Appendix K:

Automated Vehicles in the Tahoe Context

Effective Regional Revenue Sources to Address Regional and Local Transportation Projects, Services, and Operations in the Lake Tahoe Region

Task 12: Review of Autonomous Vehicle Technology

prepared for

Tahoe Transportation District
Morse Associates Consulting, LLC

prepared by

Cambridge Systematics, Inc.
555 12th Street, Suite 1600
Oakland, CA 94607

date

July 3, 2020

List of Acronyms

ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
AVs	Automated Vehicles
EIA	U.S. Energy Information Administration
GHG	Greenhouse Gas Emissions
GPS	Global Positioning System
LIDAR	Light Detection and Ranging
NHTSA	National Highway Traffic Safety Administration
NLC	National League of Cities
SAE	Society of Automotive Engineers’
SAVs	Shared Autonomous Vehicles
TNCs	Transportation Network Companies
TTD	Tahoe Transportation District
UDOT	Utah Department of Transportation
UTA	Utah Transit Authority
VMT	Vehicle Miles Traveled

Introduction

The Tahoe Transportation District (TTD), working in conjunction with federal, state, local, and private sector partners, has the authority and responsibility for providing a safe, environmentally-positive, multi-modal transportation system for the Lake Tahoe region. Unfortunately, the TTD faces challenges in fulfilling this responsibility for the region due to a lack of sustainable, adequate funding. The permanent population in the Tahoe Basin is currently estimated at 55,000 residents, so it has a small base population that cannot afford to pay for all of the needed transportation projects and services. Much of the transportation needs in the Tahoe Basin are the result of the many visitors that come to enjoy its natural beauty and many recreational opportunities.

The Tahoe Basin is facing a number of transportation challenges because the majority of travel in the Basin is the result of visitors. Visitors come from across the United States, as well as around the world, to see the beauty of Tahoe and enjoy the many summer and winter recreational opportunities. The majority of these visitors reside in California and Nevada and can easily drive to Lake Tahoe. Of all vehicle trips into, out of, and within the Basin, 75% are made by visitors and 25% by residents. There are winter and summer peak travel seasons, but the summer travel is twice the volume of winter travel. Winter travel delays can be as bad or worse than summer, given the snow storms that slow traffic, cause difficult driving conditions, accidents, and road closures. Peak summer visitor travel creates congestion and unsafe travel movements as visitors search for parking along extremely busy and narrow 2 lane highways. During the peak visitor season, the parking and congestion conditions result in major problems for emergency service response, particularly when large scale evacuation is necessary. Residents of Tahoe Basin routinely struggle to find convenient access to employment centers and needed services during these peak parking and congestion periods.

The analysis of Automated Vehicles (AVs) in the Tahoe Basin must consider the issue of communications infrastructure capability. AV operation is heavily dependent on communication, including GPS, vehicle to vehicle and/or passenger to vehicle data. Currently, communications into and within the Lake Tahoe Basin is extremely difficult due to the topography in the area. Microwave communications have limited success beyond a few miles due to the direct line of sight requirements needed for point-to-multipoint (PtMP) systems. The use of fiber optic communications is limited or non-existent for center-to-center (C2C) communications. California and Nevada's radio systems do not provide adequate coverage for first responders and land managers, additionally significant interference occurs in several areas. During peak visitation the existing limited broadband capacity deteriorates as more devices are connected. Furthermore, Intelligent Transportation System (ITS) devices that can decrease accidents and congestion and provide traveler information are limited to non-existent and lack coordination between states and federal agencies. Transportation strategies that use information and communications technologies such as autonomous vehicles, TNCs, parking management systems, car and bike sharing, real-time transit information, vehicle-to anything (V2X) communications, and transportation demand management (TDM) programs that have the potential to reduce vehicle miles traveled, save energy, and reduce GHGs have limited success and application due to inadequate communications currently available.

To address the current transportation situation, and to maintain Lake Tahoe as a desirable destination for leisure which is essential to sustaining the Basin's tourist-based economy, the TTD is looking into emerging technologies to understand how they might affect decisions regarding investment priorities, as this ensures proactive planning for the future. This is of greater importance especially in the case of Lake Tahoe, as securing adequate funding is already a challenge due to recreation and tourism travel related funding not being a priority in existing funding mechanisms.

This memo discusses AVs, one of the emerging transportation technologies that could potentially alter how people travel in the future, and consequently have an impact on future transportation needs and funding. The memo provides a description of AV technology and current trends in the US in terms of technology testing and piloting. This is followed by a discussion on the potential deployment methods and opportunities and constraints of AVs based on industry research and trends. The memo then presents examples of how AVs are being utilized to address recreational travel, and concludes with key findings and final remarks.

Photo Credit: Lara Farhadi

AV Technology Advances

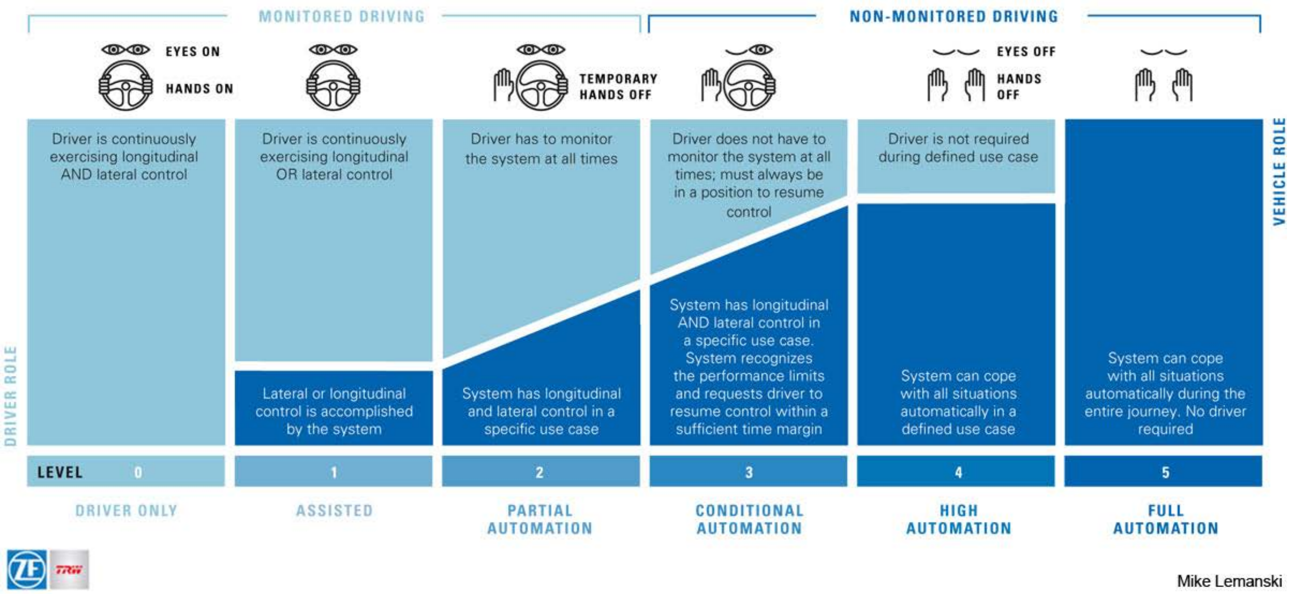
AVs are one of the most exciting emerging technologies that offer to solve our transportation challenges in an intelligent and innovative way. The reality of AVs is becoming tangible, as more automation features are being introduced in commercial vehicles today and as the industry continues to heavily invest in the development and testing of AVs with the goal of producing truly self-driving vehicles. While it is hotly debated exactly when AVs that are largely self-driving will be ready for mass deployment, there is a general consensus that communities need to start preparing for AVs and their potential effects on traffic and mobility.

Defining AV Technology

AVs are vehicles with some capability to sense their environment and navigate without relying entirely on human input. Vehicles with very high levels of automation could potentially allow passengers to sleep, work, or engage in other activities during their travels. AVs make intelligent decisions regarding a vehicle's direction, speed and interaction with other road users (i.e., cyclists and pedestrians) through the utilization of global positioning system (GPS), radar, and light detection and ranging (LIDAR) technology.

There are six levels of driving automation as defined by the Society of Automotive Engineers' (SAE) vehicle standards committee, and as adopted by the National Highway Traffic Safety Administration (NHTSA). **Figure 1** shows the levels of vehicle automation, each varying by the level of driver and vehicle control.

Figure 1. Six Levels of Vehicle Automation



Source: Society of Automotive Engineers'

Level 0 represents no automation where the driver is fully responsible for driving and monitoring the road. Levels 1 and 2, include advanced driver assistance system (ADAS) which performs some driving tasks, yet the driver has control at all times. Most commercially available vehicle automation features fall into SAE Levels 1 and 2. Such features include adaptive cruise control, parking assist systems, lane keeping systems, blind spot detection and autonomous braking. These technology features help the vehicles understand their surroundings, and either warn the driver or act to avoid a crash. SAE Level 3 includes automated driving system (ADS) that can perform all aspects of driving under some conditions. The human driver needs to be ready to take back control at any time when the system requests the driver to do so. Levels 4 is a high automation level where the driver does not need to pay attention to the road at all times and the vehicle will provide warnings in need of assistance from the driver. Level 5 is full automation where the ADS performs all driving tasks during the entire journey without the need of a driver. The latest Level 5 ADS developments require significant data communications to enable safe and effective operation. This level of data communications may be impossible in large portions of the Tahoe Basin; in fact, portions of the Tahoe Basin have virtually no data communication capability due to topography and lack of communications infrastructure.

Current AV Trends

Over 40 corporations are currently trying to develop a fully autonomous, or level 5, passenger vehicle (CB Insights, 2019). These include automobile manufacturers such as Tesla, Ford, General Motors, and BMW, as well as technology and software companies such as APTIV, Google and Apple, just to name a few. These companies are working together with local, State, and Federal partnerships to shape the future of AVs. Several industry leaders are also designing and testing autonomous commercial vehicles, such as driverless podcars, shuttles, buses, and trucks.

In the process of developing AVs that can operate safely on the roads, AV testing and piloting are necessary steps. Through on-road testing, AVs can develop their Artificial Intelligence (AI) by creating highly detailed and three-dimensional maps of an area using sensors, and by experiencing driving in different situations such as at night, in rain, during rush hours, etc. Rain and snow have proven to be challenges for AV. They sometimes obscure and confuse the sensors on the vehicles and in the communications with traffic signals. Also, lower levels of sunshine make it difficult for the algorithms on autonomous vehicles to pick out cars and pedestrians. However, as autonomous vehicle testing is shifting to locations with winter weather, companies are trying to solve these issues (Wired, 2020). Unlike other winter testing sites such as Michigan, the Lake Tahoe Basin can see up to a foot of snow an hour at times which currently limits the opportunity for testing Tahoe type conditions. Often following successful testing in a controlled environment, pilots are undertaken where the AV provides operational services; currently, there are three types of AV pilots operating in the United States (Chatman et al., 2019):

- Fixed-route autonomous shuttles;
- Flexible-route passenger travel by autonomous sedans, minivans and SUVs; and
- Freight deliveries by autonomous sidewalk robots, road-based microcars and conventional vehicles.

Uncertainty around Future AV Deployment Methods

There are many different models under which AVs might be rolled out in the future depending on the evolving character of the mobility marketplace and the efforts being undertaken in AV development and piloting.

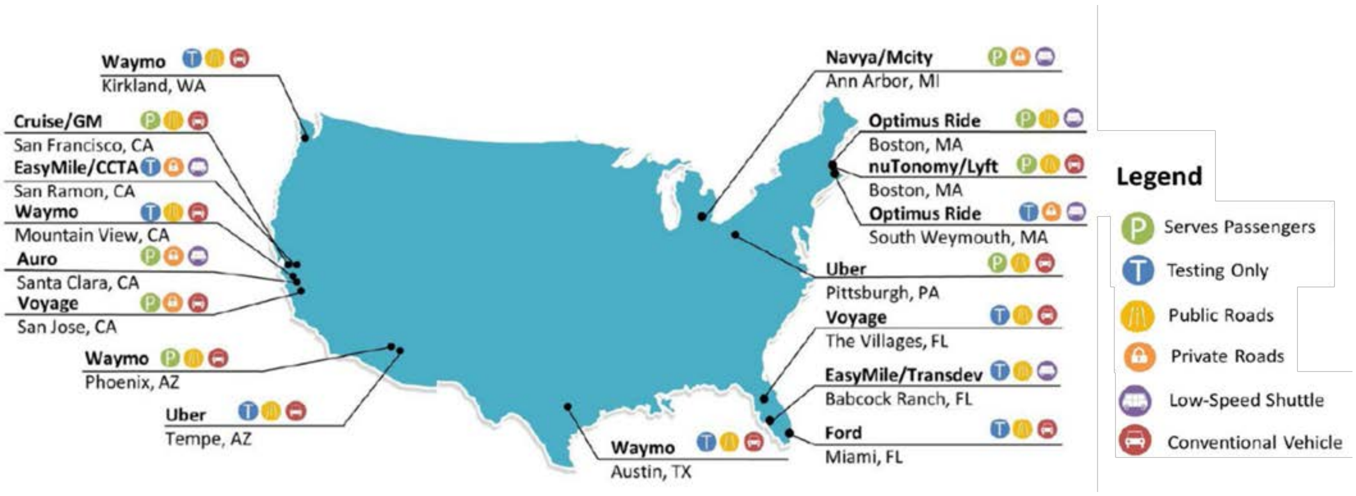
Privately Owned AVs

The National League of Cities (NLC) report *City of the Future: Technology & Mobility* provides short-term 2020 predictions for changes in the urban environment that will affect how people move from one place to another and long-term predictions that could be seen by the year 2030 and beyond. The NLC envisions a future where driverless technology is initially mass deployed in fleet vehicles and buses (NLC, 2015), further reducing the need for privately owned vehicles.

One evolving trend is that AV developers and technology companies are pursuing the deployment of AVs as part of a shared fleet, similar to modern-day car sharing services, or sometimes referred to as shared automated vehicles (SAV). This could indicate that the shared AV fleet model may be far more prevalent than personally owned AVs, at least in the initial years of AV deployment. In addition, experts estimate that Level 4 automation will cost an additional $10,000 to $50,000 per vehicle (Stocker et al., 2017), which will make these vehicles substantially more expensive than the price of an equivalent non-automated vehicle. If this is accurate, it may be an incentive for participating in a shared fleet rather than personally owning a highly automated vehicle. **Figure 2** provides an overview of some of the SAV pilots happening across the country as of February 2018. The SAV pilot projects shown below are all located in urban/suburban areas with sufficient communications infrastructure to allow their operation. As mentioned earlier, the limited communication infrastructure in the Tahoe Basin will need to be upgraded before it will be possible to consider SAV deployment at Tahoe.

It is important, however, to note the historical success of private vehicle ownership, where vehicle owners may be less likely to share vehicles due to convenience and insecurities. Vehicle manufacturers have shown interest in building the capabilities of their vehicle fleets by adding increasingly more sophisticated driver assistance options. This has the potential to preserve the current privately-owned vehicle model that is of obvious profitability to vehicle manufacturers. In one potential future, most if not all drivers still own and operate their own highly automated vehicles, the only significant change being that they are more productive while in the car (doing work, accessing entertainment, sleeping, etc.). Even under this scenario, there will be substantial limitations on AV utilization in the Tahoe Basin, since all AVs will be forced to share roadways with non AV vehicles, given the inability of low-income workers to afford expensive technology, the inability to construct new AV-only lanes, and the questionable effectiveness of AVs in Tahoe snow events.

Figure 2. Active SAV Pilots in the U.S.



Source: Stocker et al., 2018

Autonomous Shuttles

Driverless shuttles, which operate at maximum speeds of 25 mph and typically have a capacity of 8-10 people, are being piloted in city neighborhoods throughout the country. These shuttles have the potential to serve as downtown circulators, as well as in enclosed spaces where public transportation is not readily available such as airports, university campuses, business parks, etc. Early implementation involves the shuttles running short distances on fixed routes, but the vision for the future as the technology continues to develop, is operating at higher speeds and capacity to replace conventional bus vehicles, and potentially provide on-demand door-to-door service. Companies such as Navya, Auro Robotics, Varden Labs, Local Motors and EasyMile are currently the main manufacturers of these driverless shuttles (CB Insights, 2017). There will need to be amendments to state and/or local laws and regulations to allow for AV operation in the Tahoe Basin. Both Nevada and California have been progressive and supportive of testing of AVs in urban areas. The specific limitations and requirements of the Tahoe Basin will require additional legislation that ensures safe AV operation, considering the communication infrastructure requirements, snow conditions, and the need to operate on both local and state highways with mixed fleets of AVs and non-AVs.

Las Vegas is an example of a city that carried out an autonomous shuttle pilot. An eight-passenger autonomous shuttle was tested and later piloted providing passenger travel services free of charge, on a downtown loop within the City's Innovation District. The shuttle was provided by AAA and the Regional Transportation Commission of Southern Nevada, in partnership with the City of Las Vegas and Keolis North America. Keolis was the operator of the autonomous shuttle, which is manufactured by Navya. The shuttle was tested for a ten-day period, and later piloted for twelve months from November 2017 to October 2018, carrying approximately 32,000 riders (AAA Las Vegas, 2018). **Figure 3** shows the AV passenger shuttle piloted in Las Vegas.

Figure 3. Autonomous Shuttle Pilot in Las Vegas, Nevada

AV Ride Hailing/Ride Sharing Services

Private AV companies have been testing, and in some cases operating AVs or AV technology as a part of a private fleet which customers can request from smartphones in an on-demand fashion. Such companies include Waymo (owned by Alphabet), Cruise (owned by General Motors), Uber and Lyft. While these companies are at different points in testing and piloting, the end goal is to provide full commercial ride-hailing/ride-sharing services to passengers. Uber and Lyft's large investment in AV technology supports this prediction (Hawkins, 2018b; Shields, 2019), as do reports to date that predict fleet AV services will offer significantly lower prices per ride than today's manually-driven ride-hailing (Bösch et al., 2018). Other research points to the added cost of new expensive AV vehicles and other factors that will make it difficult to predict any reduction in cost per trip compared to current conventional driver TNC vehicles (Ashley Nunes and Kristen D. Hernandez, MIT 2019).

In addition, the current conventional driver vehicle business models followed by ridesharing companies like Uber and Lyft continue to be unprofitable. On average, Uber loses about $1.20 per ride. In 2018, this equated to a reported loss of $3 billion in revenue. (Intrinio, 2019). As ridesharing companies continue to invest in AV technologies, their hope is that the technology can help them reduce costs and turn a profit.

Waymo have been providing passenger rides in its AVs in Arizona as part of the Waymo's Early Rider Program. The service is called Waymo One and has been operating since April 2017. Although Waymo One is not commercialized yet, Waymo has applied to the Arizona state government for a license to launch app-based AV ride-hailing services, likely partnering with Lyft in Phoenix. (Chatman et al, 2019; Stocker et al, 2018). In Las Vegas, Lyft has partnered with auto company Aptiv to provide AV ride-hailing/ride-sharing services since May 2018. 30 AVs have been deployed and passengers get the option to consent to be picked up by an AV via the Lyft mobile application (Chatman et al, 2019; Stocker et al, 2018). **Figure 4** shows the Waymo Early Rider Program in Phoenix (left) and Aptiv/Lyft service in Las Vegas (right).

Figure 4. SAV Pilots in Phoenix and Las Vegas

Feeder to Transit System

AVs may provide a solution for transit's first mile/ last mile issue. Whether through autonomous shuttles or AV ride-hailing/ride-sharing services, an easily accessible fleet of shared AVs could support shorter trips that are too expensive for traditional transit. Currently, some transit agencies have begun addressing the first mile/last mile issue through partnerships and subsidies with TNCs.

In the Tahoe region, a new service called Mountaineer is providing "micro transit" service in the Squaw Valley and Alpine Meadows communities. Mountaineer is an on-demand, app-based transit service available to residents and guests of Squaw Valley and Alpine Meadows. This service is available at no cost to any in-valley rider who summons the vehicle with the Mountaineer app. Mountaineer also serves the TART bus stops on Highway 89 and in Squaw Valley, linking the Mountaineer to TART transit service to both Truckee and Tahoe City. The service runs from December to March and is provided by 4WD Sprinter vans that are equipped with ski and snow board racks. The nonprofit Squaw Alpine Transit Company (SATCo) is funding Mountaineer through the combination of a one percent assessment on lift tickets sold on-site by Squaw Valley | Alpine Meadows, and a one percent assessment on lodging and vacation rentals within Squaw Valley and Alpine Meadows.

While Mountaineer is not provided with AV, it is a good example of how microtransit in the Tahoe region can work to supplement the existing fixed-route public transit services to improve accessibility and mobility and hopefully reduce personal vehicle trips. During December 2019 through mid March 2020, over 69,000 passenger trips were provided by Mountaineer, at an estimated cost of $737,000 The impact of Mountaineer on personal vehicle trips and TART usage is not currently known, but the detailed trip data collected by the app should allow for these questions to be answered in the future.

Another example is the partnership of Metro and Lyft on a new pilot program in St. Louis City, Missouri. Riders of Lyft can ride to or from a nearby Metro Transit center/stop for only $1.00, with the remaining cost of the trip subsidized by the transit agency. The trip must begin or end within 500 feet from selected streets identified for the pilot project (Metro St Louis, Lyft Pilot Program). In the longer term, it is likely that partnerships will continue to happen between transit agencies and TNCs with AV fleet.

Autonomous Shuttle Pilot in Canyons Village, Utah

The Utah Department of Transportation (UDOT) in partnership with the Utah Transit Authority (UTA) launched an autonomous shuttle pilot in 2019 at various locations around Utah providing free ride services. One of these locations is the Canyons Village, one of the three ski resorts located at Park City which attracts more than two million visitors annually (Funderburk, 2019). The UDOT and UTA aimed to explore AV technology as a solution for last-mile connection to existing bus system and/or to riders' final destination. The pilot was also an opportunity to familiarize the public with the technology and get their feedback. The autonomous shuttle circulated in a loop around the village providing ridership capacity up to 12 people (http://www.avshuttleutah.com).

The pilot began in mid-2019 and there are limited conclusions available at this point, but it is worth monitoring.

Driverless Pods in Lake District National Park, UK

The Lake District National Park is collaborating with Westfield Technology Group to undertake a feasibility study to test driverless pods as a new means of transportation to access the National Park in a more environmentally sustainable way. Richard Leafe, Chief Executive at the Lake District National Park says: "We're constantly looking at new ways to balance the needs and enjoyment of people as they visit and move around the Lake District, whilst being mindful of the impact on the environment" (Lake District National Park, 2018).

The Lake District is a UNESCO World Heritage Site and is considered one of the popular tourist destinations in northwest England, attracting on average 15.8 million visitors annually (https://www.lakedistrict.gov.uk/learning). The feasibility study will allow people to try the technology and provide feedback on whether they feel it is an effective transport solution, and this will inform future planning decisions for the National Park.

This program began in 2018 and there is limited documentation of the results

AV Car Sharing

Looking at the mobility sector today, we realize that there is a growing trend toward a shared economy, characterized by lower car ownership, enhanced car sharing and improved mobility services through TNCs (Uber/Lyft) and micro-mobility (scooters and bikes). The car sharing market is growing with its key vendors being Zipcar, Car2go, Turo, Maven and Getaround (Clean Fleet Report, 2019). In the long run, it is anticipated that the shared economy trend will continue and perhaps merge with the emergence of new vehicles systems such as AVs.

**Note that TNCs are discussed in greater detail in a separate memo.*

Anticipated Market Penetration

There are more than 272 million conventional cars in the United States (https://www.statista.com/). Those cars are not going to suddenly become driverless cars. Autonomous cars will gradually emerge and there will be a decades-long transition period, where conventional cars will share the streets with cars having different levels of autonomy. The penetration rate will depend on the operational performance of the technology, the effectiveness of its use, the cost, and the infrastructure considerations.

The prediction of the speed of AV adoption varies greatly. The transportation community has issued widely varying timelines as to when users can expect the high and full levels of automation (i.e. SAE Level 4 and 5). In 2016, Serbjeet Kohli and Luis Willumsen presented the results of a Delphi survey on the field of AV transportation. The results show that, on average, transportation experts expect that AV technology, specifically level 4/5 which can operate without a driver, will be available in the U.S. by 2021 (with a two-year standard deviation); and that there will be a 20-percent penetration rate in the U.S. market by 2033 (with a six-year standard deviation) (Kohli et. al. 2016).

Other industry researchers expect that by 2040, over 90% of all vehicles sold will be of Levels 4 and 5 (Munster, 2017). It is also anticipated that there will not be a gradual transition from one level to the next; but most players will skip Level 3, going straight from partial automation to high or full automation (Munster, 2017).

It is difficult to speculate what the AV penetration rate will be in the future, given that the technology is still developing and there are many obstacles in terms of regulations, costs and user acceptance that are yet to be overcome. However, we can say that the most likely scenario for near future is one of a “mixed fleet” where level 4 and 5 AVs share the roads with vehicles with low to nonexistent automated functions.

Potential Effects of Vehicle Automation on the Transportation System

Most of the transportation industry’s efforts today are centered on developing the AV technology to ensure that these vehicles will safely operate on our transportation system while also trying to understand the effects that they may have. At this point, we are uncertain on how the AV technology will mature or how fast will it be deployed, how it will influence key characteristics of travel behavior (cost, time, etc.), or how customers will react to them. There is great uncertainty surrounding the effects of AVs.

There is a large body of relevant academic research and documentation of industry expectations on the potential effects of AVs. These considerations are more towards an outlook to the longer-term rather than the short or medium-term, as the short and medium-terms are harder to forecast given that the vehicle fleet will most likely be mixed with various levels of AV automation. Also, we are assuming that in the long term, the AV technology is fully functional and reliable.

In order to accommodate full AV function, the obvious first step for the Tahoe Basin will be a major upgrade of the communications infrastructure. This is a clear priority, given the major communication problems that emergency responders and other public services currently face in the Tahoe Basin. In addition, improving the communications infrastructure will allow for expanded traffic signal optimization, traffic management, and other intelligent transportation system services to exist or expand. While AV communication needs are not a top priority in the Tahoe Basin, they should be part of the future planning for what will be needed in the Tahoe Basin, even though there will likely be only a small number of AVs in operation over the next 5-10 years.

Safety

Over 37,000 people die in road crashes each year and an additional 2.35 million are injured or disabled in the United States. (Association for Safe International Road Travel). Human error causes 94 percent of all motor vehicle crashes, due to impaired driving, distraction, and speeding or illegal maneuvers. (National Highway Traffic Safety Administration, 2017). AVs offer an opportunity to significantly reduce the number of deaths and injuries from roadway crashes.

The biggest safety advantage to AVs is the potential to eliminate human driving errors. AVs could be programmed to obey all traffic rules; AVs won't speed and can't be distracted. In addition, the AV technology relies on sensors and software that allow an expansive view of the surroundings across a range of lighting and weather conditions. When trained through adequate testing, AVs provide the potential to accurately detect, recognize anticipate, and respond to the movements of all transportation system users including pedestrian and cyclists (U.S. Department of Transport AV 3.0).

Mobility and Access

AVs present a new travel option for those unwilling to drive, or unable to drive such as the elderly, disabled, and young. The U.S. Department of Transport is initiating efforts to partner with the U.S. Department of Labor, U.S. Department of Health and Human Services, and the broader disability community to focus research efforts in prototyping autonomous vehicles that enable people to travel independently and conveniently, regardless of their individual abilities (U.S. Department of Transport AV 3.0).

Vehicle Miles Traveled and Congestion

There are many discussions on how AVs will impact travel patterns and accordingly vehicle miles traveled (VMT) and congestion levels. Although, it is possible to set out general expectations, a concluding direction of AVs impact on VMT and congestion, whether positive or negative, is unpredictable. Table 1 presents an outlook of how AVs might increase or decrease VMT (Victoria Transport Policy Institute, 2019; Center for Automotive Research, 2017; Millard-Ball, 2019).

Table 1. Potential AV Effects on VMT

VMT can increase due to:	VMT can decrease due to:
• Increased mobility of non-drivers (i.e. induced travel) • Increased travel demand due to lower time costs associated with travelers being able to spend their time traveling more productively • Encouraged sprawling development by virtue of reduced travel costs • Zero occupancy VMT to pick-up/drop-off passengers • Mode shift from mass transit and non-motorized modes • Parking is not an issue encouraging vehicle ownership and travel • AVs "cruising" between trips when parking is unavailable or more costly	• Convenient SAV services reduce vehicle ownership and use • SAV services increases vehicle occupancies • First-mile/last-mile solutions combined with transit • Reduced vehicle travel in search for parking

There are other effects that AVs can have on congestion levels, with no direct relation to VMT. For example, AVs should in theory improve road safety and reduce accidents, thereby reducing the associated delays and congestion encountered due to accidents. A study by the US Energy Information Administration (EIA), indicates that 25% of congestion is caused by traffic incidents, and that low level of automation (Levels 1 and 2) could achieve the benefit of reduced congestion from accidents, if their market penetration is high enough (EIA, 2017).

A field experiment undertaken by the University of Illinois at Urbana-Champaign shows that with as little as 5% penetration of autonomous vehicles in a controlled environment, traffic flow could significantly reduce traffic congestion. This is achieved by eliminating the stop-and-go movement that is caused by human driving behavior (Goldin, 2018).

Emissions

Together with AVs' potential to lower congestion levels comes reduction in CO_2 emissions. Having the capability to eliminate the stop-and-go movement, AVs have smoother acceleration and deceleration behavior that results in less idling and more consistent speeds, and therefore better fuel consumption. According to a study from Ohio University, "Since software will drive the car, the modern vehicle can now be programmed to reduce emissions to the maximum extent possible. The transition to the new-age cars is expected to contribute to a 60% fall in emissions." (Goldin, 2018). Note that if AVs lead to more VMT, these savings will be limited unless AVs become electrified.

Public Transit

AVs have the potential to significantly effect transit services. Automated driving systems can be incorporated within transit services (self-driving buses or shuttles), potentially driving down labor costs and improving the existing driver shortages, which is a national problem.

AVs may increase VMT, which could make the roadways that public transit operate on more congested roadways, and perhaps drive policy-makers to pursue elements advantageous to transit like congestion pricing, bus only by-pass lanes, or outright time-of-day or seasonal bans on cars regardless of whether they are AV or not.

Parking and Curb Space

As the market penetration of high-level AVs increases, the resulting effects on parking and curb space are difficult to predict. The demand for parking may decrease and in fact change to pick-up/drop-off areas that serve both SAVs and personal AVs. It is likely that commuters using personal AVs would be dropped at their destination and the AV would park itself at the parking that is most economical or as programmed by the owner, which may or may not be the nearest available parking. In cases where commuters utilize SAVs, the SAV could park at the most economic location or continue to cruise before finding another customer.

Not only parking demand will change but also parking infrastructure. A report from Ohio University states that a "significant impact of driverless cars is that such cars can be parked in 15% less space. Currently, cars need to be parked with enough space between them for the driver to exit after parking and enter when removing the car from the parking space. With self-driving cars, vehicles can be stacked right next to each other." (Goldin, 2018). Off-street parking lots could be consolidated optimizing parking or freeing up land for other use. Given the undersupply of parking, this will help address the seasonal demand of recreation travel in Lake Tahoe, but not eliminate it at the major traffic generators in the Tahoe Basin.

The Tahoe Basin has limited parking infrastructure to meet the seasonal variations of demand associated with the heavy visitation and recreation travel. AVs may spend more time cruising in between rides as opposed to parking themselves then traveling to the larger proposed parking hubs. Having a large number of AVs cruising on Tahoe streets has the potential to increase overall congestion. A study conducted by Adam Millard-Bell, published in Transport Policy, examined the potential effects of AV cruising on major city streets. He found that AV cruising between rides can have a large impact on congestion. Focusing on San Francisco, he found that AVs could slow street speeds down to 2 km/h (Millard-Ball, 2019). The same effect is possible in the Tahoe Basin, where parking is limited, which could impact the visitor experience that Lake Tahoe is known for.

What These Effects May Mean for the Tahoe Basin

Lake Tahoe is a destination offering activities and events all year-round, attracting on average 24 million visitors annually and peak visitation demand in summer months and winter weekends. Because of limited transportation options to get to and around Lake Tahoe, visitors typically access the Basin by private vehicle. The region is facing significant congestion and parking issues associated with recreation travel which could inhibit future sustainability and economic development, and increase GHG emissions and congestion. Although the effects of AVs are uncertain, it is worthwhile exploring how AVs could negatively impact, or potentially enhance, the transportation situation in Lake Tahoe. Below is a high-level speculation about possible consequences of AV technology in Lake Tahoe given the current research, trends and industry speculations.

In the long term when AV technology is fully developed and commercialized, it is expected that much of the conventional vehicle fleet will be converted to AVs. As previously mentioned, the Tahoe Basin will need to first build an adequate communications infrastructure to allow full AV operations. In addition, the Tahoe Basin snow events will create special problems for AVs that will likely delay their use at Tahoe. Finally, the limited highway system in the Tahoe Basin will require the AV and non-AV fleet to share the roadway since there is virtually no capacity to build new AV-only lanes. Given these constraints, we can still imagine a future where **A high penetration of personally-owned AVs** could drive changes to Lake Tahoe's transportation system such as:

- Increased road safety, as AVs hold the promise of faster and more accurate detection and reaction to roadway users and conditions.

- With more efficient fuel consumption, AVs have the potential to reduce emissions which is particularly important for an environmentally-sensitive place like Lake Tahoe. The reduction of emissions could be maximized if AV and electric vehicle technologies are merged. However, emissions are dependent on VMT. The effect of AVs on VMT is highly ambiguous and, if AVs increase VMT, this could substantially offset the gains made with more efficient AV vehicle operation. The conversion of the existing private vehicle fleet to AVs is going to take many years to occur, based upon current trends, and achieving SAE Level 5 automation will be the most difficult and time-consuming.

- Greater mobility for Lake Tahoe visitors and residents as a larger population (including the elderly, young, and disabled) has access to safe private vehicle transportation. Or due to increased public transit, with both frequency and coverage improvements by public transit operating AV shuttles for greater neighborhood circulation, and AV buses on the mainline. Free public transit services within the Tahoe Basin will create strong financial incentives to choose public transit over private hire AV trips.

- The effects of AV on the number and types of visitor vehicles are difficult to predict. Barring significant changes in ownership models, it is likely that the number of vehicles could increase as the difficulty of driving lowers and as populations continue to increase in the Northern California and Nevada Megaregional drive-up market. In this case there would be more congestion during visitor peaks, driven in part by the fact that drivers of high-level AVs may not be as bothered by delays or weather systems given they can use their time otherwise. Demand for local, convenient parking would follow suit, which will be a serious challenge in the Tahoe Basin, which is suffering from a shortage of parking near many attractions, and limited available land for new parking lots and structures, as well as environmental concerns with constructing more parking facilities that are not expressly to facilitate the use of public transit.

- One of the major factors currently impacting the quality of the visitor experience at Lake Tahoe is traffic congestion. The degree to which AVs reduce or increase congestion could have a significant impact on the desirability and competitiveness of Tahoe as a destination and, thus, the health of the Basin's largely tourism-based economy.

- Driving-related jobs may decline as AVs provide more convenient mobility. While this would be an obvious negative for drivers, it may slightly lessen the burden of the workforce on the roadways, given much of it commutes in from Carson City and Reno.

If **AV technologies prove capable in future TTD transit applications**, the transit fleet could consider autonomous vehicles as part of the transit fleet which have the potential to effect transit costs. For example, fully autonomous buses should have better fuel efficiency and require no driver, lowering operational cost, assuming this is not offset by the increased capital and operating cost of an AV transit vehicle There are opportunities for bus platooning leading to more efficient bus operations, cutting costs further. However, the upfront cost of autonomous buses, and their maintenance and insurance costs are yet unknown. Researchers in Singapore indicate that with automation, the bus cost will go down from $0.72–1.25 (equivalent to US $0.53-0.92) per passenger-km to Singapore $0.31–0.55 (equivalent to US $0.23-0.41) (Ongel et al., 2019). Currently, TTD will need to wait for AV technology to improve, and it is not clear how many years it will take before level 5 AV technology is fully operational, cost-competitive and commercially available.

If **SAVs are operated under a TNC-type model**, the following effects could be expected:

- SAVs will not likely compete with transit for short trips, given the adopted policy to provide free local transit and short average trip lengths (TTD average trip length of 1.5 miles would be free on transit and approximately $10 on an SAV), unless no transit is available. SAVs could complement transit by providing a first mile/last mile pick and drop off at the nearest transit stop in those situations, but this service would need to comply with ADA requirements and need to be subsidized by the transit provider, for which there is no funding currently available.

- The large trip-peaking on weekends, and also seasonally, will limit the ability of TNCs, whether conventional driver, or AV, to meet a substantial portion of the peak demand.

- Congestion may increase as a result of AVs cruising between rides, as there is limited space for them to park.

Note that TNCs are discussed in a separate memo.

In the short term and as AV technology continues to develop, the impacts could be highly variable making it difficult to speculate. As AV technology becomes available for both private vehicles and transit vehicles, and it becomes cost-effective compared to conventional vehicles, AVs of various sizes should be considered in the public transit fleet in the Tahoe Basin to maximize mobility and minimize cost. The need to reduce congestion, VMT, and parking demand while increasing mobility require that public transit service be maximized as allowed by AV technology and cost constraints. Given that it is unclear how much current TNC trip prices will go down, if at all, with AVs, the policy directive of free local public transit service in the Tahoe Basin will ensure that mobility and person trips will be maximized while the total VMT and parking demand will be minimized, regardless of the decision of TNCs and private vehicle owners to acquire and operate AVs. As previously stated, an important first step and high priority for the Tahoe Basin will be a major improvement of the communications infrastructure; while the need is not driven by AVs, it would be helpful to consider AV needs that might exist in 5-10 years as part of the communications infrastructure planning process. In the longer term, if AVs can be developed that are fully functional in the Tahoe operating environment, and become a significant part of the vehicle fleet, it will be important to monitor how congestion, accidents, VMT and parking conditions are being affected by use of AVs.

Conclusions

This memo provides a high-level overview of AV technology, current market trends, anticipated AV deployment methods and potential AV effects on the transportation system; to help inform transportation planning and investment decisions by TTD for the Tahoe Basin.

AV technology is among the key topics of research and development in the U.S. and worldwide. AVs could alter mobility in a way that could potentially help solve or could negatively affect the transportation issues related to safety, congestion, accessibility and GHG emissions. The effects of AVs are not yet fully understood, and predictions vary on how fast the technology will develop and how AVs will be deployed and adopted in the future. However, there are significant investments in developing and testing AVs and some cities are already preparing for them.

For TTD, AV considerations are highly dependent on the way the technologies and vehicle market evolve and the specific operating environment of Lake Tahoe, something TTD has little opportunity to control. If AV technology proves operationally feasible in the Tahoe Basin, and actually becomes cost-effective compared to conventional transit, the TTD will likely be a leader in procurement and use of AV vehicles. The best opportunities in the near-term are likely to follow the changes in technology, provide input into the state-level AV discussions as state regulations on vehicle permitting and licensing will have a major impact on the vehicles that access Tahoe. The TTD should consider the communication needs of AVs as part of the communications infrastructure planning process, even though AVs will likely be a small portion of the private vehicle fleet for many years. In the longer term, if AVs eventually become a significant part of the private vehicle fleet, there will be a need to study their impacts in the Tahoe Basin and make regulatory adjustments as necessary, to minimize congestion and parking impacts.

The idea that TNCs will provide large fleets of SAVs to serve the Tahoe region is unlikely, given the extreme peaking of demand for relatively short periods. The idea of deadheading large numbers of TNC vehicles from an hour or more away seems very unlikely. The policy direction is to greatly increase public transit service and then provide free local service within the Tahoe Basin, making the profitability of deadheading in a fleet of SAVs even more questionable. Cost considerations aside, if fleets of light-duty AVs, (whether operated by TNCs or individuals), increase VMT and congestion, this could compel the use of public policy tools to encourage moving trips to larger transit vehicles where and when this would be appropriate.

**TNC possibilities are discussed further in the TNC memo.*

References

AAA Free Self-Driving Shuttle Pilot Program, November 2018-October 2018. (http://www.aaahoponlasvegas.com/).

Association for Safe International Road Travel, road Safety Facts.(https://www.asirt.org/safe-travel/road-safety-facts/).

Bösch, P.M., F. Becker, H. Becker, and K.W. Axhausen. 2018. “Cost-Based Analysis of Autonomous Mobility Services.” Transport Policy 64 (May): 76–91. (https://doi.org/10.1016/j.tranpol.2017.09.005).

CB Insights, 2019. “40+ Corporations Working on Autonomous Vehicles” (https://www.cbinsights.com/research/autonomous-driverless-vehicles-corporations-list/).

CB Insights, 2017. “5 Companies Working On Driverless Shuttles And Buses” (https://www.cbinsights.com/research/driverless-shuttle-companies/).

Center for Automotive Research, 2017. “Future Cities: Navigating the New Era of Mobility”. (http://www.cargroup.org/wp-content/uploads/2017/10/Future-Cities_Navigating-the-New-Era-of-Mobility.pdf)

Chatman, D. and Moran M., UC Berkeley 2019. “Autonomous Vehicles in the United States: Understanding Why and How Cities and Regions Are Responding.” (https://escholarship.org/uc/item/29n5w2jk).

Clean Fleet Report, 2019. “Update: 10 Best Car Sharing Programs”. (https://cleanfleetreport.com/best-car-sharing/).

Eno Center for Transportation, 2017. “Cities Now Exploring Autonomous Buses – But Is It Worth It?”. (https://www.enotrans.org/article/cities-now-exploring-autonomous-buses-worth/).

Funderburk, The Charlotte Observer, 2019. “ Wanderlust: Escape to Park City, Utah—a must-see destination year-round”. (https://www.charlotteobserver.com/charlottefive/c5-food-drink/article236121178.html).

Goldin, Pete, ITS digest 2018. “10 Advantages of Autonomous Vehicles”. (https://www.itsdigest.com/10-advantages-autonomous-vehicles)

Hawkins, A.J., The Verge, 2018. “Lyft Unveils a New Self-Driving Car and Acquires an AR Startup.” (https://www.theverge.com/2018/10/23/18014200/lyft-self- driving-car-acquires-blue-vision-lab-ar).

Intrinio, 2019. “What Does the Future of Uber Look Like?” (https://blog.intrinio.com/uber-financial-future/)

Kohli et. al. 2016. “Traffic Forecasting and Autonomous Vehicles”. (https://www.steergroup.com/sites/default/files/2019-10/Traffic-forecasting-and-automated-vehicles-Kohli-Willumsen.pdf)

Lake District National Park, April 2018. “Lake District looks to the future with ‘driverless’ vehicles”. (https://www.lakedistrict.gov.uk/aboutus/media-centre/latest-news/news-releases/lake-district-looks-to-the-future-with-driverless-vehicles)

Metro St Louis. “Lyft Pilot Program - $1 Trips to Transit Connections”. (https://www.metrostlouis.org/lyft/).

Millard-Ball, Adam, 2019. “The autonomous vehicle parking problem”. (https://www.sciencedirect.com/science/article/abs/pii/S0967070X18305924)

National Highway Traffic Safety Administration (NHTSA), 2018. “2017 Fatal Motor Vehicle Crashes: Overview”. (https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812603).

National League of Cities, 2015. “City of the Future, Technology & Mobility”. (http://www.nlc.org/Documents/Find%20City%20Solutions/Research%20Innovation/City%20of%20the%20Future/City%20of%20the%20Future%20FINAL%20WEB.pdf).

Ohio University Blog. “The Future of Driving”. (https://onlinemasters.ohio.edu/blog/the-future-of-driving/).

Ongel, A; Loewer E.; Roemer, F.; Sethuraman G.; Chang, F.; Lienkamp M., 2019. “Economic Assessment of Autonomous Electric Microtransit Vehicles”. (https://www.mdpi.com/2071-1050/11/3/648).

Shields, N., Business Insider, 2019. “Uber Is Doubling down on Autonomous Vehicle Tech.” (https://www.businessinsider.com/uber-softbank-toyota-autonomous- vehicle-tech-investment-2019-3).

Stocker, A., and Shaheen, S., 2018. “Shared Automated Vehicles: 2018 Update on Developments and Policies.” (http://onlinepubs.trb.org/onlinepubs/AVSMForum/events/july2018/ShaheenSAVupdate.pdf).

Stocker, A., and Shaheen, S., 2017. “Shared Automated Vehicles: Review of Business Models.” (https://www.itf-oecd.org/sites/default/files/docs/shared-automated-vehicles-business-models.pdf).

US Energy Information Administration, 2017. “Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles”. (https://www.eia.gov/analysis/studies/transportation/automated/pdf/automated_vehicles.pdf).

Victoria Transport policy Institute, October 2019. “Autonomous Vehicle Implementation Predictions – Implications for Transport planning”. (https://www.vtpi.org/avip.pdf).

Wired. “Snow and Ice Pose a Vexing Obstacle for Self-Driving Cars”. (https://www.wired.com/story/snow-ice-pose-vexing-obstacle-self-driving-cars/)