

FLORIDA DEPARTMENT OF TRANSPORTATION FUTURE MOBILITY RESEARCH SYNTHESIS

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LIST OF ABBREVIATIONS

ACES	Automated/Connected/Electrified/Shared
AV	autonomous vehicle
BRT	bus rapid transit
CAV	connected and autonomous vehicle
CV	connected vehicle
C-V2X.....	cellular vehicle-to-internet communication
DSRC	dedicated short-range communications
EV	electric vehicle
ITS.....	intelligent transportation system
LRTP	long-range transportation plan
MaaS.....	Mobility as a Service
MPO	metropolitan planning organization
MTP.....	metropolitan transportation plan
NHTSA	National Highway Traffic Safety Administration
PAV	privately or personally owned autonomous vehicle
SAE	Society of Automotive Engineers
SAV	shared autonomous vehicle
SWOT	Strengths, Weaknesses, Opportunities, Threats
TNC.....	transportation network company
TRB	Transportation Research Board
UAS.....	unmanned aircraft system
VMT.....	vehicle miles traveled
vp/lnh.....	vehicles per lane per hour
ZOV	zero-occupant vehicle



1.0 INTRODUCTION

This task work order synthesizes recent research on and practices around rapidly evolving transportation technology and trends. This synthesis will help FDOT support State metropolitan planning organization (MPO) staff and prevent duplicative research among the State's 27 MPOs. The subject of the synthesis reflects the growing interest in both the technology and societal impacts of future mobility, which FDOT defines using the acronym ACES, which stands for Automated/Connected/Electrified/Shared mobility options. MPOs preparing their next long-range transportation plans (LRTPs), which will have a horizon year of 2045 or beyond, are concerned with how to address these issues. This synthesis will ameliorate those concerns and offer guidance for MPOs developing LRTPs.

The synthesis first required a literature review. RSG set two limiting factors to guide the review:

1. Cite only academic research.
2. Cite no research published after February 1, 2018.

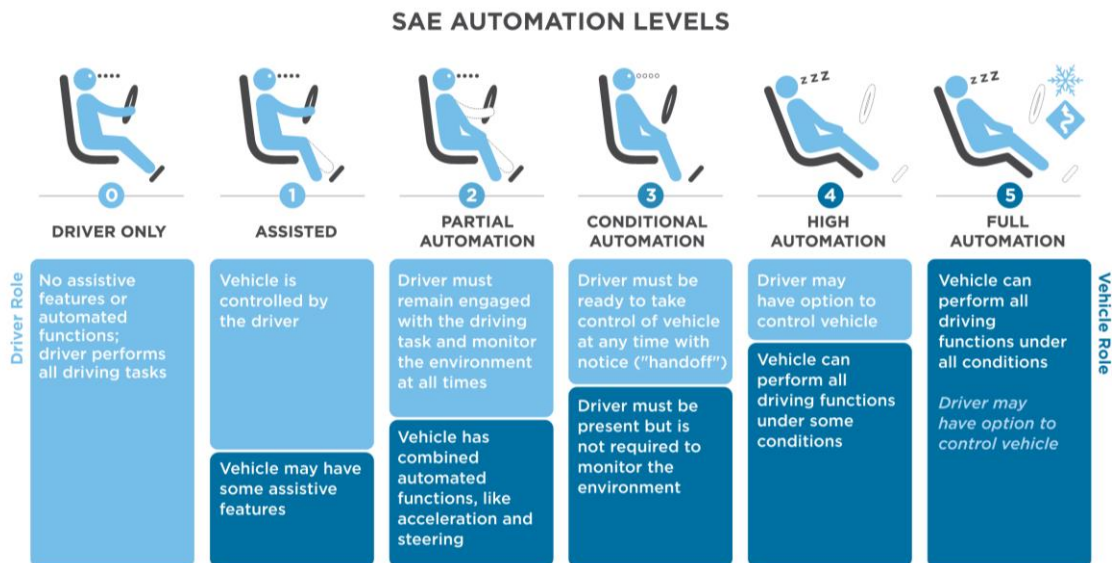
This synthesis relies primarily on the academic sources contained in the literature review, but it also cites some additional sources that are footnoted.

The framework depicted in Figure 2 and Figure 3 provided further structure using these definitions:

- **Passenger Modes**
 - **Connected vehicle (CV).** These are otherwise conventional vehicles that have on-board communication technology—either dedicated short-range communications (DSRC) technology, a cellular alternative (C-V2X), or a network wide communication such as 5G. The purpose of these methods is vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or vehicle-to-everything (V2X) communication.
 - **Autonomous vehicle (AV).** These may range across the SAE spectrum depicted in Figure 1.
 - **Privately owned autonomous vehicle (PAV).** The ownership model would not change from current standards, with AVs replacing conventional autos.
 - **Shared autonomous vehicle (SAV).** Transportation network companies (TNCs) (like Uber or Lyft), transit authorities, or new business models may own autos. They are expected to operate in an on-demand model through reservations made via smartphone app and use algorithms to optimize trip-sharing and trip-chaining. The shared terminology is often used to refer to

both privately owned vehicles that are shared (e.g., Turo) and nonprivate ownership (e.g., fleet ownership). The shared terminology is sometimes incorrectly used to define vehicle occupancy.

FIGURE 1: LEVELS OF AUTOMATION DEVELOPED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) INTERNATIONAL AND ADOPTED BY THE US DEPARTMENT OF TRANSPORTATION



Source: RSG

- **Freight Modes**

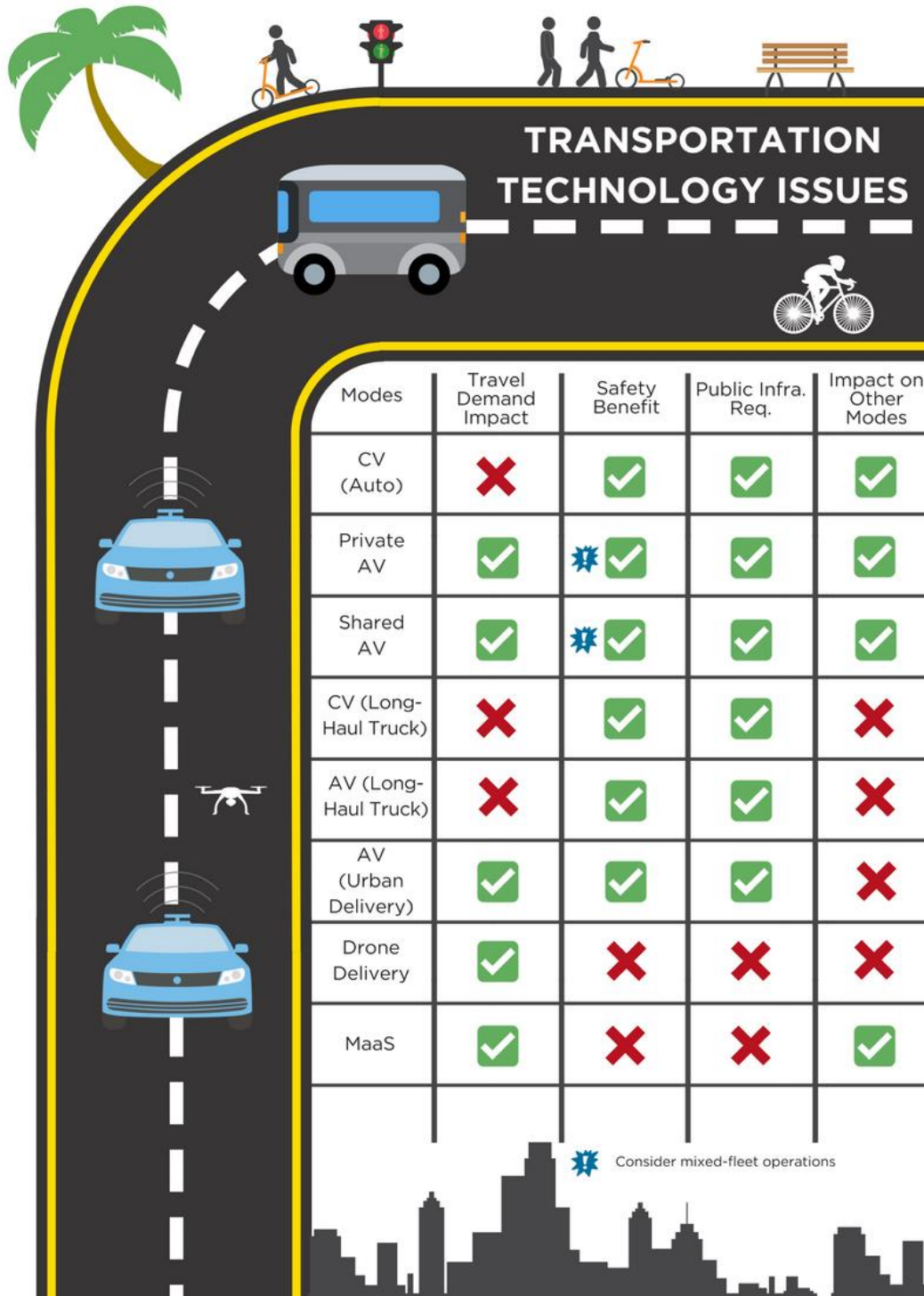
- **Connected vehicle, long-haul truck (CV-truck).** These are otherwise conventional tractor-trailers that have on-board communication technology to support V2V, V2I, and V2X. A key V2V function is truck platooning. This allows trucks to travel in closely spaced groups to save fuel.
- **Autonomous vehicle, long-haul truck (AV-truck).** These will include high and full automation. Their use would likely be limited to long-haul trips.
- **Autonomous vehicle, urban delivery (AV-urban truck).** This includes trucks and related vehicles that are fully autonomous. They may be used for many purposes, including parcel delivery to homes and businesses, wholesale delivery to businesses, and garbage pickup and maintenance functions.
- **Unmanned aircraft system (UAS).** A subset of UAS are unmanned aerial vehicles, or drones, which have many uses; in this context, the purpose is package delivery.



- **Mobility as a Service (MaaS).** MaaS is not about specific vehicle types; it is about people purchasing *trips* rather than vehicles. Currently, a person in a household that owns no vehicles may use transit, bikeshare, carshare, auto, or TNC for any given trip. Future mobility adds SAV to household choices.
- **Transportation Technology Issues**
 - **Travel demand impact.** Overall impact of each mode on trip-making by households and trips generated by businesses; effect on vehicle miles traveled (VMT), travel time, and congestion.
 - **Health and safety benefit.** Ability to reduce the number and severity of crashes. Positive public health benefits from automation, while maintaining benefits from utilization of active transport modes.
 - **Public infrastructure requirements.** What must transportation system owners and operators construct or deploy for a given mode to operate?
 - **Impact on other modes.** Most prominent is the impact on public transit, as it is currently constituted. Active modes, like walking and biking, have also been negatively affected by rise in ridesharing and TNCs.
- **Societal Issues**
 - **Social equity.** Impact on low-income and minority populations:
 - Will pricing preclude use of certain options by these populations?
 - Will underserved neighborhoods lack service? Or will these populations gain new mobility options?
 - Will technology barriers reduce access to new mobility options?
 - Will less desirable land uses like satellite parking or automated distribution centers be in underserved neighborhoods?
 - **Land use.** How will new mobility options change the way people select residential or business locations?
 - **Zoning and parking.** Impact on zoning requirements, especially in the realm of site design, and on-site and off-street parking. Adaptability of land uses to respond to new mobility options.
 - **Accessibility.** Impact on multimodal access to desired destinations.
 - **Employment—type and location.** Impact on specific employment types, both within and beyond the transportation sector and changes in location.

The breadth of findings revealed by this synthesis reflects the initial stages of development of the modes cited here. The purpose is not to draw conclusions, but to explain current thinking. This may sometimes be done via a “majority/minority” approach that indicates that much of the research supports a certain set of findings, but that other credible sources reach different conclusions. In other cases, no clear direction may yet exist, and that will also be shared.

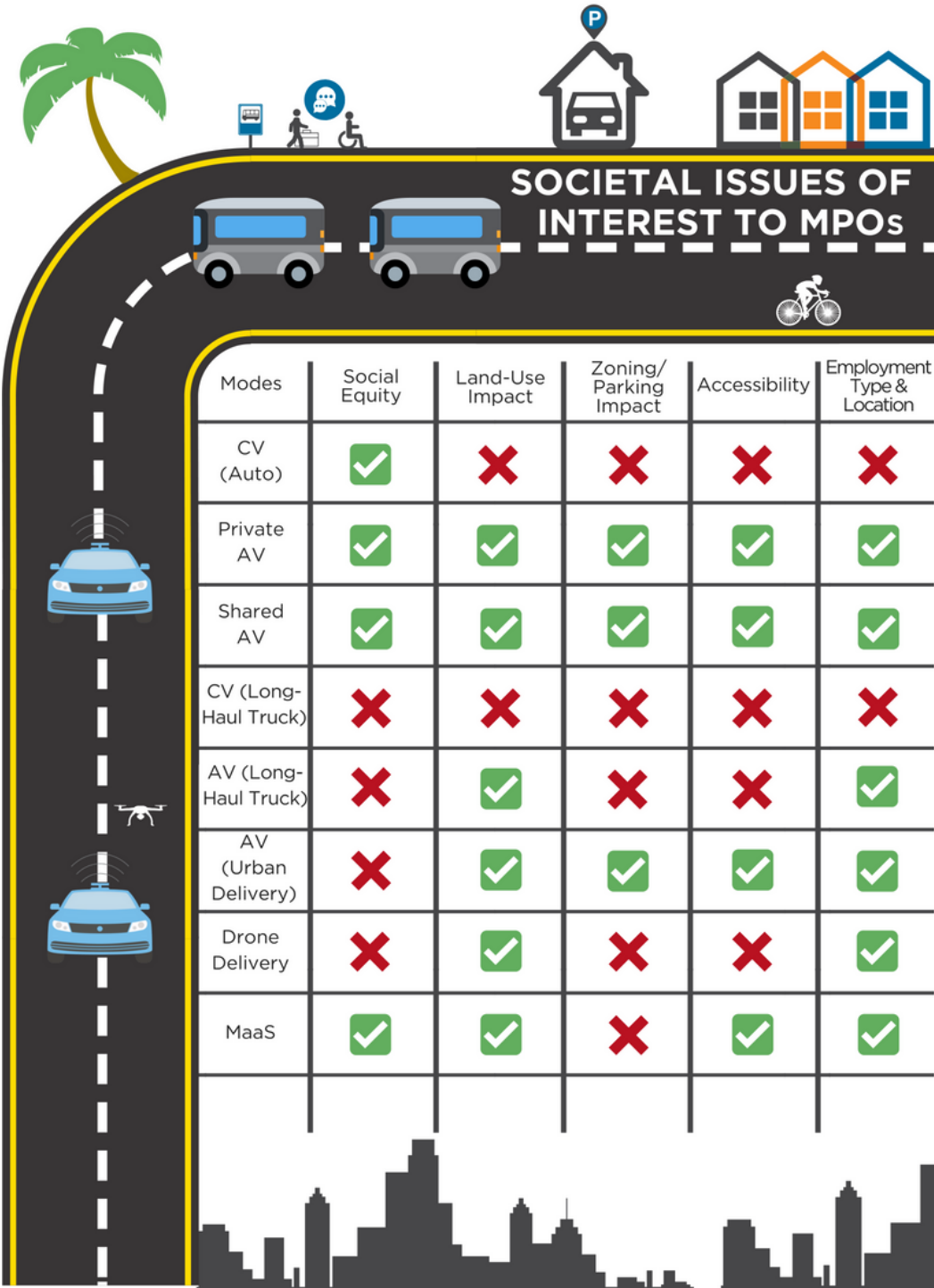
FIGURE 2: TECHNOLOGY FRAMEWORK—TRANSPORTATION TECHNOLOGY ISSUES



Source: RSG



FIGURE 3: TECHNOLOGY FRAMEWORK—SOCIETAL ISSUES OF INTEREST TO MPOs



Source: RSG

2.0 SYNTHESIS¹

MPOs are required to adopt a long range transportation plan (LRTP) that has a horizon year at least 20 years beyond the adoption date. An LRTP often relies on demographic forecasts that describe the future of population, employment, and land use to forecast travel demand. Next, a determination is made about the multimodal transportation system needed to serve that future region. This is then translated into a set of projects, actions, and strategies that guide the investment of federal, State, and other available financial resources.

Until recently, no reason existed for an MTP to assume significant changes in mobility options. Personal trips would be made by single or multioccupant auto, transit, bicycling, or walking. However, as suggested by this synthesis's framework, developing a successful LRTP with a horizon of 2045 or beyond now requires asking new questions that focus on the impact of future mobility options on personal travel and goods movement, transportation infrastructure, and land use:

- What is the expected fleet composition and array of available mobility options at the midpoint of the LRTP and at the horizon?
- What is the expected timeline for implementing each form of future mobility?
- What is the expected impact on VMT and person-miles traveled (PMT)?
- What is the expected impact on mode share?
- Will there be new requirements and standards for physical infrastructure? For communications/intelligent transportation system (ITS) infrastructure?
- How will land-use forecasts be affected?
- How will transportation investment priorities and funding methods change to meet the region's transportation needs?

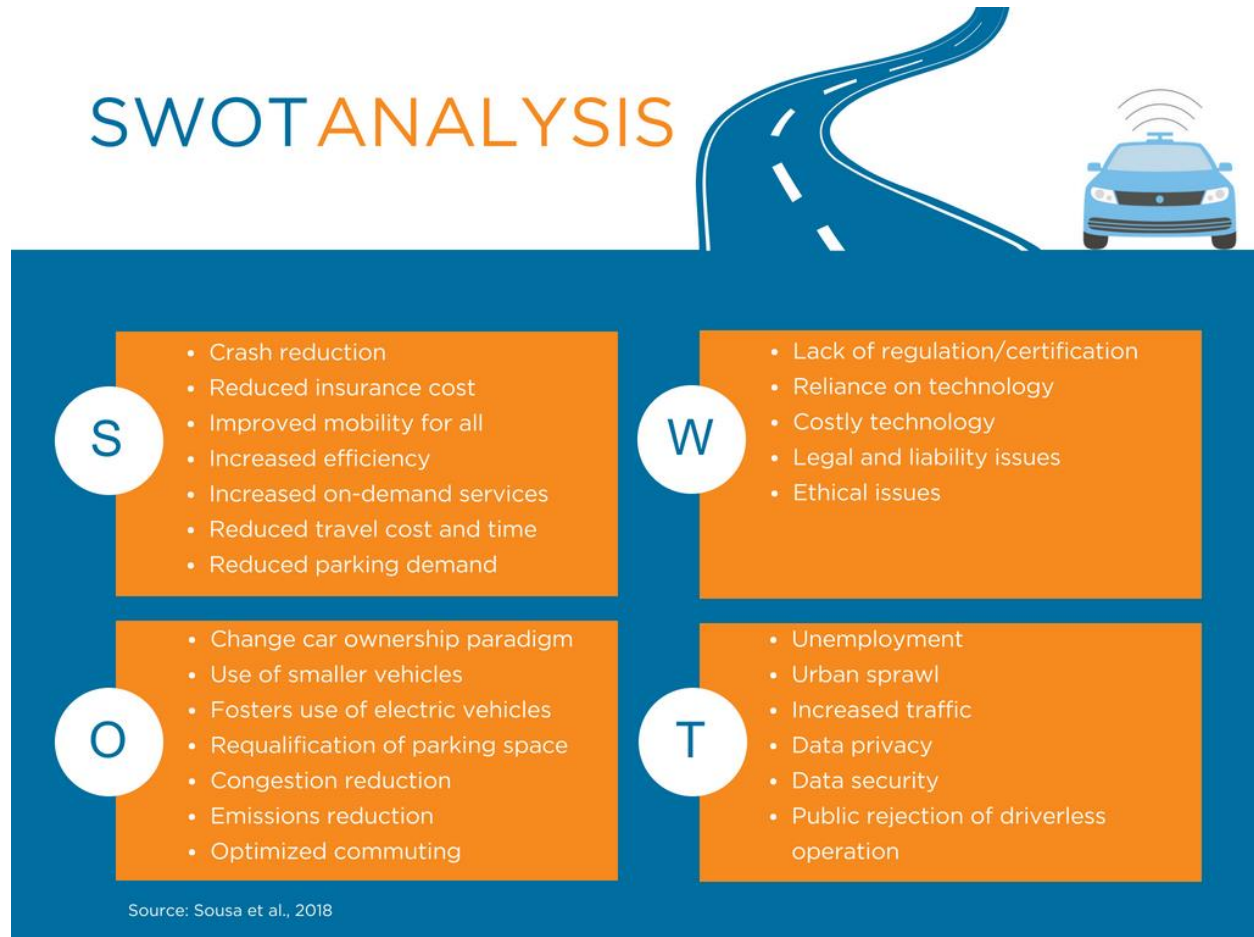
The Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for AV shown in Figure 4, which is adapted from Sousa et al. (2018), provides a basis for working through many of these planning concepts.

Developing a successful LRTP with a horizon of 2045 or beyond now requires asking new questions that focus on the impact of future mobility options on personal travel and goods movement, transportation infrastructure, and land use.

¹ Sources from the Literature Review are identified with the author and date in parentheses and are listed in Section 3.0. Other references are footnoted.



FIGURE 4: SWOT ANALYSIS FOR AV



Source: RSG, based on research conducted by Sousa et al. (2018)

2.1 OVERARCHING ISSUES

This synthesis helps define two key overarching issues: the timeline of CAV² adoption and the CAV ownership model. Both are central factors to the development of LRTPs.

Timeline

Some uncertainty exists about the CV and AV adoption timeline (Figure 5), but agreement exists in the literature that CV adoption is imminent, with an important caveat. The National Highway Traffic Safety Administration (NHTSA) issued a Notice of Proposed Rulemaking in December 2016 regarding V2V communication. The proposed rule would require that all light-

² Because broad agreement exists that AVs will also be connected through similar forms of communication as conventional CVs, the acronym CAV (connected and autonomous vehicle) is often used.

duty vehicles come equipped with DSRC capability. NHTSA has not issued a Final Rule, leaving both the auto industry and public sector traffic operations agencies uncertain about whether DSRC or a cellular communication method will become the universal CV platform. Public agencies may consider the risk of deploying roadside devices and communication infrastructure to be too great until regulatory agencies promulgate clear guidance.

FIGURE 5: ADOPTION STEPS TO IMPLEMENTATION



Source: RSG

With AVs, the timespan between the introduction of AVs in the market and the achievement of near-universal fleet penetration is critical. The regulatory response and public costs and benefits are entirely different in mixed-fleet operations than for exclusive CAV operations. Specific impacts are addressed in the following section. An example scenario is whether CAV owners will demand exclusive AV lanes or facilities, so they can enjoy the full benefit of their vehicles.

Market penetration has been addressed by some research (Bozorg & Ali, 2016) in terms of modeling user acceptance. Vehicle cost, perceived risks and benefits, and peer influence will influence adoption rates. Savings on insurance and parking may offset, in part, added vehicle cost. Litman (2018) has proposed a detailed timeline of adoption and benefits (Table 1). While Litman (2018) sees fully autonomous vehicles available for sale in the 2020–30s, with some benefits accruing, he takes a more conservative view of market penetration. Litman (2018) projects a major share of AVs after 2040, near-universal use after 2050, and mandated use after 2060. A survey of OEMs³ reveals that they all see fully autonomous vehicles being available around 2020. Several researchers (Wadud et al., 2016; Fagnant et al., 2015) note the average automobile fleet turnover rate of approximately 15 years, suggesting that it will take at least that long after initial market availability to realize significant penetration. This will require careful monitoring as to the potential for shared fleets that might alter expected behavior.

³ Walker, J. 2018. “The Self-Driving Car Timeline — Predictions from the Top 11 Global Automakers,” *Tech Emergence*. Please visit [The Self-Driving Car Timeline - Predictions from the Top 11 Global Automakers: https://www.techemergence.com/self-driving-car-timeline-themselves-top-11-automakers/](https://www.techemergence.com/self-driving-car-timeline-themselves-top-11-automakers/).



TABLE 1: CV AND AV ADOPTION TIMELINE (SUGGESTED SCENARIO)⁴

Impact	Functional Requirements	Planning Impacts	Time Period
Become legal (already legal in Florida)	<ul style="list-style-type: none"> • Demonstrated functionality and safety 	<ul style="list-style-type: none"> • Define performance, testing, and data collection requirements for automated driving on public roads 	2015–25
Increase traffic density via vehicle coordination	<ul style="list-style-type: none"> • Road lanes dedicated to vehicles with coordinated platooning capability 	<ul style="list-style-type: none"> • Evaluate impacts • Define requirements • Identify lanes to be dedicated to vehicles capable of coordinated operation 	2020–40
Independent mobility for nondrivers	<ul style="list-style-type: none"> • Fully autonomous vehicles available for sale 	<ul style="list-style-type: none"> • Allows affluent nondrivers to enjoy independent mobility 	2020–30s
Autonomous carsharing/taxi	<ul style="list-style-type: none"> • Moderate price premium • Successful business model 	<ul style="list-style-type: none"> • May provide demand-response services in affluent areas • Supports carsharing 	2030–40s
Independent mobility for lower-income	<ul style="list-style-type: none"> • Affordable AVs for sale 	<ul style="list-style-type: none"> • Reduced need for conventional public transit services in some areas 	2040–50s
Reduced parking demand	<ul style="list-style-type: none"> • Major share of vehicles are autonomous 	<ul style="list-style-type: none"> • Reduced parking requirements 	2040–50s
Reduced traffic congestion	<ul style="list-style-type: none"> • Major share of urban peak vehicle travel is autonomous 	<ul style="list-style-type: none"> • Reduced road supply 	2050–60s
Increased safety	<ul style="list-style-type: none"> • Major share of vehicle travel is autonomous 	<ul style="list-style-type: none"> • Reduced traffic risk • Possibly increased walking and cycling activity 	2040–60s
Energy conservation and emissions reductions	<ul style="list-style-type: none"> • Major share of vehicle travel is autonomous • Walking and cycling become safer 	<ul style="list-style-type: none"> • Supports energy conservation and emission reduction efforts through vehicle electrification and more nonmotorized travel 	2040–60s
Improved vehicle control	<ul style="list-style-type: none"> • Most or all vehicles are autonomous 	<ul style="list-style-type: none"> • Allows narrower lanes and interactive traffic controls 	2050–70s
Need to plan for mixed traffic	<ul style="list-style-type: none"> • Major share of vehicles are autonomous 	<ul style="list-style-type: none"> • More complex traffic • May justify restrictions on human-driven vehicles 	2040–60s
Mandated AVs	<ul style="list-style-type: none"> • Most vehicles are autonomous and large benefits are proven 	<ul style="list-style-type: none"> • Allows advanced traffic management 	2060–80s

⁴ Litman, T. 2018. “Autonomous Vehicle Implementation Predictions: Implications for Transport Planning,” Victoria Transport Policy Institute. Please visit [Autonomous Vehicle Implementation Predictions: Implications for Transport Planning: https://www.vtpi.org/avip.pdf](https://www.vtpi.org/avip.pdf).

Ownership

Several researchers (Shaheen, 2017a; Fagnant & Kockelman, 2015; Litman, 2018; Redd & Jensen, 2018) have identified the critical nature of the car ownership model that emerges with CAV technology. If AVs are privately owned like today's conventional vehicles, then outcomes will significantly differ from a scenario where a shared ownership model emerges. The following sections discuss these potential outcomes in detail, including attendant impacts on VMT, mode share, infrastructure requirements, and land use.

Other Planning Issues

Alongside the potential changes described here, factors external to the transportation sector become important to any discussion regarding future outcomes, including how technology will affect employment across economic sectors like manufacturing, warehousing/distribution, and the service industries. Will 3-D/additive fabrication enable neighborhood micromanufacturing sites that change supply chains? How will fully automated warehouses impact logistics? Will online education reduce the need for school campuses?

Local governments that are accustomed to regulating use of public space are being caught off guard by private market initiatives.

States and local governments must also grapple with policy and regulatory implications as they seek to influence how new mobility options are deployed. These range from what may seem like minor issues—like whether electric shared-use scooters are allowed on sidewalks or in bike lanes and streets—to major concerns about licensing and operation of fully autonomous cars and trucks. E-scooters (electrically powered scooters) are a new mobility mode that can be deployed for a modest capital investment. Several problems can result from indiscriminate use of the public right-of-way, scooters being left in inappropriate places, and safety of the user and the public. The lesson learned is that local governments that are accustomed to regulating use of public space are being caught off guard by private market initiatives.

New regulations will emerge. As CAVs become ubiquitous, cities may seek to regulate zero-occupant vehicle (ZOV) trips to reduce AV-induced VMT growth. Both private and shared-mobility models will require municipalities to examine how they regulate use of curb space and decide if streets are to be redesigned to accommodate a pickup/drop-off function. Rather than consolidated trips at a parking lot entrance, curb space will be used more frequently and create conflicts with other users on the street like other vehicles, bicyclists, and pedestrians on the sidewalks.

2.2 TRAVEL DEMAND IMPACT

Researchers agree that CAVs and MaaS will have an impact on travel demand, but there is a range of opinion as to the magnitude and timing. These factors are cited in the literature as leading to increased VMT:

- **Accessibility increases.** New level of mobility to those currently unable to drive, including the young, elderly, and disabled (Fagnant & Kockelman, 2015; Asher, 2014; Shaheen, et al., 2017a; Bozorg & Ali, 2016).
- **Adoption of a private/personal car ownership model.** If people replace conventional cars with AVs, then more ZOV trips will occur as cars are sent home to transport a second family member, sent to remote parking, or allowed to circle the block while the owner runs an errand (Litman, 2018; Fagnant & Kockelman, 2013).
- **Lower costs overall.** Reduced cost of travel per mile through higher utilization of the capital investment and lower variable costs (lower insurance, parking, and propulsion cost with utilization of EV) encourages more discretionary trip-making (Bozorg & Ali, 2016).
- **Turn away from transit.** Disincentive to use traditional public transit, especially fixed-route bus and rail for local trips due to relative convenience vs. cost trade off given new mobility options.
- **Land-use changes.** People may move to exurban or rural locations because it would cost less to travel and that in-transit time could become productive and would not incur a cost. Counter trends are discussed in Section 2.7.

The literature cites these factors as leading to reduced VMT:

- **Adoption of a SAV ownership model.** This model would require fleets of AVs owned and operated by TNCs, transit operators, or new mobility businesses. Like current TNCs, people could use a smartphone to summon an AV. Algorithms could dynamically match trips (like uberPOOL or Lyft Line) or chain trips. Depending on the density of demand, this could improve fleet utilization and significantly reduce ZOV trips (Shaheen, 2018; Boesch et al., 2016).
- **Redefining transit.** While there may still be a role for fixed-route transit service, especially the efficiency offered by rail or bus rapid transit (BRT), the institutionalization of microtransit service by providers like TransLoc, Chariot, Via, and others could group trips as both a feeder to a fixed route and for end-to-end travel. This may, however, lead to public subsidies of inefficient services (Watkins, 2018).
- **Replacing trips.** Trends are already in place that replace shopping trips with e-commerce and work trips with telecommuting. Both of these trends may continue or accelerate. Web-based education may replace school trips, and telemedicine may

replace some medical office visits (Polzin, 2016). Home-based and neighborhood-based 3-D printing may also replace shopping trips.

2.3 SAFETY IMPACT

Broad agreement exists among researchers on the positive safety benefits of CV technology. NHTSA has focused on safety as the primary benefit of connected CVs, identifying these benefits:⁵

- **V2I Applications**
 - Red light violation warning.
 - Stop sign violation warning.
 - Stop sign gap assist.
 - Pedestrian in signalized crosswalk warning.
 - Curve speed warning.
 - Spot weather impact warning.
 - Reduced speed work zone warning.
- **V2V Applications**
 - Forward-collision warning.
 - Emergency electronic braking.
 - Intersection-movement assist.
 - Left-turn assist.
 - Do-not-pass warning.
 - Blind-spot/lane-change warning.

NHTSA estimates that V2I and V2V applications together could eliminate or mitigate 80% of crashes where the driver is fully attentive (i.e., not impaired, distracted, drowsy).

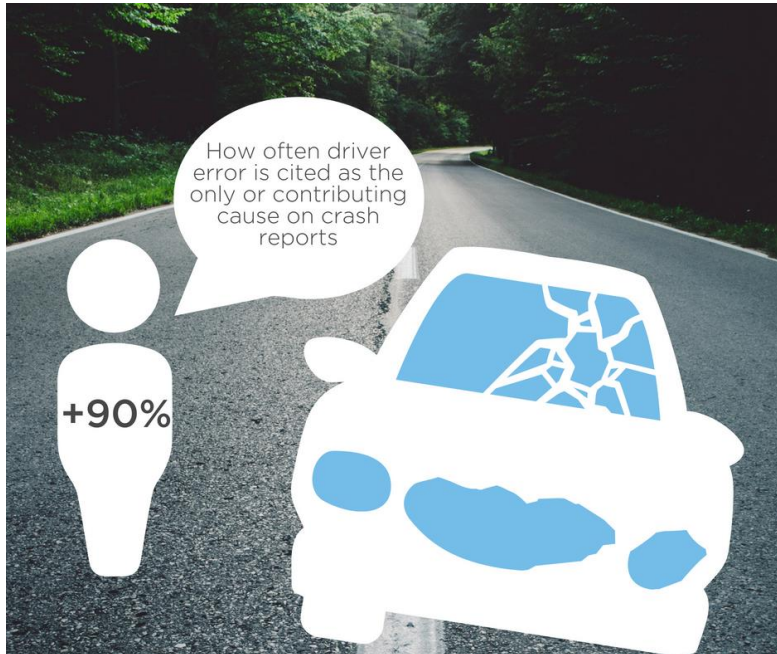
CAV technology brings additional safety benefits, but some research has also raised concerns. According to NHTSA, driver error is cited as the only—or a contributing—cause on the crash report in over 90% of crashes (Figure 7). The initial belief was that by eliminating the driver, CAVs with mature tested technology would eliminate these crashes. But certain scenarios exist in which crashes are deemed unavoidable (e.g., a pedestrian or animal darts in front of a car closer than the stopping distance). Kim, et al. (2017) also cites motorcycles, which will still be

⁵ US Department of Transportation, Intelligent Transportation Systems Joint Program Office. 2017. “Connected Vehicle – Safety. ITS Benefits, Costs, and Lessons Learned: 2017 Update Report,” ITS JPO Publication FHWA-JPO-17-500. Please visit [Connected Vehicle – Safety. ITS Benefits, Costs, and Lessons Learned: 2017 Update Report:](https://www.itsknowledgeresources.its.dot.gov/its/bcllupdate/pdf/BCLL_CVSafety_2017_FINAL.pdf) https://www.itsknowledgeresources.its.dot.gov/its/bcllupdate/pdf/BCLL_CVSafety_2017_FINAL.pdf.



permitted and operated in conventional human-driven mode and provide a continued opportunity for human-caused crashes.

FIGURE 6: HUMAN DRIVER ERROR CRASH STATISTICS



Source: RSG, based on NHTSA crash statistics

What is more problematic, and a subject on which little research was discovered, is forecasting the impact of CAVs operating in mixed traffic. One study (Kim et al., 2017) estimated results at market penetration rates of 10%, 50%, and 90%. For safety, crash types with human error causes were categorized as one of the following: driver intoxicated, aggressive, distracted, and inexperienced; lane-keeping errors; and all others. Kim et al. (2017) assigned crash reduction factors to each and adjusted for CAV fleet percentage. This study did not, however, estimate the safety concerns of mixed-fleet operation.

The threat of cybersecurity failure is also identified as a potential safety problem. Either individual vehicles or systems are vulnerable to hackers, with crashes being one potential result. The risk increases as more vehicles and devices are connected to the internet. The industry is aware of the need to address these issues at the early design stage of new systems (Petit & Shladover, 2014) and continuously monitored for intrusion. Traffic management centers (TMCs) become critical focal points. Protocols must be put in place by the agencies that operate TMCs for routine checks and upgrades of communications software.

In sum, the accepted expectation regarding safety benefits is that conventional CVs will show crash reduction rates of up to 50%, and CAVs will show reductions of up to 90%. The caveat is that this is based both on a high market penetration and full instrumentation of the infrastructure.

CVs can benefit from V2I applications where they are available, but V2V applications require many participating vehicles to be effective. Similarly, CAVs operating in mixed traffic are expected to experience a somewhat higher crash rate than in an exclusive CAV setting.

2.4 INFRASTRUCTURE REQUIREMENTS AND IMPACT

Broad agreement exists in the literature that both CV and AV technology will have infrastructure impacts. Some of these actions will require public investment; many will create benefits. CAV has much more profound impact on the transportation infrastructure. As noted for most of the CAV impacts, many of these will not be realized until there is a near-universal market penetration.

As explained earlier, CV V2V applications require the installation of communication technology in vehicles, while V2I applications also require roadside device capability. In this sense, CV is a new generation of ITS that enables direct communication to vehicles and drivers. The caveat in planning for investment is confirmation of the communication protocol or standards for interoperability regardless of the technology. Because NHTSA has not issued a Final Rule regarding V2V in all light-duty vehicles, public agencies may first choose to wait to see where the industry is going. Currently some car manufacturers (e.g., GM and Toyota) are relying on DSRC while others (e.g., Audi, VW, and Ford) are using C-V2X. To enable any of the V2V and V2I applications, an accepted communication backbone has to be available.

With CAVs, general agreement exists in the literature that the array of sensor technology in use on CAVs being currently tested requires highly visible pavement markings and signs. While a human driver may be able to interpret faded or absent pavement markings and continue within the designated lane, a CAV may need to “see” where to position itself on the pavement using a combination of cameras and other sensors like radar and lidar. This has implications for transportation agency business practices and budgets.

Many researchers (Fagnant, 2013; Shladover, 2015; Kim et al., 2017) predict that CAV technology will greatly reduce the need for the “safety buffer” that governs the design of streets and highways. Lanes can be narrower and vehicle spacing reduced. The applications of Cooperative Adaptive Cruise Control and Cooperative Speed Harmonization are forecasted to result in freeway capacity increases from 2,100 vehicles per lane per hour (vplph) to 2,500 vplph at 60% fleet penetration to 5,970 vplph at 100%. However, lane capacity is ultimately controlled by interchange and intersection capacity. Research was not found to propose capacity at these points with CAV optimization. The maximum benefit level can be achieved during the lengthy changeover period to CAV via designating exclusive lanes by converting either a general-purpose lane or an existing HOV/HOT lane. Doing so would maximize the time saving and safety benefits for CAV users, which may in turn act as an incentive for greater market acceptance.



The potential also exists that CAVs can be smaller and lighter (Sousa et al., 2018) as future vehicles would not necessarily look like today's automobiles. The narrowing of city streets can make public space available for other purposes (see Section 2.7). A countervailing need is curb space for pickup and drop-off by either privately owned or shared CAVs. This is an issue already being identified in terms of TNCs in urban areas and airports. The space freed by narrower lanes may permit an entire redesign of critical urban streets as an alternative to a policy approach to curb space use.

Another infrastructure issue is traffic control devices. While the literature does not anticipate changes in the mixed traffic transition period, it has been shown that a fully connected/autonomous fleet may not require traffic signals and stop signs; instead, they will make right-of-way decisions cooperatively and in real time⁶. This presupposes that pedestrians, cyclists, and other users of personal mobility devices will have a means to communicate with vehicles to request right-of-way to cross streets.

Other research (Chen et al., 2016; Mersky & Samaras, 2018) explores how adoption of a SAV model can create the basis for greater use of electric vehicles (EVs). Resources are currently available to advise municipalities on the deployment and placement of publicly accessible EV charging stations. Stations are sometimes provided by employers in parking areas or by other businesses for customers. EV market penetration is influenced by consumer concerns about charging station access and vehicle range for unexpected travel. While a privately owned electric CAV can be sent home or to an available charging station, such a use would add to ZOV travel. A SAV fleet owner could optimize charger placement, manage charging time utilization, and always dispatch vehicles that have adequate range for the requested trip.

2.5 IMPACT ON MODE SHARE

Some sources reviewed for this synthesis expressed concern that shared AV services will result in substantial ridership loss on existing public transit systems. Evidence exists that TNCs have caused a shift away from transit (fixed-route rail and bus lines) in large cities, including New York City and San Francisco. However, researchers (Watkins, 2018; Polzin, 2016) have pointed out that the definition of public transit should encompass all forms of collective or shared mobility. On that basis, an uberPOOL vehicle with three passengers traveling to similar destinations is no less a transit service than a fixed-route bus. Rather than focusing on the potential loss of ridership in traditional service models, they propose reexamining the role that transit can play in providing mobility in a more automated world. In many places, transit agencies already serve the role of mobility manager, arranging appropriate rides for customers. These services may include fixed-route planning, paratransit, and nonemergency Medicaid trips.

⁶ "Beyond Traffic Signals: A Paradigm Shift: Intersection Control for Autonomous Vehicles", FHWA Exploratory Advanced Research Fact Sheet, Publication No.FHWA-HRT-10-023 HRTM-04/11-09(1M)E

These agencies may consider one or more of the following mobility-oriented actions directly or in collaboration with private-sector providers:

- Continue to run bus, BRT, or rail on routes that meet high-volume demand.
- Replace inefficient service with ride-hailing services including microtransit; these can provide a wide area of coverage with higher level of service to the customer at a lower cost to the provider.
- Provide first/last mile connection to fixed-route service with microtransit.
- Use technology to improve demand-response paratransit service; persons with disabilities can avoid advance reservation requirements by ride-hailing an accessible vehicle that meets their specific needs.
- Serve as a testbed for autonomous bus or shuttle services.
- Maintain the traditional role of providing affordable mobility to those with few options.

The other mode share question relates to bicycle and pedestrian travel. Cost, convenience, and safety will continue to primarily govern mode use. Bikeshare, including the evolving dockless business model and electric bikes, has increased convenience by making bikes available on a per-trip basis, eliminating the need for purchase and secure storage. Some people may perceive riding near CAVs to be less safe until there is more experience with control sensors and algorithms. Additional street space could be used for more protected bike boulevards. No research suggests an impact on pedestrian mode share.

Rather than focusing on the potential loss of ridership in traditional service models, [researchers] propose reexamining the role that transit can play in providing mobility in a more automated world.

2.6 EQUITY CONCERNS

Transportation equity has long been a concern in both underserved urban neighborhoods and rural areas. Access to employment, health care, and social services is problematic for those who do not drive or do not have access to a car.

Research has examined access to both traditional public transit and new transportation services in low-income and minority communities. While the findings are not uniform, most demonstrate lower access. Specific concerns about TNC service are reflected in a recent Transportation Research Board (TRB) report, as illustrated by this excerpt:

The innovative mobility options...have the potential to increase the accessibility of transportation for many Americans, including these disadvantaged populations. But they may also leave people who are already transportation-disadvantaged further behind, either because they will not be able to take advantage of these new services (making

them relatively worse off) or because the rise of these new services could reduce some existing services (making them absolutely worse off).⁷

Mobility services like ride-hailing and bikeshare are built on the foundation that the consumer has both a smartphone and internet-accessible banking via credit card or other means. A study by the Pew Research Center in 2016 found that only 64% of low-income adults have a smartphone.⁸ The Brookings Institution found that 22% of low-income families did not have bank accounts.⁹ This suggests that access to SAV and microtransit services via ride-hailing apps or services will be a challenge in low-income neighborhoods.

Another equity concern is transportation access by persons with disabilities (Claypool et al., 2017). Claypool et al. (2017) find that those with a disability that prevents them from driving face barriers to employment and community support services. While appropriately designed CAVs will provide improved mobility for those with cognitive or mobility impairments, public policy initiatives have not yet addressed the issue of guaranteeing accessible services.

To the extent that public transit operators lose mode share to SAV and do not take corrective actions (see Section 2.5), the conventional bus service that low-income households rely on could face service reductions (Shaheen, 2018). The result is a dual impact on mobility for some households: a lack of means to use new mobility services and a loss of access to conventional services.

An issue unique to certain parts of the country, including Florida, is emergency evacuation in response to large-scale natural or human-caused events. In a future that relies primarily on SAV, the vehicle owners may have an incentive to remotely move their vehicles to safe locations rather than providing them on demand to evacuate people. States will have the opportunity to preempt this problem with legal requirements that all mobility providers participate in evacuation planning and operations.

Little research exists on the impact of future mobility on rural residents. Low population density creates the same barriers to SAV as it does currently for public transit and TNC availability.

⁷ National Research Council's Committee for Review of Innovative Urban Mobility Services. 2016. "Special Report 319: Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services," Transportation Research Board. Please visit [Special Report 319: Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services: http://www.trb.org/Main/Blurbs/173511.aspx](http://www.trb.org/Main/Blurbs/173511.aspx)

⁸ Anderson, M. 2017. "Digital divide persists even as lower-income Americans make gains in tech adoption," Pew Research Center. Please visit [Digital divide persists even as lower-income Americans make gains in tech adoption: http://www.pewresearch.org/fact-tank/2017/03/22/digital-divide-persists-even-as-lower-income-americans-make-gains-in-tech-adoption/](http://www.pewresearch.org/fact-tank/2017/03/22/digital-divide-persists-even-as-lower-income-americans-make-gains-in-tech-adoption/).

⁹ Barr, M. 2004. "Banking the Poor: Policies to Bring Low-Income Americans Into the Financial Mainstream," Brookings Institution, p.1. Please visit [Banking the Poor: Policies to Bring Low-Income Americans Into the Financial Mainstream: https://www.brookings.edu/research/banking-the-poor-policies-to-bring-low-income-americans-into-the-financial-mainstream/](https://www.brookings.edu/research/banking-the-poor-policies-to-bring-low-income-americans-into-the-financial-mainstream/).

Longer trips and less demand mean higher costs for the provider and consumer. Personally owned AVs will offer users benefits by making travel time productive, but these services will not have an impact on improving equity.

Equity is an issue that is most often addressed by public policy. Examples include public subsidies for transit operations, the Americans with Disabilities Act (1990), and the Executive Order to Address Environmental Justice in Minority and Low-Income Populations (1994). None of these explicitly address the impacts that may result from various forms of future mobility. The expectation exists that government at all levels will need to act to ensure that additional barriers are not erected for transportation access in already-underserved communities.

2.7 IMPACT ON LAND USE AND ACCESSIBILITY

Much speculation—but little certainty—characterizes the discussion of future mobility’s land-use impact. The land-use question has several facets:

- What is the effect on residential location choice?
- What is the effect on employment-based site location choice?
- What are the impacts on parking demand and location in the urban core and in suburban locations?
- What are the constraints and opportunities for the reuse of street space?

Many factors go into a residential location choice decision. Those who have written about CAV/SAV encouraging moves to far suburban and exurban locations focus on value of (travel) time and cost of housing. Reducing travel time is less important because occupants may productively use time spent in an AV. That change, of course, applies only to the driver. Passengers in conventional cars or on bus or rail transit can already use their digital devices or sleep. The cost of housing is typically less in locations more distant from city centers, although a report from the Federal Housing Finance Agency that examined eight large cities found that the rate of appreciation over previous years to be essentially the same from central city to distant suburb.¹⁰ Increased demand for those locations will likely drive prices up.

Of equal importance are other factors influencing the choice of home location. These vary by age and stage of life. First, the travel time focus has been on the work trip commute, but households have many other travel needs. They may be much less willing to accept long travel times to health care and shopping, for example, even though they are in an AV. A stated preference survey on residential relocation in response to SAV (Lavasani et al., 2016) found that individuals (between the ages of 30 and 34) most likely to have younger children were the least likely to want to move to distant locations. Both young people and active older people are

¹⁰ Federal Housing Finance Agency, “The Market Slowdown and Home Prices in the Suburbs and ‘Exurbs’.” Please visit [The Market Slowdown and Home Prices in the Suburbs and "Exurbs"](https://www.fhfa.gov/DataTools/Downloads/Documents/HPI_Focus_Pieces/2006Q4_HPIFocus_N508.pdf): https://www.fhfa.gov/DataTools/Downloads/Documents/HPI_Focus_Pieces/2006Q4_HPIFocus_N508.pdf



attracted to the urban core because of convenience and accessibility to a breadth of social and cultural activities. An effort to model residential choice (Zhang et al., 2015) for those with access to SAV service found that people also responded to a perceived better level of transport service in compact zones. Residents of distant suburbs or exurbs are more likely to want to own their CAV, increasing personal costs and offsetting some of the collective benefits of SAV.

Less research has been done on the influence of future mobility on the location of commercial, industrial, and institutional employers. The continued growth of e-commerce and demand for quick delivery may require locating more warehouse/distribution/fulfillment centers in or close to urban cores where property is relatively more expensive. The advent of automated delivery vehicles could facilitate cheaper urban fringe locations by removing labor costs and restrictions.

2.8 PARKING

More research has been done on future mobility's impact on parking than on general land-use issues. Because privately owned cars are parked for 90–95% of a typical weekday (Figure 7), the provision of parking has always been a focus of land-use management. On-street parking is addressed through curb space management, and off-street parking is addressed through zoning and site plan regulation.

Several estimates exist of how much land in central cities is consumed by parking, from 14–25% (Chester et al., 2015; Shoup, 2011). While parking lots and structures are perceived as an undervalued use of urban land, the cost of parking can provide an incentive for commuters to use transit and ride-hailing services.¹¹ Zoning codes establish minimum parking requirements for each land use, typically based on residential units and square footage of commercial space. These requirements often lead to an oversupply of parking. Some cities are eliminating these requirements by recognizing the contribution of shared parking in urban settings. For example, a space used by an office employee during the day may be available for restaurant patrons or concert attendees in the evening.

Cities will still need to monitor dynamic changes in parking demand and modify on-street parking ordinances and off-street parking zoning requirements accordingly.

Curb space management is a challenge in central cities of all sizes. Retail establishments often demand on-street parking near their stores. Many cities were not designed with off-street or alley access for deliveries, resulting in some curb space being set aside for loading zones.

¹¹ Cortright, J. 2016. "Cities and the price of parking," City Observatory. Please visit [Cities and the price of parking: http://cityobservatory.org/cities_and_the-price-of-parking/](http://cityobservatory.org/cities_and_the-price-of-parking/).

While taxi stands are common in high-demand locations like hotels and transportation terminals, ride-hailing has increased demand for curb space for pickup and drop-off. While many airports are reserving curb space in their ground transportation areas for TNC pickup, it is uncommon in urban core locations.

FIGURE 7: PARKING STATISTICS



Source: RSG, based on research conducted by Chester et al. (2015), and Shoup (2011)

Parking is affected by CAVs in several ways:

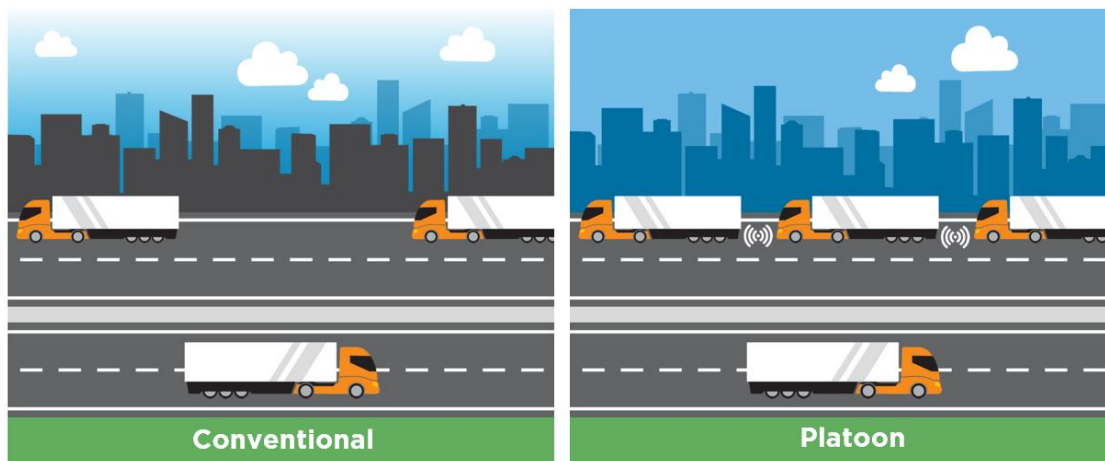
- Personally owned CAVs may be sent home or to fringe parking to avoid costly urban parking. This will reduce the number of spaces required but increase VMT.
- Shared CAVs will reduce parking demand (Litman, 2017; Shaheen et al., 2018; Asher, 2014; Fraedrich et al., 2017; Zhang et al., 2015). Zhang (2015) places parking demand reduction estimates as high as 90%, while Shaheen finds that each SAV could remove 4.6–20 cars with concomitant parking reduction.
- SAVs will require sites for vehicle maintenance, cleaning, fueling/charging, and parking during periods of lower demand. These may be satellite facilities constructed on lower-value land outside the urban center.
- SAVs will continue the trend of increasing demand for curb space for pickup and drop-off.
- Automated delivery trucks and secure delivery lockers will facilitate off-hours delivery and may reduce the need for curbside loading zones. Amazon Hub provides lockers in apartment buildings; recipients receive a code by e-mail to open their locker. Similar secure systems are being explored for larger deliveries to small businesses.

Cities will still need to monitor dynamic changes in parking demand and modify on-street parking ordinances and off-street parking zoning requirements accordingly. One potential solution proposed by Pandya (2016) is to work with designers to facilitate adaptive reuse of parking structures. Appropriate design considerations can also facilitate reconstruction of garages into commercial or residential space at modest cost, obviating the need for demolition.

2.9 FREIGHT MOVEMENT

Advanced transport technology will affect two primary categories of freight movement: long-haul shipping and urban delivery. While freight is moved by a variety of modes, trucks account for about 70% of US domestic freight movement measured by tonnage¹² and about 60% of tonnage and value for all freight including imports and exports.¹³ The potential to improve the efficiency of truck movements can generate significant benefits. Several tests have demonstrated the feasibility of truck platooning using CV technology to improve efficiency. Truck platoons (Figure 8) will operate only on freeways, perhaps initially on rural interstate highways where there is little congestion and long spacing between interchanges. The V2V application of cooperative adaptive cruise control allows trucks to travel in more closely spaced groups (as little as 30 feet between vehicles) than would otherwise be safe. All these tests have involved conventional trucks with drivers, so the only benefit shown to date is fuel savings. Proposals exist for a hybrid system whereby the lead truck has a driver and the following trucks are autonomous. This could signal a future with AV trucks traveling separately or in platoons. Deng and Ma (2015) modeled the fuel savings and benefit to general traffic flow of truck platooning. They found positive benefits via increased highway capacity and fuel savings once penetration rates reach 40%.

FIGURE 8: CONVENTIONAL TRUCK TRAVEL (LEFT) AND TRUCK PLATOONING (RIGHT)



Source: RSG

¹² American Trucking Association, Reports, Trends, and Statistics, 2017.

¹³ Bureau of Transportation Statistics, "Freight Facts and Figures 2017." Tables 2-1 and 2-2, 2018.

One of the challenges with truck platooning is whether platoon participation is dynamic or fixed. In other words, there will be a much lower rate of penetration if the platoon must travel together from origin to destination. The potential may exist for a broker role to be created that would arrange for platoons for certain trip segments. A fully dynamic model would allow a truck to request entry into a platoon.

Opportunities also exist to apply future mobility to urban goods movement, but little research has been done on the strategies, costs, and benefits. One study (Kamin & Morton, 2015) compared parcel delivery using self-driving trucks with “lockers on wheels” that would replace direct delivery with recipients retrieving parcels from coded lockers. Self-driving trucks would allow the courier to prepare subsequent deliveries while the vehicle was in motion. In the latter application, lockers would be loaded at a central location and set at a reserved location for a specified period. Kamin and Morton (2015) did not evaluate using a self-driving truck to move the lockers.

2.10 CONCLUSION

Upcoming rounds of MPO LRTPs and statewide transportation plans will need to address future mobility and its impact on multiple transportation and societal issues. This synthesis of recent research provides some direction to FDOT and its MPOs that are operating in an uncertain planning environment. It also underscores the value of a scenario-planning approach to consider the factors that exhibit the greatest uncertainty.

The two most important overarching factors from a planning perspective are the timeline for adoption of CV and AV technology and the ownership model (privately owned vs. SAV).

The two most important overarching factors from a planning perspective are the timeline for adoption of CV and AV technology and the ownership model (PAV vs. SAV). CV represents a near-term future opportunity, but development and deployment may stall while auto manufacturers and public agencies await a decision from NHTSA on communications technology and standards. If NHTSA opts not to finalize the rulemaking, the private sector may take the lead. Although general agreement exists in the literature that fully autonomous vehicles will be operational within the next five years, there is a greater range of opinion on how soon CAVs will be on the market and when they will be a near-universal presence on roadways. In the near term, as there is a transition from testing to independent operation, the technique of “geo-fencing” may be used to restrict CAV operation to a defined area or municipality. Because the timeline has specific implications for LRTPs, MPOs may craft scenarios around different levels of fleet penetration at the midpoint and horizon years of their plans.

The question of private/personal ownership versus shared use of CAVs is equally important. Research highlights the benefits and challenges associated with each model, but the present literature provides little basis for forecasting the ultimate choice. Waymo's recent announcement of its intended purchase of up to 62,000 Chrysler Pacifica minivans for use as robotaxis¹⁴ provides some evidence that CAVs may appear first in shared-use fleet operation. However, serving a specific mobility niche does not mean that SAV will ultimately predominate over personally owned CAVs. This choice ultimately affects VMT forecasts, adaption of transportation infrastructure, social equity, and land-use and parking changes. All levels of government can influence the direction of this trend through policy initiatives. For example, promotion of SAV could occur by taxing private CAV purchases or imposing a VMT-based user fee. The technology will also exist to impose mileage-based fees on ZOV trips.

Impact on mode choice is also a significant issue for LRTPs. The research suggests that it may be more important to redefine transit than to forecast declining mode share in the face of shared-mobility options. This may involve working with transit agencies to see themselves as providers of shared mobility rather than operators of fixed-route bus and rail service. Broadening their service portfolio to include all sorts of shared mobility, including microtransit and ride-hailing, creates opportunities rather than threats.

One area where agreement exists in the literature is on the safety benefits of CV. This reflects the high percentage of crashes that are caused by human error and the opportunity to use technology as a preventive measure. An LRTP may include the caveat that safety benefits rely in great part on fleet penetration. A small number of CV-equipped cars will not measurably change the situation since benefits rely on V2V and V2I communication. CAVs are also likely to improve safety, noting that there are technical challenges to be resolved. Little research also exists on CAVs operating in mixed traffic, a situation that is likely to last for decades after their initial introduction.

Research also suggests that various applications of future mobility will shape the transportation infrastructure. At high levels of CAV use, roadway capacity is expected to increase. This may allow the roadway system to either absorb any increase in VMT or convert travel lanes to other uses. Many of these benefits may not be realized in mixed traffic situations unless exclusive AV-use lanes are designated. Accommodating changing demand for on- and off-street parking will present issues for curb space management and land use.

Land use has always been a critical component of transportation plans, as travel forecasts are based on location of residences, employment, and other key nonwork trip destinations. It is well understood that improving access increases land value and higher levels of utilization. But it is

¹⁴ Boudette, N. 2018. "Waymo to Buy Up to 62,000 Chrysler Minivans for Ride-Hailing Service," *The New York Times*. Please visit [Waymo to Buy Up to 62,000 Chrysler Minivans for Ride-Hailing Service: https://www.nytimes.com/2018/05/31/business/waymo-chrysler-minivans.html](https://www.nytimes.com/2018/05/31/business/waymo-chrysler-minivans.html).

also recognized that the site selection decision-making process is guided as much by local factors as by default values. In some regions, the availability of CAVs may lead to greater fringe development as people search for cheaper land, while others may experience continued urban densification where people find more convenient transport options. Scenario planning supported by local knowledge may be the best means of addressing land use.

Consideration of future mobility is not new to Florida. Legislation was passed in 2012¹⁵ to permit testing of automated vehicles on public roadways; and in 2016 to permit pilot testing of driver-assistive truck platooning applications, and amending the parameters for autonomous vehicle testing operation.¹⁶ More recently, Florida statute defines an autonomous vehicle¹⁷ and the requirement and role of a driver, allowing a person with a valid driver license to operate an autonomous vehicle when properly equipped.¹⁸ FDOT is also participating in a pilot operation of autonomous shuttles in Gainesville. Named GAToRS, the University of Florida is a partner, as the shuttles will travel on a fixed route between the campus and downtown. One of the outcomes is to test public acceptance.

In sum, current research provides some direction to the consideration of future mobility in LRTPs. Florida's MPOs may use this information to make strategic decisions in their plans that seek to enable desirable outcomes while considering policies to avoid or mitigate negative impacts. They could be considering how underserved communities can receive full access to improved accessibility and productivity that SAV, microtransit, and other shared-mobility services may bring. They may also consider the benefit of early collaboration with private-sector interests, from AV manufacturers to mobility service providers. Acknowledging that the timeline and implementation of future mobility remains uncertain, each MPO should consider how to use its potential to help achieve their vision constrained by economic and behavioral principles, of how 21st century transportation technologies can help their region to thrive.

¹⁵ HB 1207

¹⁶ HB 7027

¹⁷ Florida Statute 316.003

¹⁸ Florida Statute 316.85



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