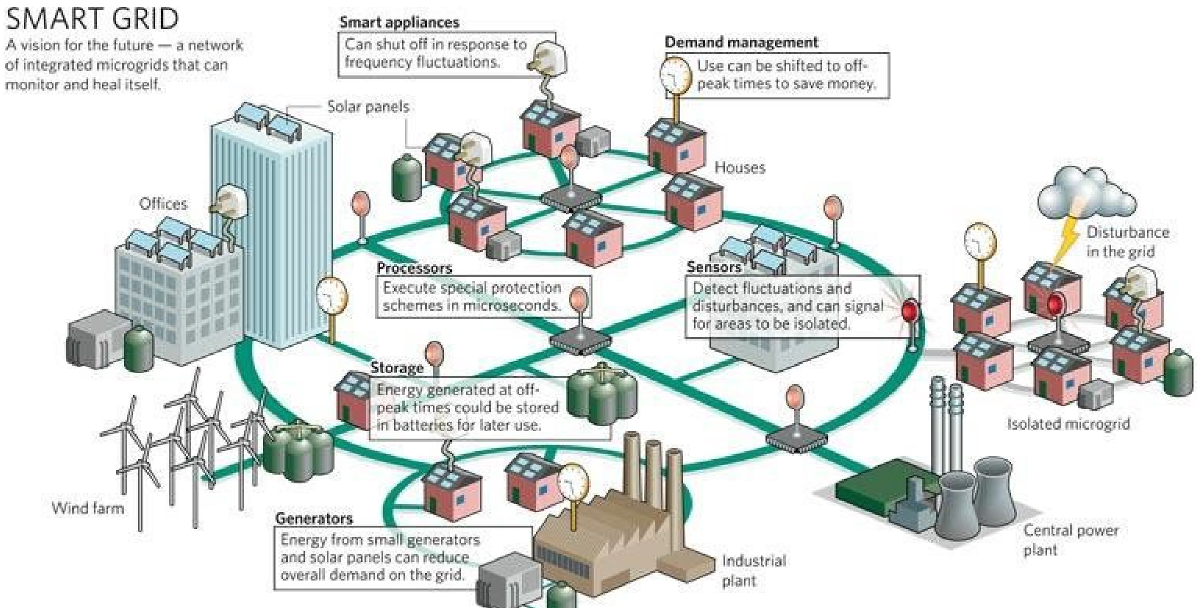


Figure 22: Smart Grid City Network (Source: Smart City Hub)

Smart Cities and Transportation Systems Challenges and Opportunities

Building Smart City capacity: Private companies such as Google and Amazon have used Big Data for many years for product and service planning and personalized marketing.
Public agencies are in the preliminary stages of integrating Big Data into their planning and management systems and will need to invest in the skills and tools to effectively use data to inform planning, policy, and operations.

Making more of our existing infrastructure: We can maximize our existing investments and preserve 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.

Building a nationwide consortium of Smart Regions: Regional agencies and cities must establish mechanisms to share and leverage public dollars spent on ITS projects across the nation. Smart regions across the nation benefit from sharing technical documents (design documents, ConOps, systems engineering, agreements, RFIs, and RFPs), standards, and software artifacts (data ingestion, extraction, transformation and loading tools, storage, dashboards, ITS control, and management).

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[89] Data governance practices are key to the operation of many public agencies. These procedures help ensure data accuracy and reliability, transparency about how data is used, and data security and protection.

Shift to network thinking demands interagency coordination: Nationally, and within the San Diego region, the trend for all tools and systems is to shift from concentrating on isolated transportation systems to focusing on multimodal performance-management tools that provide transportation choices across multijurisdictional boundaries. This requires coordination and cooperation between agencies to integrate regardless of jurisdictional boundaries, creating a seamless transportation experience for the traveling public.

Regional consistency and collaboration are critical to the success of Smart Cities and Transportation: This includes compliance with national and universally accepted standards while also examining opportunities for cross-cutting protocols that help advance new and innovative technologies like on-demand mobility applications. This effort will ensure that future systems are technically adaptable and viable over time and support advancement and synergies between Smart Cities and Transportation systems.

Future of AI in Mobility

Artificial Intelligence (AI) is computer system that enables human-like interaction through immense data processing and analysis. AI has become important in many different applications; however, it is posed to be especially potent in planning for transportation and cities. Within transportation, there are two main avenues that AI can be applied to for current transportation networks. These two routes would be either through vehicles or through infrastructure and would then be connected to AI and create a similar result through different processes.

Figure 23- AV Technology Mockup
(Source: Alamy AV dashboard Stock Vectors)

Autonomous vehicles have been implemented in some cities such as Phoenix or San Francisco. These limited deployments are yielding significant data which is helping original equipment manufacturers to fine-tune their software, sensors, communications, and security features. The current challenge with AVs is integration into current traffic conditions with vehicles piloted by human drivers, which necessitates enormous safety precautions. Autonomous vehicles will continue to need extensive real-world and lab-testing to minimize safety issues to enable this integration. Additionally, manufacturers and IOOs need to understand what the extents of computing will be between their respective.

Infrastructure can also be equipped with artificial intelligence. Some agencies have begun using AI for prediction of incidents to plan and mobilize necessary resources in a timely fashion. AI modeling can help improve traffic flow, reduce congestion, and improve safety on the roadway. As AI continually improves, models that can process more data are able to provide planning agencies and traffic operations with significant information that can shape how individuals move in real time.

Next OS is positioned to reap immense benefits of advances in AI. Artificial intelligence and machine learning can utilize data sets created by Next OS to create predictions, implement traffic management solutions, and enable infrastructure to have a much more instrumental role in the management of congestion. Agencies, owners, and users will benefit immensely through data-sharing agreements that enable Next OS to compile data that is then leverage by artificial intelligence to provide a variety of services from optimization of corridors to dynamic routing for public transit that is scientifically identified as being beneficial to the transportation network.

There is a litany of other items where AI can be employed for the benefit on transportation network uses. AI can be equipped to buses to predict when maintenance is needed to avoid disruptions to schedules, optimize GHG emitting vehicles to minimize output, or analyze bridges for faults to mitigate catastrophes. As the capabilities of AI increases, there become virtually limitless applications of AI to provide insight into solving or mitigating transportation flow.

Next Gen ICM & Evacuation Management

Integrated Corridor Management enables agencies to utilize ITS to improve traffic flow through a region for recurring or non-recurring congestion. As ITS develops with advancements in technology, agencies can consider utilizing elements of ICM to develop contingency plans in case of an emergency that requires immediate mass movement of individuals from area to another. ICM tools, such as emergency vehicle signal preemption, 511, ATMS controlling traffic signals and CMS, can enable optimized routing when coupled with powerful models that can enable the controlling agency to implement a safe and effective traffic movements This modeling can be improved upon when coordinated with Next OS, which will provide large quantities of specific, regional data that will be instrumental in creating and using an evacuation plan.

Evacuation Management

As Integrated Corridor Management advances in use and capability, the development of systems needs to consider "worst-case scenarios" such as tsunamis, wildfires, or earthquakes, that would see a rapid influx of users into the network. The utilization of Artificial Intelligence or Machine Learning can enable ICMs to be able to respond nimbly via Decision Support Systems to unpredicted events. These tools would enable less human interaction to affect the system in a far greater capacity. Nextgen ICM has the capability to provide in-vehicle signage, arterial management through Smart Intersection technology, dynamic routing, and other features that would coordinate movement through a corridor in a much more detailed fashion. In-vehicle signage could significantly improve driver awareness of on-road conditions that may impact traffic flow. Arterial management, a major component of ICM, would see more customizability in NextGen ICM that would increase corridor capacity. Dynamic routing would be possible on managed corridors through AI/ML that would be capable of producing an ordered evacuation response. Next OS would enhance the capabilities of any ICM through the provision and ability to store data is essential to using AI and having information available for Machine Learning.

In tandem with Connected Vehicles (CV), ICM must consider development that involves cellular communication methods to ensure coordination between vehicles, devices, and infrastructure reliably occurs. Connected Vehicles also present a unique challenge to access broader data sets through data sharing agreements. This can be a further measure of ICM performance.

Policy Considerations

While there is uncertainty about how these technology trends will evolve, there is no doubt 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 guide the integration of technology and new mobility services toward an equitable and sustainable transportation future. It will also be vital to ensure an effective transportation policy shapes our use of technology and not the other way around. The Vision for the 2021 Regional Plan presents a transportation future in the San Diego region that seizes the opportunities and benefits of technology while minimizing 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 Flexible Fleets and public transit are convenient, affordable, and comfortable. Communities that have been historically underserved have greater personal mobility and access to economic opportunity.	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 and hydrogen fueling infrastructure to support shared electric fleets.	The lack of charging infrastructure and hydrogen fueling stations prohibits the rapid expansion of zero-emission 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 the Next OS and smart infrastructure, reducing the need 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
High-quality broadband service is available to everyone in the region regardless of income. This level of connectivity allows more people to benefit from online work, learning, remote services, and app-enabled trip-planning and transportation services. Fast and efficient transit and Flexible Fleets enhance mobility for all, including seniors, low-income people, the disabled, and those without access to a privately owned vehicle. The delivery of goods and services is optimized in a connected and autonomous environment. Local Complete Corridor projects become easier to implement with less right-of-way needed for cars. Roads are slower and safer for pedestrians and cyclists, and shared mobility services have designated pick-up and drop-off zones. Less space being needed for parking allows more opportunities for productive uses, like housing.	Complete Corridor projects become more difficult to implement. Ridehailing and commercial 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. The digital divide limits remote access to services, education, and economic opportunities to those who can afford broadband service and a device, exacerbating social and economic inequities. 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.
Smart Cities infrastructure is widely deployed. Data generated from the transportation system and mobility services significantly improve transportation planning and decision making through the Next OS.	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.

The San Diego region has been a leader in piloting and deploying innovative transportation services and technologies. By continuing this legacy of action and leadership, 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 the discussion by policymakers as they take steps toward adoption of a 2021 Regional Plan.

Policy and Investment Considerations

Next OS and Transportation System Management Operations

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. Establish a regional forum for cross-agency collaboration, data sharing, and technical research and pilot projects.

Develop a coordinated Next OS roadmap for the region that identifies high-priority transportation applications and accelerates their deployment. This includes smart intersection systems, curb management, next-generation integrated corridor management systems, and a regional border-management system.

Invest in Next OS demonstration projects that build data management and sharing capabilities and lead to operational coordination across jurisdictions. Consider new service delivery models that make more effective use of public resources and enable cities to adapt to changing conditions.

Develop and implement a Digital Equity Strategy and Action Plan that will close gaps in high-quality broadband access that is essential to the future of transportation and advancing equity in the region.

Pricing and Transportation Demand Management (TDM)

Consider equitable pricing mechanisms that include incentive programs that encourage people to consider their travel choices. Design a pricing and revenue strategy that can address congestion and reduce VMT while creating more travel choices, improving equitable access, and increasing safety.

Continue to invest in TDM incentive programs that reduce drive-alone trips through rideshare incentives, vanpool subsidies, Try Transit passes, and bike encouragement programs.

Invest in telework assistance programs that support businesses with expanding remote work to reduce commute trips. Telework assistance programs in conjunction with Digital Equity efforts will ensure more employees can take advantage of teleworking opportunities.

Adopt a regional TDM policy that builds upon the SANDAG iCommute Employer program to reduce drive-alone commute trips. Enhance regional modeling tools to better account for the impact of technology on transportation demand and travel behavior.

Develop and update technical resources and tools that support local government agencies with planning and preparing for technology and new mobility services, such as updating the Parking Management Toolbox to account for emerging modes and developing a regional curb management strategy. Encourage information sharing, coordination, and capacity building.

Mobility Hubs: Land Use and Housing

Invest in Mobility Hub and Flexible Fleet demonstration projects and supportive policies that improve access for all, ensure equity, and promote safety across modes.

Position the region as a true testbed for pilots and P3s that provide the greatest public benefit. Establish funding programs to incentivize local pilots such as the shared streets concepts or demonstrations of emerging mobility and technology solutions.

Encourage land use and housing policies that focus development within mobility hubs to create well-connected communities that are integrated with public transit and seamlessly connect people between shared modes.

Active Transportation: Bike Network, Vision Zero, and E-Bikes

Invest in safe street designs, slow speeds, and adopt Vision Zero policies that promote safe movement, allowing more people to feel comfortable choosing to walk, bike, and ride micromobility to get around their communities.

Invest in Next OS applications and technology solutions that improve safety and complement Vision Zero policies to protect vulnerable roadway users.

Invest in e-bike incentives to expand the number people of who can use biking as a viable travel option.

Zero-Emission Vehicles: Charging and vehicle incentives, buses and other fleets

Adopt policies and incentive programs that accelerate EV adoption in Mobility Hubs and along Complete Corridors by providing publicly accessible EV charging and hydrogen stations.

Develop policies that encourage Transit Leap and Flexible Fleets services to adopt EVs for transit, passenger, and commercial delivery vehicles.

Optimizing Infrastructure: Climate Resilience and Adaptation, Fix It First

Invest in enhancing critical infrastructure vulnerable to climate change through Climate Resilience and Fix It First strategies, which can help to sustain transportation and technology investments on regional roadways.

Appendix A – Summary of Technology Maturity, Challenges, and Risks of Vehicular Technologies

Quoting from the groundbreaking UC Davis report, *Three Revolutions in Urban Transportation:*

> *"Our central finding is that while vehicle electrification and automation may produce potentially important benefits, without a corresponding shift toward shared mobility and greater use of transit and active transport, these two revolutions could significantly increase congestion and urban sprawl, while also increasing the likelihood of missing climate change targets[90].*

The report highlights *Electrification*, *Automation,* and *Shared Mobility* as the three technologies that will revolutionize the future of mobility. Without *shared mobility*, our sustainability and access goals will not be met. The following table summarizes technology maturity, challenges, risks, and how they address the following major goals of the 2021 Regional Plan—Equity and Access, Congestion and Emissions Reduction, and Safety.

Technology Maturity	Challenges and Risks	Alignment with Goals
Shared Vehicles: Carshare		
Now: App-based sharing of personally owned vehicles or fleet vehicles enabled by remote keyless entry using smartphone.		
Future: New technologies enable access for unbanked and those without smartphones. Complete electrification of carshare fleets by 2030.		
Shared Rides: Rideshare and Microtransit Excluding Ridehail[91]		
Now: App-enabled on-demand rideshare and microtransit are already commercially deployed. **Future:** Scaling up fleet sizes will continue to improve service performance and vehicle occupancy. Complete electrification of rideshare fleets by 2030.	• Difficult to provide carshare service to unbanked and those without smartphones. • Lack of policies and incentives to make microtransit and ridesharing more widely available and accessible to underserved communities	• Pooling results in **significant reduction in VMT and GHG** due to high occupancy rides and all electric fleets • Lower cost, greater coverage footprint, and better level of service than existing fixed-route transit service, results in **improved access and equity.**

Technology Maturity	Challenges and Risks	Alignment with Goals
Electric Vehicles		
Now: 95 EV models are available in the U.S. as of 2023. Battery technology continues to mature. But EV charging infrastructure lagging (not keeping pace) with the market. **Future:** UK, California, and China have established aggressive targets for 2035 that are creating scale. Advanced charging infrastructure and improvements in battery technology will address range anxiety.	• A dramatic increase in electricity production and build-out of the distribution grid, are needed. Deployment of public charging infrastructure is lagging. • Environmental impact of battery raw material extraction and disposal/recycling/reuse.	• EV adoption will lead to **significant GHG reduction** and improved air quality.
Telematics and Cloud Connectivity		
Mature: Commercially deployed now in high-end models and coming to all models.	• Data is locked into proprietary ownership.	• Data can inform planning for **infrastructure improvements**, as well as congestion monitoring and corridor management. • Usage-based insurance discounts can promote **safety**.
Connected Vehicles (CV) V2X		
Now: V2X Technology is available now but no widespread deployments to achieve maturity. **Future:** We anticipate widespread adoption by 2030. It appears that U.S., China and Europe have settled in favor of C-V2X. With a single technology, adoption can proceed.	• Widespread deployment is awaiting valuable use case or government mandate. • Highway congestion reduction from platooning may lead to increased VMT and move the congestion bottleneck to the on- and off-ramps.	• **Congestion reduction** through transit signal priority, freight signal priority and bus on shoulders, etc. • **GHG reduction** through commercial vehicle platooning on highways. • V2X can supplement on-board sensing to **enhance ADAS safety** features being commercialized now.

Technology Maturity	Challenges and Risks	Alignment with Goals
Advanced Driver Assistance Systems (ADAS)		
Now: Convenience and safety features are being commercialized now for high-end vehicle models **Future:** ADAS features will be available in all new vehicles sold within a decade.	• Current cost of sensing and computing of safety technologies limits deployment in mid- and low-end models.	• **Significant safety benefits** through ADAS features including lane keeping, adaptive cruise control, blind spot elimination, pedestrian and bicycle detection, automated braking, and collision avoidance.
Autonomous Vehicles (AV)		
Now: Currently 50 companies have permits to test AVs on CA roads[92]**.** In 2023, the CPUC authorized Waymo and Cruise to begin charging for fares in San Francisco[93]. Technology is expensive, but the cost of sensors and computing is falling. **Future:** Widespread deployment is unlikely until 2035, but more and more cities will have AV ridehail and rideshare available in selected geofenced portions of the city.	• In the absence of pooling, studies show that AVs will lead to increased congestion and VMT. • Challenges remain to expand to different regions, different weather and lighting conditions, interactions with other drivers and road users.	• **Improve safety** beyond ADAS features to achieve **Vision Zero**. • By eliminating the need for a driver, AVs lower the cost of providing ridehail and rideshare to **improve access and equity.** • Reduced vehicle ownership leads to **lower VMT and GHG**, but only with increased rideshare and microtransit. In the absence of pooling, AV ridehail will result in increased VMT.

Notably, we would like to highlight near-term technology trends.

1. Technologies are available now to expand rideshare, microtransit, and carsharing. Reduced private car ownership has been shown to result in reduced VMT and reduced household cost for transportation. Policy interventions are necessary to encourage riders and providers to increase pooled rides and vehicle occupancy.
2. Driver assistance and safety features that decrease fatalities of vulnerable road users are being commercialized now, and automakers are expanding these features to all vehicles.
3. EV adoption is accelerating rapidly, assisted by regulators, policy targets, and technology.

In the longer term,

4. Level 5 AVs will offer increased safety benefits and improve the ridehailing business model by eliminating the labor cost of a driver. Without policy intervention, AVs will likely increase VMT and provide little benefit to people

who stand to benefit most from automation (disabled people, seniors, and those who rely on transit).

Appendix B – COVID-19 Considerations

COVID-19 drastically changed travel behavior and increased reliance on technology for work, school, and accessing goods, services, and social activities. Whether or not the pandemic will have a lasting effect on how people travel is unknown but teleworking and participating in e-commerce are two behavior changes enabled by technology that will impact transportation well into the future.

The traditional peak-period congestion could become a thing of the past for a portion of the workforce. Prior to the pandemic, 10% of the U.S. labor force worked from home. During the pandemic, an incredible 42% of the U.S. labor force worked from home full-time[94]. While it is likely that employees will return to the office at some level after a majority of the population is vaccinated, higher rates of remote work are expected to continue. Beyond remote work, other services, like telehealth and online learning, have skyrocketed, and we can expect to see more services accessed remotely in the future.

While telework has the potential to relieve some peak-period congestion in the future, roughly 61% of all occupations in the San Diego region are not conducive to working from home. A common misperception is that teleworkers do not drive much. Data from the SANDAG 2016 Regional Transportation Study demonstrated that while teleworkers may not contribute as much to peak-period congestion, they tend to make more discretionary trips for shopping, leisure, and social purposes. This is supported by data from the U.S. National Household Travel Survey, which found that teleworkers took 11% more non-work trips per day, and on average, those trips were 16% longer. This may explain in part why traffic levels on highways rose as the year progressed and reached close-to-pre-pandemic levels by the end of 2020.

Employees are increasingly seeking flexibility in their workweek, whether this consists of compressed workweeks, part-time work, or telework, these create change to the transportation patterns of the traditional work week[95]. The changing nature of connecting to the office means that new patterns will have to be anticipated interpreted, and incorporated into planning efforts that gauge an evolving transportation network. Not all work is suitable for telework however, and various stakeholders can work together to understand the suitability of telework for various fields to create accurate modeling that will benefit transportation planning.

A major challenge to telework is the change in management style that is required to still measure the productivity of employees. Switching from in-office to online can create a disconnect between management that could create distrust between employee and manager[96]. This can be mitigated through achievement-based productivity measurement rather than trusting that an employee is completing goals by being in the office. Again, this requires planning organizations to have an up-to-date understanding of what are considered best practices and predicted industry trends for local businesses.

Another big behavioral change that will have long-lasting implications for transportation is online shopping. E-commerce was already impacting transportation prior to the pandemic, with online shopping growing as a percentage of total retail sales from 0.6% at the end of 1999 to 14% in 2020[97] The boom in e-commerce has accelerated growth in freight distribution and delivery services[98]

Shared mobility services across the board experienced a decline in ridership. The use of public transit and privately operated shared mobility services fell sharply and has been slower to recover compared to private automobile travel. However, during the COVID-19 pandemic, shared mobility services have proven their role in ensuring economic opportunity for a significant sector of the workforce comprising primarily low-income and minority employees in the service industries who depend on public transportation. Transit operators implemented germ barriers, rear-door boarding, and cashless no-contact fare payment to help protect both riders and transit operators. In addition, microtransit has enabled cities and transit agencies to offer flexible, on-demand rides for essential workers and those who depend on public transportation. This shift to on-demand transit has allowed transit agencies to provide right-sized service that fills gaps created by reduced transit operations during the pandemic. The shift towards microtransit that has the potential to proliferate in ensuing years.

Transit ridership should recover as more of the population is vaccinated. In summer 2020, SANDAG surveyed approximately 3,800 households on their travel behavior during the pandemic; 42% of respondents reported that they used transit at some level before COVID-19 and will continue using transit in the future, and 18% of individuals who did not use transit before COVID-19 said they will use transit after a vaccine. Only 4% of people who took transit previously said they will not use transit after the COVID-19 pandemic concludes. While transit and shared mobility ridership was negatively impacted by the COVID-19 pandemic, biking and walking activity increased across the nation as public health lockdowns led to people finding solace in outdoor recreational activities. Locally, biking volumes were up 42% on average from mid-March to mid-August 2020 compared to the same period in 2019 as measured on the San Diego regional bike network[99]. A SANDAG survey of local residents discovered that 84% of residents surveyed who said they were biking more since the stay-at-home order began said they expect to continue biking. COVID-19 also brought to light the impacts of the digital divide. Although this is not a new issue, unconnected and under-connected residents suffered greatly during the pandemic when work, school, social and civic activities, and critical services shifted from in-person to online. Up to 40% of students in some school districts in the San Diego region do not have a broadband subscription at home or a device to access the internet; 23% of households in the region earning less than $50,000 per year do not have broadband service at home. Access to the internet has become essential to our lives, and for this reason, policymakers at all levels of government are scrambling to get every community connected.

Ubiquitous broadband is critical to the future of transportation and the ability to fully benefit from the technology advancements that this white paper addresses. SANDAG is developing a Regional Digital Equity Strategy and Action Plan to ensure everyone in the region has broadband access and the ability to use ICT to improve their lives.

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