Shared, Electric, and Self-Driving:
How states and municipalities can encourage autonomous vehicles to be shared and electric

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Authored by Will Toor, Mike Salisbury, and Matt Frommer

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About SWEEP

The Southwest Energy Efficiency Project is a public interest organization dedicated to advancing energy efficiency and clean transportation in Arizona, Colorado, Nevada, New Mexico, Utah and Wyoming. For more information, visit: www.swenergy.org

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I. INTRODUCTION

The transportation sector is now the largest source of greenhouse gas (GHG) emissions in the U.S. economy. Without high levels of vehicle electrification and an accelerated decarbonization of the electricity sector, it is unlikely that the transportation sector, and thus the entire US economy, will be able to attain the significant GHG reductions necessary to reduce the impacts of climate change.

The auto industry is in the middle of multiple transformations in both technology and business. Over the last decade, the emergence of Transportation Network Companies (TNCs), such as Uber and Lyft, introduced unprecedented travel flexibility and raised the prospect of reduced individual car ownership in the future. Autonomous Vehicle (AV) technology has also developed rapidly, with the likelihood of self-driving vehicles becoming commercially available within a few years. Government policies and rapid declines in the cost of batteries also have encouraged a significant shift towards electric vehicles (EVs). However, most vehicles sold today continue to use internal combustion engines (ICE), and in the United States, the Trump Administration is attempting to rollback federal fuel economy standards, which would thwart much of our progress on GHG emissions reductions from the transportation sector.

The advent of AVs\(^1\) brings tremendous promise for increased safety, increased mobility, reduced vehicle ownership, reduced parking demand, and increased levels of carpooling. However, it also has the potential to lead to large increases in VMT by opening up car travel to sectors of the population who cannot currently drive (children, and some elderly and disabled people), decreasing the cost of travel, encouraging urban sprawl, and potentially decreasing vehicle occupancy.

Shared-AV fleets are expected to be highly utilized, with the vehicles used eight to 10 times more hours per day than individually owned vehicles, and driven 80,000 miles or more per year (Fagnant, 2015). Their lifetime mileage is also expected to be significantly higher than conventional individually-owned vehicles. Some analysts project that shared AVs could have lifetimes as high as 500,000 to 1,000,000 miles (Arbib, 2017).

Early evidence from the advent of TNCs shows that these new business models are probably increasing vehicle miles travelled (VMT), congestion, and emissions. A recent analysis found that even shared-TNC rides, where two or more passengers share one vehicle, add to VMT because most users switch from other non-auto transportation modes such as transit, walking, or biking (Schaller, 2018), and because of the amount of time that TNC vehicles spend driving around and waiting for ride requests with no passengers in the vehicle. This experience may be a preview of future trends

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\(^1\) Our discussion around AVs focuses on Level 4 “high automation” and Level 5 “full automation” technologies, at which point the vehicles become fully autonomous and would therefore could begin to seriously impact travel behavior and decisions.
unless states and municipalities put in place policies that can minimize the AVs’ potential for increases in emissions, congestion, and VMT. Without thoughtful policy and direction, future transportation systems will continue to deliver personal convenience at the expense of system efficiency.

Robin Chase, the founder of Zipcar described this scenario:

*In an AV world, where we won’t actually need to be doing the driving ourselves, each and every errand whim we might dream of is now a reality. If single-occupancy vehicles are the bane of our congested highways and cities right now, imagine the congestion when we pour in unfettered zero-occupancy vehicles (Chase, 2014).*

This paper focuses on some of the policy tools available to state and local governments to try to maximize the benefits and minimize the risks associated with widespread adoption of AVs. In anticipation of AVs, policymakers can introduce legislation and structure economic incentives to encourage more intelligent use of the soon-to-arrive technology.

This paper also covers emerging issues that should be addressed as the California Air Resources Board begins to consider Advanced Clean Car Standards for model years 2026 and later. These standards are especially important because other states can adopt California’s standards instead of the federal standard, and because California standards often drive improvements to the federal standards. This paper also addresses other steps that can be taken by state and local governments to reduce emissions and congestion from AVs.

**Autonomous Vehicle Policy Recommendations:**

- Require or heavily incentivize TNCs and AVs to be zero emission vehicles (ZEVs);
- Invest in the charging infrastructure required to transition TNC and AV fleets to electric vehicles;
- Provide extra credits or incentives in the Low-Emission Vehicle (LEV) or Zero-Emission Vehicle (ZEV) standards for AVs that achieve high-vehicle occupancy;
- Create vehicle miles travelled (VMT) fees for AVs and TNCs that vary by vehicle occupancy.

We acknowledge that there are substantial uncertainties in how the technologies and the marketplace will evolve, and that any policy tools adopted should be reviewed frequently (and modified if necessary) as we learn more about the actual trajectory of vehicle automation.
II. AUTONOMOUS VEHICLES SHOULD BE REQUIRED OR HEAVILY INCENTIVIZED TO BE ZERO-EMISSION VEHICLES

What is the projected impact of autonomous vehicles on emissions?

It may make sense to regulate AVs separately because of their potential to generate higher levels of vehicle travel and associated per vehicle emissions. Depending on how they are deployed and what technologies they use, AVs could have a wide array of impacts on the fuel consumption, energy use, and related emissions of light-duty vehicles. AVs could dramatically expand energy use in the transportation sector as they could increase vehicle travel by underserved populations, increase safe vehicle speeds, and increase travel due to their convenience and potential low cost-per-mile. A well-designed policy will support the positive aspects, such as increased equity for elderly and disabled travelers, while minimizing the impact on VMT and emissions.

Several studies have attempted to estimate the range of potential impacts on vehicle travel, fuel consumption, and GHG emissions due to the use of autonomous vehicles. The impacts range from a 50-90 percent decrease to a 100-300 percent increase depending on what type of vehicle (gasoline or electric) and what levels of vehicle sharing are assumed (Stephens, 2016; Brown, 2014; Morrow, 2014; Wadud, 2016).

Figure 1. Range of Potential Impacts from Autonomous Vehicles
**What is the projected impact of autonomous vehicles on travel behavior?**

If AVs are individually owned, they may well lead to large increases in vehicle travel due to the convenience of not having to drive. People may choose to live further away from their jobs because the daily commute will be much more pleasant when the human no longer has to concentrate on the road and instead can read, sleep, work, or otherwise make productive use of time previously spent driving. This change could lead to more dispersed land use patterns, which would further increase driving distances. Vehicle owners may also use their AVs for running errands with no human passengers present, potentially adding many miles of zero-occupant travel to the roads. Shared-AVs may also increase mileage as the cars go back and forth between locations to transport different people at different times. Between passengers, AVs may travel a large number of miles “ghosting” without any passengers at all (Fagnant et al, 2015).

A recent study from the National Renewable Energy Labs (NREL) reviewed the literature on the potential impacts that AVs could have on travel demand and VMT. The NREL document provides a range of impacts on several anticipated effects from full vehicle automation.

**Figure 2: Estimated Impact of Autonomous Vehicles on Total Vehicle Miles Traveled (VMT)**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Percentage Range</th>
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<tbody>
<tr>
<td>Empty Miles</td>
<td>0 to 11%</td>
</tr>
<tr>
<td>Increase in Ridesharing</td>
<td>-12 to 0%</td>
</tr>
<tr>
<td>Less Walking, Transit &amp; Air Travel</td>
<td>0 to 5.5%</td>
</tr>
<tr>
<td>More Travel by Underserved Populations</td>
<td>2 to 40%</td>
</tr>
<tr>
<td>Easier Travel</td>
<td>20 to 160%</td>
</tr>
<tr>
<td>Less Hunting for Parking</td>
<td>-5 to -11%</td>
</tr>
</tbody>
</table>

Some authors (Stephens et al, 2016) have argued that AVs inevitably will be shared and electric. These researchers argue that costs of travel by shared-AVs will be so low compared to owning a vehicle that most people, at least in urban areas, will opt to use shared services rather than pay the costs associated with car ownership. They also assert that these vehicles will be driven so many miles that their operating costs will be dominated by fuel and maintenance, both of which are significantly lower with EVs, making electrification economically appealing.
Why Autonomous Vehicles Should Be Electric:

- AVs likely will be driven more miles than today’s cars, so a gas-powered AV will emit more carbon and other pollution;
- Due to EVs lower operating costs, and AVs higher annual mileage, electrified AVs make more sense economically;
- Limited constituency for AVs in early years reduces opposition to new policies.

How is the auto industry planning for autonomous vehicles?

Many automakers agree that AVs will be primarily electric, rather than gas-powered. For example, General Motors plans to deploy fleets of autonomous, fully-electric Chevy Bolts for ridesharing in urban areas in 2019, and senior management said in presentations to investors that GM anticipates that all AVs will be EVs (Wayland, 2017).

Waymo, a self-driving technology company and subsidiary of Google’s parent company, Alphabet, is the furthest along in the race to make fully-autonomous vehicles. As of July 2018, their autonomous fleet had driven over 8 million miles on public roads (Hawkins, 2018). Through its ‘Early Rider Pilot Program’, Waymo is currently offering AV rides to select travelers in the Phoenix metro area and plans to launch the first AV ride-hailing service by the end of 2018. Waymo’s new fleet will be comprised of 62,000 Chrysler Pacifica plug-in hybrid (PHEV) mini-vans and 20,000 Jaguar I-PACE all-electric SUVs, rounding out the trifecta of an electric, shared, and autonomous transportation future.

Other automakers, however, are headed in the direction of internal combustion engine (ICE) AVs. For example, Ford has announced that it will develop a hybrid-ICE-AV, which uses a gasoline-powered engine as its primary power source and would be designed primarily for commercial purposes, such as delivering pizza. Ford specifically stated that because the company expects the vehicles to be driven many hours per day, and EVs would need to recharge multiple times per day, a fleet of EVs would not be able to spend as much time on the road (Martinez, 2017).

Hyundai also announced that the company does not intend for its AVs to be electric, reasoning that 1) fully autonomous vehicles would consume very high amounts of electricity 2) the AVs may need 1 to 2 kilowatts (kW) of power continuously for the AV systems, 3) and that this energy drain would decrease the range of the vehicles so much as to make EVs impractical (Schweinsberg, 2017).

This scenario, however, does not mean that AVs cannot be electric. Clearly, some automakers are making large investments to achieve an electric and autonomous future. But the fact that other automakers are pushing in the opposite direction implies that, without policy intervention by
government, a significant portion of the AV fleet is likely to run on fossil fuels — carrying serious implications for continued GHG emissions and other air pollution. Peter Slowik at the International Council on Clean Transportation warns that “Without robust policy measures, the future of transportation will be autonomous and still involve burning dead dinosaurs.” (Slowik, 2018)

We argue that because of AVs’ potential to contribute to higher mileage use and emissions, that all AVs should meet:

- A stricter regulatory standard such as a requirement that all AVs be zero-emission vehicles;
- Higher zero-emissions vehicle (ZEV) requirements than conventional vehicles;
- Higher GHG emissions standards than conventional vehicles;
- Or other actions that heavily incentivize AVs to be ZEVs.

**California’s Advanced Clean Car Standards 2026-2030: Policy recommendations**

**Redefining Standards compliance calculations**

The California Advanced Clean Car Standards include a Low-emission vehicle (LEV) standard, which governs urban air pollutants and greenhouse gas (GHG) emissions, and a Zero-Emission vehicle (ZEV) standard that requires automakers to gradually increase the market share of EVs among new vehicle sales.

Currently, California bases its GHG standards for light-duty vehicles (such as passenger cars, small trucks, and most sport utility vehicles, or SUVs) on a vehicle’s tailpipe emissions of greenhouse gases per mile, measured in grams of CO2 per mile. This standard made sense in the past, because California officials reasonably assumed that most light-duty vehicles would have similar uses. These standards, however, do not account for a factor that critically affects a vehicle’s actual GHG emissions: how far the vehicle is driven. In a probable future scenario, where self-driving cars operate on TNC platforms like Uber and Lyft, such high-utilization vehicles may travel upwards of 80,000 miles per year. With today’s GHG standards, the 80,000 mile-per-year shared-AV would be considered in the same category as a 12,000 mile-per-year personally-owned vehicle, despite producing almost seven times the annual GHG emissions. Personally-owned AVs may also be driven far more than traditional personal vehicles. A more suitable metric would categorize each vehicle by annual emissions to more precisely account for its actual impact on air quality.

Policymakers also may need to rethink how ZEV credits are assessed for AVs. Under the current ZEV program, the number of credits is directly related to a vehicle’s range (UCS, 2018). For example, a battery-electric vehicle (BEV) with 150 miles of range would earn two ZEV credits, while a vehicle with 300 miles of range would earn 3.5 credits. In the future, it is possible that shared-AV
business models will rely on lighter, shorter-range vehicles due to their lower cost, and more frequent fast charging.

**Amending the ZEV standard for autonomous vehicles**

In absence of this stricter regulation, gasoline-powered AVs could significantly increase emissions compared to current levels. As California considers the next generation of Advanced Clean Car Standards, which will govern cars beginning in model year 2026, the state should consider four approaches for regulating AVs:

1. **ZEV Mandate for AVs:**

   The simplest approach would be to require that all light-duty AVs also must be ZEV vehicles. This standard would set a clear expectation for automakers, and would maximize the emission reductions. In this scenario, any automaker that wants to sell AVs in the California marketplace, or the other states that have adopted California’s ZEV standards, would have to manufacture ZEV-AVs. Since AVs are not yet widely available in the marketplace, this policy would set the standard at a very early stage, before automakers have invested billions of dollars in factories to build ICE-AVs, and before consumers begin buying ICE-AVs.

   We acknowledge, however, that adoption of such strict rules might also slow down the introduction of AVs – and the benefits that the vehicles may bring in high-occupancy ridesharing, decreased parking requirements, increased safety, and increased mobility for underserved populations.

2. **Establish a separate ZEV standard for AVs**

   A related, somewhat less ambitious approach would be to allow some light-duty AVs to be ICE vehicles, but set a separate ZEV standard for AVs that is substantially higher than the standards for non-autonomous vehicles. The policy could require the percentage of ZEVs to rise over time. This incremental approach would address concerns that the potential of a 100 percent ZEV requirement might delay the deployment of AVs.

   A less direct approach would be to set a ZEV standard for TNC fleets in anticipation of the industry’s transition to AVs. California is currently considering SB-1014, the [Clean Miles Standard and Incentive Program for Zero-Emission Vehicles](https://leginfo.legislature.ca.gov/faces/billNavFullText.xhtml?billId=20182019bh01014), which would establish GHG emission targets for passenger-miles driven by TNCs (SB-1014, 2018). The standards would go into effect in 2023, ramp up each year, and require all TNCs to develop a GHG emissions reductions plan to meet the goals. An early draft of the proposal included a 100 percent ZEV requirement for TNC fleets by 2030.
3. **Apply a multiplier for Zero-Emission AVs**

A third approach would not set a separate ZEV standard for AVs, but instead would provide a multiplier for zero-emission AVs to account for the likelihood that they will get significantly more use than other vehicles, and so will contribute a greater share of clean vehicle-miles traveled. ZEV credits for an AV would be calculated as the product of the vehicle model’s ZEV credits, which is based on its electric range, and the vehicle’s VMT relative to the baseline fleet average. For example, a zero-emissions AV with a 300-mile range (typically worth 3.5 ZEV credits) traveling 72,000 miles per year (or 6 times the fleet average) might be assigned a 6x multiplier, and thus earn 21 ZEV credits. Such a multiplier would make it easier for automakers to comply with the ZEV standard with fewer vehicles, and therefore encourage them to invest in zero-emission AVs. If this approach were taken, policymakers also could consider increasing the ZEV requirements for 2026-2030 to maintain an accelerated production rate for ZEVs.

4. **Introduce separate GHG emission standards for AVs**

A fourth approach, which could complement any of the first three, would be to address AVs differently than other vehicles in the GHG standards. Policymakers could either set a separate standard for AVs, requiring lower emissions per mile of travel, or by weighting AVs more heavily than other vehicles in recognition of the likelihood that they will travel more miles.

Independent of the upcoming updates to the California Advanced Clean Car Standards, AVs are expected to contribute greater VMT than conventional vehicles, and thus higher emissions, so it is appropriate to impose more stringent emissions requirements.

**Policy tools for local and state governments:**

**Outright ban on fossil-fuel AVs**

Some governments may deal with the problem by simply banning AVs that burn fossil fuels. Countries across the world, and some jurisdictions within the United States, are already discussing the idea of banning all internal combustion engines, or have already set a future date when they cannot be sold. Both Britain and France have announced plans to ban the sale of gasoline and diesel vehicles by 2040, while India aims to end their sale by 2030. China has announced plans for such a ban but has not set a date so far (Petroff, 2017). Some California legislators have discussed a similar type of ban, while cities such as Los Angeles and Seattle are pledging to ban gasoline and diesel vehicles by 2030.

Such a ban could be phased in, beginning with AVs. This approach has a number of important advantages. For one thing, AVs are likely to be deployed first in higher-priced vehicles so a phased-in ban probably will not affect low- or moderate-income consumers. For another, AVs also are likely to be introduced first into urban environments where charging is more available. And because the
ban will only apply to a new vehicle category, opposition may be muted because it will not prohibit the sale of any existing model that already has a constituency. This approach has many of the same benefits and drawbacks as the option of California setting a 100 percent ZEV requirement for AVs in its car emissions standards. The difference is that a ban on ICE vehicles would not be part of an emissions standard, so potentially could be adopted by jurisdictions, including cities, independent of the federal or California clean car standards.

**Zero-Emission AV Incentives**

A suite of other policies could be politically easier to implement, and still encourage electrification of AVs. For example, many states and metropolitan areas may designate special lanes for AVs, similar to how they designate HOV lanes today. A dedicated AV lane likely could operate at higher speeds, but with less congestion than adjacent lanes handling cars with human drivers. Policymakers could, however, restrict access to these designated AV lanes only to zero-emission AVs. Cities could also give electric-powered AVs preferential access to curb space for loading and unloading – a key issue for TNCs and TaaS (transport-as-a-service) companies.

While we argue that a regulatory requirement is necessary to make sure that AVs are also EVs, we also know that the transition from fossil fuel-powered vehicles to electric ones can only be possible if our communities install the needed infrastructure. TNC drivers, and future fleets of electric AVs deployed in a TaaS system, may have charging patterns and needs that are very different from those of individual drivers today. Policymakers can encourage tomorrow’s AV fleets, as well as today’s TNC companies, to adopt electric vehicles by also encouraging public utilities to install enough capacity on the electric grid to handle the EV charging load, and for the installation of charging stations along major roads, at key business or activity centers, and in residential neighborhoods. To date, however, state utility regulators have hesitated to approve public utilities’ request for rate-based investment in charging infrastructure that would support TNC fleets. We believe that this delay is misguided, and that both public sector and utility investment will be important to achieving electrification of AV, TNC, and TaaS fleets.

**Zero-Emission AV Incentives:**

- Carpool lane (HOV/HOT) access;
- Curbside priority for shared-AV pickup and drop-offs;
- Preferred parking and discounted rates;
- Vehicle purchase subsidy;
- Local and state government support charging infrastructure for shared-AVs.
III. AUTONOMOUS VEHICLES SHOULD BE INCENTIVIZED TO HAVE HIGHER OCCUPANCIES

We noted earlier that pollution and traffic congestion problems very well could result if, in the future, most AVs carry just one (or even no) human passengers. The goal should be, instead, to provide convenient access while reducing vehicle miles traveled (VMT) within a community or among communities. Policymakers can structure economic incentives to encourage more intelligent use of the soon-to-arrive technology.

If AVs are mainly shared vehicles, and are priced to encourage multiple passengers, their use could lead to higher vehicle occupancy rates and displace personal vehicle ownership, both of which should reduce overall vehicle travel within and among communities. These factors could also lead to reduced parking demand, which could lead to increased residential and commercial density as former parking lots are developed – and in turn, further reduce trip length and vehicle miles travelled. Higher-occupancy AVs will likely use “connected” technologies to make traffic flow more smoothly, and allow more efficient use of roadways, both of which may also help to reduce congestion.

In addition to requiring that AVs be ZEVs (or highly incentivizing them to be ZEVs), we also recommend that local and state governments offer incentives for AVs to be deployed as shared vehicles, and to maintain an average vehicle occupancy that is higher than the overall fleet-wide average.

High-occupancy AVs: Policy recommendations

A vehicle occupancy incentive could take the form of additional credits (earned voluntarily) that vehicle manufacturers would put toward meeting California’s greenhouse gas emissions standard. This incentive would encourage vehicle manufacturers to operate their own shared-use AV fleets or sell AVs to TNCs, rather than selling them to people who only intend to use them for personal use. Alternatively, the credits could be assigned to the AV’s current owner (assuming it is not a vehicle manufacturer), and if a market existed for selling these credits to vehicle manufacturers, a TNC or TaaS company would be able to monetize additional levels of occupancy.

A new standard would assume a baseline vehicle occupancy (currently the U.S. average is about 1.7 passengers per vehicle), and then offer additional credits if, over a period of time, the occupancy rate grew higher (FHWA, 2018). A process whereby vehicles would be measured or certified on an annual or biennial basis could be set up to assign credit values for individual vehicles. It may not be reasonable to evaluate high-mileage vehicles at their point of sale because the use case for the vehicle could shift over the course of its lifetime.

One model for vehicles receiving additional credits not related to their per mile emissions is the ZEV Credits for Transportation Systems program that California tried between 2001 and 2008.
(CARB, 2018). Under this system, ZEVs (and partial ZEVs) could earn additional ZEV credits if they were part of shared-use program incorporating certain intelligent technologies. Additional credits could be earned if the project was linked to transit. Manufacturers could use this type of extra credit to meet up to 10 percent of their total ZEV obligation in a model year.

In order to receive an incentive, the vehicles would need to be capable of recording vehicle occupancy using sensors in the seats, or through the apps used for access, and be able to report this information to state or local governments. If the shared fleet were to be operated by the auto manufacturer, enabling direct control over the fleet, the incentives could be given when the vehicles are put into service, with an auditing requirement.

We acknowledge that there is substantial uncertainty about how the AV market and AV use cases will develop, so we recommend that communities adopt an initial policy that can be reviewed and modified to assure that it actually achieves the desired goals.
IV. ROAD PRICING: PUTTING A PRICE ON CAR TRAVEL

Ultimately, vehicle standards alone are unlikely to adequately address the concerns of increased VMT and decreased vehicle occupancy, so communities may have to put a price on travel. These fees could include:

- Tolls on specific roadway facilities;
- Fees for each vehicle mile traveled;
- Differential fees by vehicle type – for example, imposing higher fees on gas-powered cars than EVs; and
- Congestion or value pricing, where the price to travel rises when roads get more crowded, or otherwise varying the fee based on how traffic changes by day or by time of day.

**Congestion Pricing**

Congestion, or value pricing, is a dynamic way to account for a vehicle's impact on a number of variables including congestion and emissions. Congestion pricing would charge variable rates per mile based on where and when a vehicle is traveling. Driving into a city center on a highway during rush hour would result in a higher per-mile charge than traveling on a suburban surface street at 10 p.m. Congestion pricing would send a strong price signal and encourage people to seek alternatives to single-occupancy vehicles during peak hours such as transit, biking, walking, telecommuting, and flexible work schedules.

Several international cities, such as London, Stockholm, and Singapore, have introduced some level of congestion pricing. London charges vehicles £11.50 (about $16) for driving in the central city between 7 a.m. and 6 p.m. on weekdays. Vehicles with nine or more seats and ultra-low emission vehicles (electric vehicles and those with fuel economies above 70 mpg) can receive exemptions from the congestion charge (TFL, 2018).

The Swedish cities of Stockholm and Gothenburg both assess congestion taxes that vary by time of day. The tax ranges from 9-22 Swedish kroner ($1.10-$2.80) in Gothenburg and from 11-30 Swedish kroner ($1.40-$3.80) in Stockholm. Charges are only assessed on weekdays between 6 a.m. and 6:30 p.m. (Transport Styrelsen, 2018).

Singapore has a dynamic pricing system that applies to heavily congested roads and adjusts the cost based on a roadway's current operating speed. Different types of vehicles pay different rates based on how much road space they occupy (ICCT, 2010).

While no U.S. cities have implemented congestion pricing, several have considered the idea including New York, Chicago, and Los Angeles. The state of Oregon may also adopt congestion pricing for interstates in the Portland metropolitan area.
**TNC Road Pricing in San Francisco:**

In July of 2018, the City of San Francisco announced an agreement with Uber and Lyft to introduce the nation’s first occupancy-based tax on ride-hailing vehicles (CBS San Francisco, 2018). The agreement was designed to incentivize high-occupancy ride-hailing with two or more passengers in the vehicle, and levies a 3.25 percent tax on single-use TNC rides and a 1.5 percent tax on shared carpool rides. Such policies provide funding for transportation infrastructure while simultaneously sending price signals that discourage low-occupancy travel and, as a result, reduce VMT and road congestion. Tax revenues from ride-hailing services will continue to grow in the future with the introduction of shared-AVs.

**VMT fee for AVs**

We believe it makes sense to assess AVs a congestion fee based on VMT to more accurately represent their impact on roadways, and to minimize their potential to create more traffic. The projected cost of travel in a shared AV is very low. Some authors have argued that the costs of travel may be as low as 1 to 2 cents per mile, vastly lower than the 50 cents per mile associated with owning and operating current vehicles. Advertising-based revenue models may actually bring the costs to riders down to zero, essentially making free AV transportation available for all. If these estimates are correct, shared-AVs will likely create congestion and pollution that are far greater than their direct operating costs. Other authors argue that the costs of shared AVs will be substantially higher, but agree that the costs of a shared AV still will likely be significantly less than current vehicle costs.

Those studies carry important implications for the level of fee that may be required to avoid large increases in total VMT and the resulting traffic congestion. In most pilot VMT-fee programs conducted to date in the United States, VMT fees have been set at about one cent per gallon, generating about $130 annually for a vehicle driven the average of 13,000 miles per year. This is roughly equal to the gas tax that would be collected from a gasoline vehicle with fuel economy in the low efficiency range, of about 20 miles per gallon. But if the intent of a VMT fee on AVs is to bring the cost of travel up to something approaching today’s variable operating costs of about 20 cents/mile or higher, the fee may need to be much higher than any of the pilot VMT fees.
Note that fees at this level would collect far more revenue than needed for a fair share of the vehicle’s impact on road maintenance, so they would generate surplus revenue that communities could use to directly address congestion and emissions by, for example, supporting public transit or investing in transportation electrification.

Any VMT or congestion fee assessed on AVs should also vary by occupancy. A standard rate would be assessed, based on an average vehicle occupancy of 1.7 people. AVs with more passengers would pay a lower per-mile fee, while those with lower occupancy would pay a higher fee. Zero-occupant passenger vehicles would be charged a proportionally higher per-mile charge to discourage empty vehicles and the associated increase in travel.

Fees also need to be high enough to affect consumer decisions about ride-sharing and TNC fleet owners’ decisions about how they operate their fleets. For example, imagine a fee structure with a base price of 20 cents/mile for a 1-person vehicle, which increases to 40 cents/mile for an empty vehicle. The fee could also drop to 15 cents/miles for AVs with two occupants; 10 cents/mile for three occupants; and 5 cents/mile for four-person carpools (See Figure 3). This might be a reasonable incentive for sharing for longer trips, but for short trips of a few miles in urban areas, those prices still would likely be too low to encourage car sharing. Thus, substantially greater fees might be needed for low-occupancy vehicles in urban areas.

**Figure 3: A model for occupancy-based vehicle fees**
The cost of zero-occupancy miles may need to be directly linked to local parking fees to avoid runaway congestion. With AVs, owners will be able to avoid the high costs of short-term city parking by instructing their cars to circle the block until they need to be picked up again. This scenario will undoubtedly lead to more urban congestion as empty AVs drive aimlessly around the city without a destination. To avoid such a future, the hourly sum of zero-occupancy mileage fees must match or exceed the hourly cost of parking the vehicle (See Figure 4). For example, in order to match the $27.00 average hourly parking rate in New York City, the zero-occupancy mileage fee for a ZEV would have to be $1.77 per mile (Parkopedia, 2018).

**Figure 4: Zero-occupancy mileage fee vs. average hourly parking rate**

*Zero-occupancy mileage calculations assume average city travel speed of 15 mph.*
We acknowledge that there are some significant complications to setting the fee based on occupancy. For example, it is quite possible that automakers will introduce a wider range of specific-purpose designed vehicles for AV use. There may be very small one-or two-seat AVs, which would be fully occupied with just one or two passengers. In addition, vehicles that are being used for deliveries may be “fully occupied” even with no driver. Any fee will have to be flexible enough to address this variety of vehicles and uses. Nonetheless, we believe that a mileage-based fee that varies by occupancy will be a critical tool to minimize the potential for vast increases in VMT associated with the introduction of autonomous vehicles.

A fee on AVs also could be enacted as a first step towards VMT fees for all vehicles: There are strong economic arguments in favor of widespread congestion pricing, and there is strong interest from many stakeholders in the transportation industry in assessing VMT fees. But neither has happened on any meaningful scale in the United States because of the political difficulty of convincing a large number of people to start paying for something that they believe they have traditionally gotten for free. But AVs offer an opportunity for policymakers to introduce the wisdom of congestion pricing because AVs do not yet have a constituency of drivers. If cities and states create the fees before AVs achieve widespread use, they may find imposing congestion pricing on autonomous vehicles to be far easier than it would be to apply congestion pricing to all vehicles. However, over time, as more and more of the U.S. fleet transitions to AVs, this shift may open up the possibility of applying such charges to all vehicles.

IV. CONCLUSIONS

Autonomous vehicles offer tremendous promise for increased safety, increased mobility, reduced vehicle ownership, reduced parking demand, and increased levels of carpooling. But AVs also could worsen traffic congestion, vehicle miles travelled, energy use, and emissions. There are enormous uncertainties in how the industry will develop. State and local governments, however, have the opportunity to take the lead in developing policies to encourage a shared, electric future for autonomous vehicles – and cleaner air and safer roads for all of us.
REFERENCES


