Using Current Practice Regional Models To Test Autonomous Vehicle Effects On Travel Demand And Public Agency Policy Responses

CORRESPONDING AUTHOR

Ronald T. Milam, AICP, PTP
Fehr & Peers
1001 K Street, 3rd Floor
Sacramento, CA 95814

AUTHORS

Adrita Islam
Fehr & Peers
1001 K Street, 3rd Floor
Sacramento, CA 95814

Kevin Johnson
Fehr & Peers
100 Pringle Avenue, Suite 600
Walnut Creek, CA 94596

Jimmy Fong
Fehr & Peers
1001 K Street, 3rd Floor
Sacramento, CA 95814

Kwasi Donkor
Fehr & Peers
1003 K Street NW, Suite 209
Washington, DC 20001

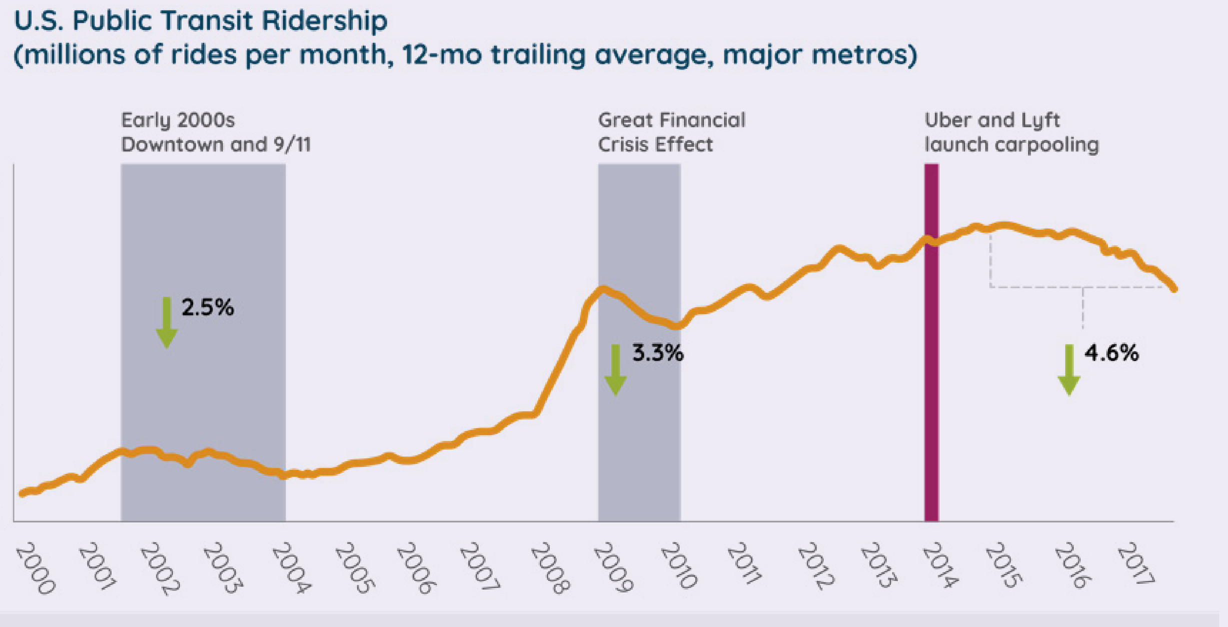
Jinghua Xu
Fehr & Peers
101 Pacifica
Irvine, CA 92618

Abstract

In this paper, autonomous vehicle (AV) effects are evaluated through the same methods that transportation professionals use in planning for new infrastructure to support population and employment growth. The authors explore AV effects using current practice regional travel forecasting models with a focus on vehicle travel and transit ridership effects. Resulting forecasts show the potential for substantial increases in vehicle travel and decreases in transit ridership as vehicle travel convenience increases and vehicle travel costs (both time and money) decline. The paper identifies a potential conflict between private market incentives for increasing the use of vehicles with public goals to reduce vehicle miles of travel (VMT) and emissions; increase active transportation; and expand transit ridership. Remedies are offered in the form of potential government policy responses and counter measures designed to offset undesirable AV travel outcomes. A scenario was tested with potential countermeasure strategies revealing the potential to fully offset VMT increases and transit ridership decreases associated with potential AV effects.

Disrupting the Status Quo

The emergence of transportation network companies (TNCs) serve as proxy for some of the potential effects of AVs. For example, TNCs reduce the need to own a vehicle and make vehicle travel more convenient by avoiding parking and taking riders door-to-door. As such, they have influenced other modes and have contributed to undesirable consequences such as reducing transit ridership



Adapted from MetLife Investment Management, American Public Transportation Association
Note: Major metros include Boston, Chicago, Los Angeles, New York City, San Francisco, and Washington D.C.

Various academic studies have attempted to predict the effects of AVs especially on metrics such as VMT. Theses studies have produced a wide range of potential effects but only three of them relied on travel forecasting models used in public agency practice. This study added results from 12 existing regional models from around the U.S.

Table 1: Short to Long Run Scenario Modeling Studies

AUTHOR	LOCATION	METHOD	AV	PARAMETERS	TOTAL VMT	MODE SHIFT
Thakur et al. 2016 (15)	Melbourne, Australia	Travel & land use model calibrated to regional forecasts	100% Personal	Value of Time (VOT)	+30%	- 3% Transit
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Azevedo et al. 2016 (20)	CBD Singapore	Activity & agent travel model (SimMobility) with travel survey, network & taxi data	100% Shared	Operating & Parking cost structure		+3% Transit +29% shared AV
de Alameidia Correia & van Arem 2016 (21)	Small city Delft, Netherland	Agent-based model with travel survey data, generalized cost functions	100% Personal	Parking Cost and VOT	+17.3% to +325%	

Methodology

To demonstrate how AVs could influence future travel demand, a series of model tests were performed using 12 regional models from around the U.S. The tests are all based on full market penetration of AVs in the horizon year of the models, which was 2035 or later. While the twelve regional models tested relied on different structures, software, quality of data inputs, etc., they represented a cross-section of the current state of the practice. Forecasting models used in this study included models from the following regions:

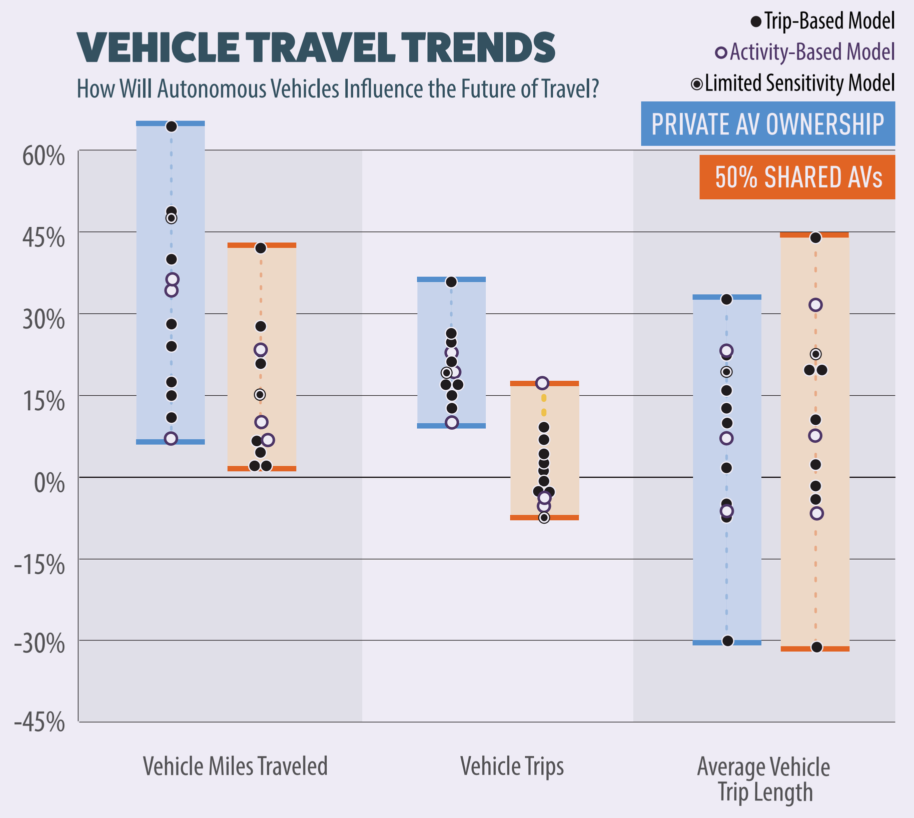
- West Coast – 3 Activity Based Models and 6 Four-Step Models
- Rockies – 1 Four-Step Model
- East Coast – 1 Four-Step Model
- Upper Midwest – 1 Four-Step Model

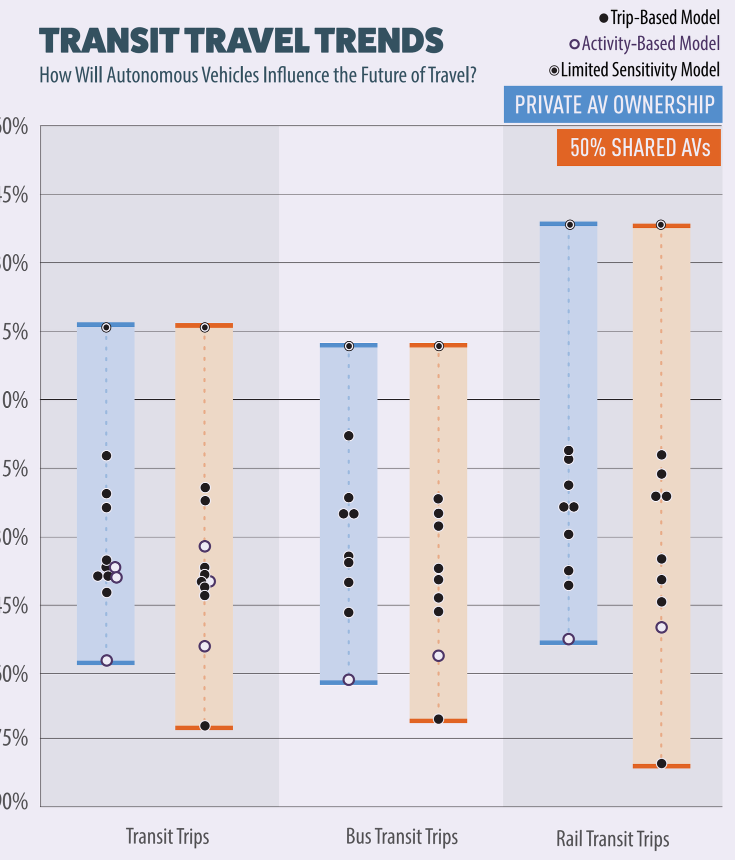
The specific variables changed in the models included the following:

- Terminal Time – reduce to 0
- Parking Cost – reduced 50%
- Value of Time – reduced 50%
- Auto Availability – all households have at least one vehicle
- Freeway Capacity – increased to 3,300 vehicles/hour/lane
- Increased Trip Making – non-work trips increased 25%
- Auto Occupancy – no change in base test but reduced drive-alone trips by 50% in shared test

Results

The highlights of the results are summarized in the charts.

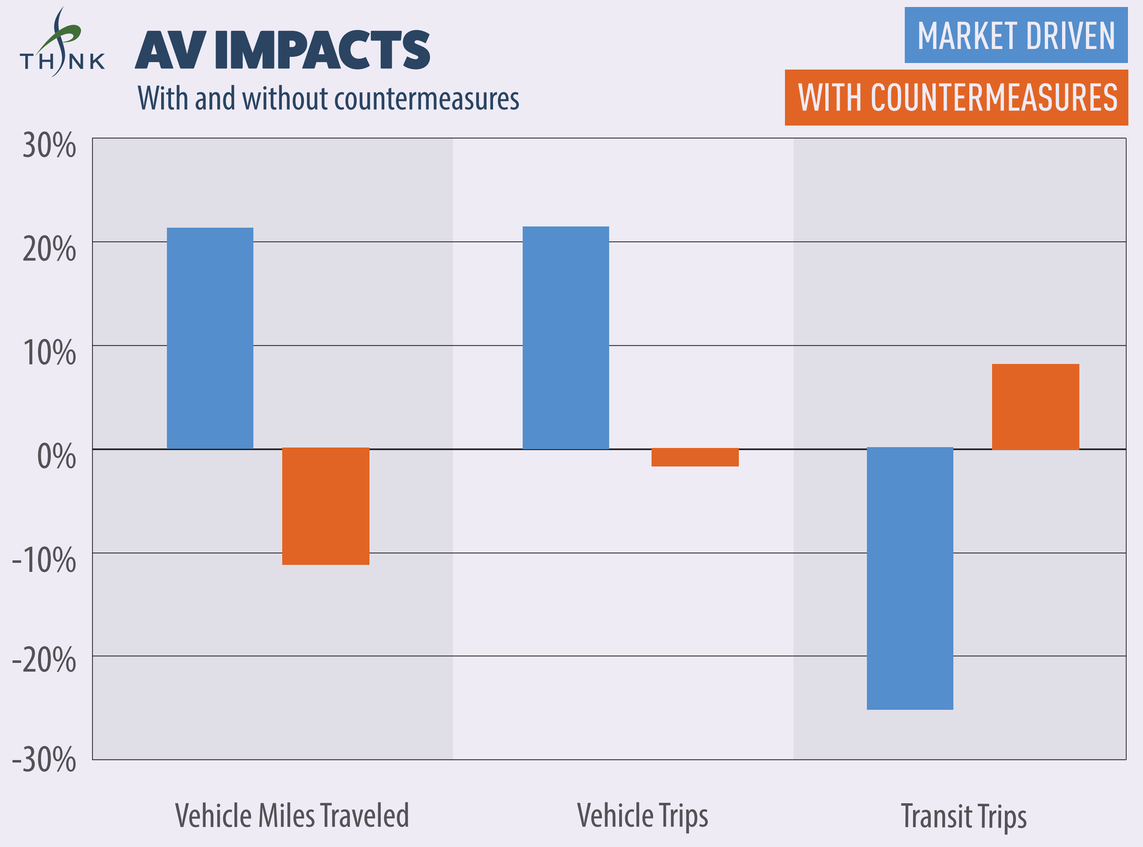




The variations in results among the models may be due to different model strengths and weaknesses rather than actual variations in effects. The models did not capture all induced growth and induced vehicle travel effects as the tests did not account for zero-occupant trips or long-term land use effects. The model tests themselves were designed as 'stress tests' to better understand potential AV effects and model sensitivity to help inform future research and analysis.

Offsetting AV Effects

The modeling results are important for framing discussions about travel demand trends and the potential policy responses for any undesirable changes. The actions of government can influence these outcomes. As such, we tested how improving transit competitiveness, increasing the cost of vehicle travel, and using technology to reduce personal and commercial trips could influence the overall AV effects. The modeling results find that countermeasures have the potential to offset the negative impacts that could be caused by AVs in the three regions tested.



Conclusions

This paper presents evidence from current practice models that AV influence on travel behavior could substantially increase vehicle travel and decrease transit ridership if public agencies do not take policy or regulatory action. This is simply a reflection of how travel behavior preferences embedded in current practice models respond to individual input parameter changes influenced by AVs. This analysis does not consider how the objectives of the private market may amplify these effects given that revenue models for TNC or mobility as a service (MAAS) depend on the level of vehicle use.

Offsetting these potential undesirable effects is possible but likely requires government actions. While ultimate outcomes are surrounded by uncertainty, public agencies can start to build on the quantitative assessments from this paper and the analysis by others cited in the paper. Public agencies can consider this analysis an important first step in a risk assessment of AV effects. The next step is to recognize that action is likely necessary to achieve desired future outcomes especially in communities already striving to reduce vehicle travel for sustainability purposes.

FEHR & PEERS

USING CURRENT PRACTICE REGIONAL MODELS TO TEST AUTONOMOUS VEHICLE EFFECTS ON TRAVEL DEMAND AND PUBLIC AGENCY POLICY RESPONSES

Ronald T. Milam, AICP, PTP, Corresponding Author
Fehr & Peers
1013 Galleria Blvd, #255, Roseville, CA 95661
Tel: 916-262-7400; Email: r.milam@fehrandpeers.com

Adrita Islam
Fehr & Peers
1001 K Street, 3rd Floor
Sacramento, CA 95814
Tel: 916-379-7005; Email: a.islam@fehrandpeers.com

Kevin Johnson
Fehr & Peers
100 Pringle Avenue, Suite 600
Walnut Creek, CA 94596
Tel: 925-357-3372; Email: k.johnson@fehrandpeers.com

Jimmy Fong
Fehr & Peers
1001 K Street, 3rd Floor
Sacramento, CA 95814
Tel: 916-262-7419; Email: j.fong@fehrandpeers.com

Kwasi Donkor
Fehr & Peers
1003 K Street NW, Suite 209
Washington, DC 20001
Tel: 202-854-2737; Email: k.donkor@fehrandpeers.com

Jinghua Xu
Fehr & Peers
101 Pacifica
Irvine, CA 92618
Tel: 949-308-6314; Email: j.xu@fehrandpeers.com

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ABSTRACT

In this paper, autonomous vehicle (AV) effects are evaluated through the same methods that transportation professionals use in planning for new infrastructure to support population and employment growth. The authors explore AV effects using current practice regional travel forecasting models with a focus on vehicle travel and transit ridership effects. Resulting forecasts show the potential for substantial increases in vehicle travel and decreases in transit ridership as vehicle travel convenience increases and vehicle travel costs (both time and money) decline. The paper identifies a potential conflict between private market incentives for increasing the use of vehicles with public goals to reduce vehicle miles of travel (VMT) and emissions; increase active transportation; and expand transit ridership. Remedies are offered in the form of potential government policy responses and counter measures designed to offset undesirable AV travel outcomes. A scenario was tested with potential countermeasure strategies revealing the potential to fully offset VMT increases and transit ridership decreases associated with potential AV effects.

Keywords: Autonomous Vehicles, Disruptive Trends, Transportation Network Company, Vehicle Miles of Travel, VMT, Countermeasure Strategies

INTRODUCTION

Transportation planning in the United States (U.S.) over the past six decades has largely been reactionary. Government agencies have focused on expanding transportation networks to accommodate increasing demand associated with population and employment growth. Travel demand forecasts have been used to justify capacity expansion projects with limited attention to the uncertainty of forecasts. New disruptive trends in transportation are changing this basic transportation planning paradigm and raising questions about infrastructure decision making risks. Early disruptive trend headlines focused on transportation network companies (TNCs), bike/scooter sharing, internet shopping, and micro transit but growing attention is centered on the potential effects of autonomous vehicles (AVs). AVs deserve this attention because of the wide range of potential beneficial and adverse effects. The beneficial effects cited in research literature include highlights such as reduced collisions, increased roadway capacity, and greater access to vehicles by those unable to drive while leading adverse effects include greater vehicle miles of travel (VMT) leading to more emissions and declining transit ridership *(1)(2)(3)(4)*.

TNCs serve as a proxy for future AV service since customers only pay when trips are made, avoid parking costs, and travel door-to-door. The ease of ordering the trip also adds to the convenience of TNCs. Much speculation has occurred that TNCs are creating adverse effects such as reducing transit ridership and increasing VMT. Transit ridership across U.S. metropolitan areas has declined since about 2015 despite increased employment and a growing economy. Figure 1 charts U.S. public transit ridership for major metro areas and notes the timing of the most recent decline in ridership coincided with the launch of TNCs *(5)(6)*. This outcome is attributed in part to the expansion of TNCs but also lower fuel prices, more travel choices, and increased car ownership *(7)*.

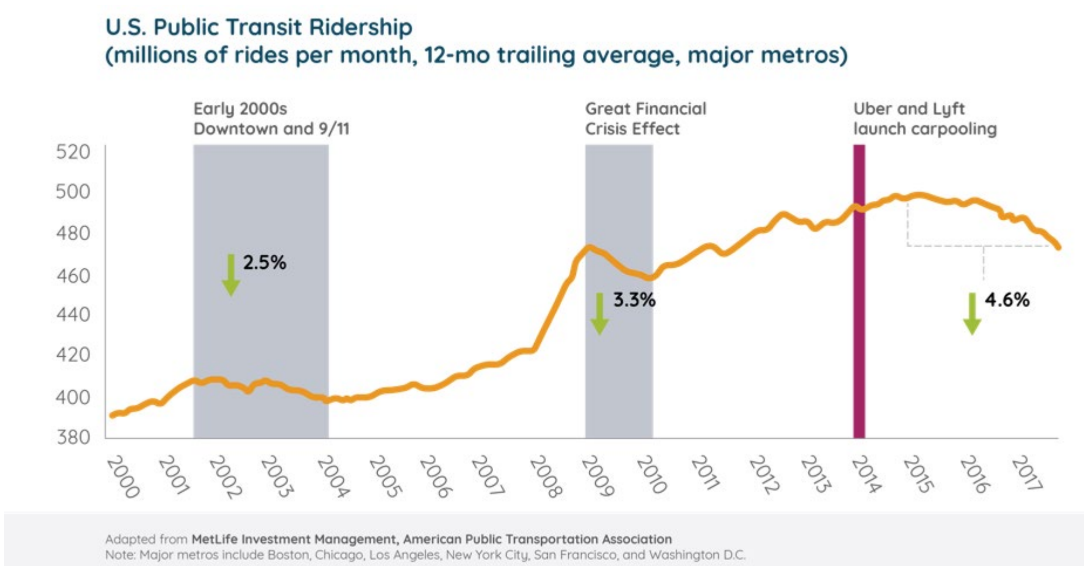

Figure 1: Disrupting the Status Quo of Transit

Sources: MetLife Investment Management, American Public Transportation Association
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Understanding whether a transition to AVs will continue the downward trend in transit ridership and corresponding increases in vehicle use, VMT, and emissions is an important policy question to evaluate now before AVs are in widespread use. Policy responses to dampen or minimize undesirable AV effects are likely to be most effective if implemented early compared to the common approach in the U.S. where policy responses are often developed only after a problem occurs on the transportation network. Further, public agencies may need to more seriously consider transportation network management approaches to address AV effects instead of the traditional capacity expansion projects that have failed to increase speeds and reduce travel times due to the predictable induced vehicle travel effects *(8)*. Communities may become more dependent on pricing travel demand as recommended by economists *(9)*.

With AVs removing the driver from TNC services and changing the travel cost equation, U.S. cities could experience a variety of travel effects *(10)*. If these effects include greater reliance on vehicles and more VMT, how will public agencies respond and will it be in time to offset undesirable effects? AVs will allow private vehicle owners to avoid the driving task and make the time spent driving available for other purposes. They will also eliminate or substantially reduce the cost and time spent parking and the time and distance between parking space and true destination *(4)(10)*.

These changes create strong possibilities for increased vehicle travel and decreased transit ridership, which raise important policy questions for public agencies. In response, we explore the influence of AVs on travel behavior and consider government policy and regulatory responses to offset potential undesirable effects *(11)*. This information is intended to demonstrate the types of actions that may be required by cities and states like California that are focused on reducing VMT and emissions to improve sustainability *(12)*.

In essence, we want to explore the question, "How will lowering the cost of vehicle travel and increasing its convenience change travel demand?" These elements of travel play a strong role in modal preferences that have consequences for sustainability, equity, return on transportation investments, and long-term land use. Other factors will also need to be considered including how human behavior could be influenced by anchoring inertia, peer influence, and mental accounting that have been exposed through behavioral science research *(13)*.

To quantify the potential AV effects, this paper measures vehicle travel demand and transit ridership using current practice regional travel forecasting models. These models are relied upon by practitioners to make significant infrastructure investment decisions involving 20 plus year forecasts. We use these models to help understand the direction and magnitude of change that could occur without the influence of new government policies and regulations. Policy responses are then offered that could offset undesirable effects. Finally, some of these policy strategies are also modelled through the travel demand models.

LITERATURE REVIEW

Potential effect of TNCs and AVs on the environment and the built environment has been studied in the past few years. A number of studies that have been performed to understand the empty repositioning required to pick up and drop off passengers *(14) (15) (16)*. Even though these studies are only focused on vehicle travel and repositioning, they also predict substantial increases in VMT. But these studies do not entirely capture the effect of AVs on travel behavior of individuals or changes in long term travel choices. Rodier, 2018 provides a list of the noteworthy studies that look at travel choice and its effect on the overall network using real world data *(4)*. These are listed in Table 1.

Table 1: Short to Long Run Scenario Modeling Studies

Author	Location	Method	AV	Parameters	Total VMT	Mode Shift
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Three of the studies in Table 1 relied on travel forecasting models used in local or regional agency practice. With such a small sample and large range of effect, this paper expands on this approach using 12 existing models from around the U.S. The intent of an expanded sample is to gain understanding about the potential range of effect, model sensitivity, and the key contributing factors. In addition, tests are expanded to include how countermeasures or policy responses influence future modeled outcomes.

METHODOLOGY

The transition to AVs represent one of many current disruptive trends in transportation related to technology. Unlike other trends such as social networking, shared mobility, home entertainment, and internet shopping, AVs have the potential to alter a much larger portion of individual activities and how people and goods travel. Predicting the specific effects is difficult because of a number of uncertainties such as:

- Government regulation of AVs;
- Costs of AVs whether shared or owned;
- Public transit agency responses to AVs; and
- Public acceptance and use of AVs and sharing them for regular travel.

Despite the ambiguities, we can test the fundamental effects of AVs using regional travel forecasting models. Transportation planners use models to help test future scenarios and to provide insights about potential future outcomes. These models are constructed to predict travel behavior outcomes when inputs such as land use, demographics, socioeconomics, or transportation network components are changed. As such, if a disruptive trend such as AVs is likely to change one of these elements directly or indirectly, a travel forecasting model can be used to provide insight to how that change may manifest itself in terms of travel demand changes. Limitations do exist in these applications especially when trends influence factors not included in the models, but they provide a starting point to help anticipate change.

To demonstrate how AVs could influence future travel demand, a series of model tests were performed using 12 regional models from around the U.S. The tests are all based on full market penetration of AVs in the horizon year of the models, which was 2035 or later. While the twelve regional models tested relied on different structures, software, quality of data inputs, etc., they represented a cross-section of the current state of the practice. Forecasting models used in this study included models from the following regions.

- West Coast – 3 Activity Based Models and 6 Four-Step Models
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Three representative models from the West Coast (Activity Based Model), Rockies, and East Coast were then tested to determine potential regulatory, pricing, and technology countermeasures to reduce the AV impacts. The purpose of this step was to study whether potential adverse impacts can be substantially mitigated if public and private sector interests quickly implement measures that will allow the improved mobility offered by AVs, without the unintended adverse consequences.

MODELING DISRUPTIVE TRENDS

Each model is structured a bit differently, so the approach varied somewhat in each case. The testing included the following travel forecasting model variables related to travel behavior.

Terminal Time

Travel models define the time needed to park your car and walk to a destination as "terminal time." The higher a terminal time, the less likely a person will choose an auto for a particular trip. AVs are likely to reduce terminal times by eliminating the need to park and providing on-demand door-to-door service. The amount of reduction will depend on how cities prioritize curb space use and management policies. For these tests, a terminal time of 0 was used.

Parking Cost

Most models include a variable for parking cost in areas where costs are imposed. AVs have the potential to lower or even eliminate parking costs. However, cities in the future may impose pick-up and drop-off costs for AV use depending on location to help manage peak period traffic demands. For these tests, parking costs were halved.

Auto Operating Costs

Vehicle travel has costs associated with purchasing or leasing, operating, and maintaining the vehicle. Travel decisions tend to focus on the operating costs such as fueling the vehicle and can be expressed in a model as a per mile cost to capture higher costs for longer distance trips. For AVs, operating costs will depend on whether the vehicle is owned or offered through a TNC or MAAS type platform and if the trip is shared or not. Studies show significant reduction in costs with AVs *(10)*. For these tests, auto operating costs were not changed.

Value of Time

Travel models also incorporate the value of time, but in different ways. Travelers using AVs will be able to make productive use of their time spent travelling and perceive lower values of time because their opportunity cost will be reduced. For these tests, the perception of in vehicle travel time was halved.

Auto Availability

Models have variables tied to trip rates and auto availability. AVs may increase trip rates due to their greater convenience and ready availability. Greater convenience could lead to more discretionary vehicle trips for shopping, social, leisure or recreational purposes. Additionally, people not licensed to drive will be able to make vehicle trips. For these tests, all households were adjusted to have at least one auto available as a proxy for the availability of AVs through TNC type service.

Roadway Capacity

As vehicles become more automated and connected, they offer greater potential to increase roadway capacity especially on freeways *(10)(22)*. The increase in capacity will come from shorter headways, less weaving, and more stable traffic flows. Roadway capacity will increase first on freeways and expressways, then on major arterials. However, the potential exists that freeway interchange off-ramps where vehicles transition to the arterial system may become bottleneck due to increased traffic. For these tests, freeway capacity was increased to 3,300 vehicles per hour per lane.

Increased Trip Making

Lowering the cost (in both time and money) of using vehicles is expected to increase non-work trip making *(4)*. By how much is a debatable question that depends on the time budgets of travelers but also the number of people unable to use vehicles due to age or other license restrictions. For these tests, non-work trip generation was increased by 25%.

Auto Occupancy

Auto occupancy is the number of persons per vehicle and it has a substantial effect on the number of vehicle trips and related effects on how the roadway network operates. In traditional auto travel, the autos all have one or more people. Studies shows that at least 41% of current ridesharing vehicles are operating at 0.8 passenger occupancy rate, accounting for deadheading *(23)*. With AVs, occupancy level could decrease due zero-occupant travel such as getting to the next passenger or reaching remote parking. However, much higher ride sharing levels could be achieved if AVs are offered through a TNC service with much lower costs *(10)*. For these tests, increase sharing was assumed by shifting 50% of the drive alone trips to shared ride trips.

RESULTS: THE FUTURE OF TRANSPORTATION DISRUPTION

The general expectation from testing AV effects was that vehicle travel would likely increase and transit ridership would decrease for the main reasons discussed at the beginning of this paper. The model results confirmed the expectations, but the magnitude of the effects may be surprising. These tests included complete market penetration of both private ownership of AVs similar to automobile ownership today plus a scenario where 50 percent of drive-alone trips were shifted to shared vehicles. In sum, the long-term effects of AVs could include more dispersion of land use growth (especially residential) and a greater willingness to make longer distance trips.

Effect on Vehicle Travel

Results show that VMT in both scenarios go up compared to baseline which is the future conditions without AVs. Number of vehicle trips increase in most cases but the average trip length varies a lot. Figure 3 shows the range of effects captured by the models for vehicle travel. Each dot in the chart represents the results from an individual model. The highlights of the results can be summarized as follows:

- VMT increased in all models (up to 68%) even if 50% of AV trips are shared.

- Trip lengths had the biggest range of effect with models showing both increases and decreases. This outcome was surprising especially when results differed for models that shared similar land use contexts.

- Sharing has the potential to minimize vehicle trip increases but did not fully offset VMT increases even if 50% of AV trips are shared.

Part of the variation in the results may be explained by a lack of dynamic model validation and reasonableness checks. While all the models performed some level of static validation, very limited dynamic sensitivity testing was reported. This may be a finding that reinforces the importance of following model development guidance contained in *Travel Model Validation and Reasonability Checking Manual, Second Edition, T*ravel Model Improvement Program, Federal Highway Admiration, 2010 and *2017 Regional Transportation Plan Guidelines for Metropolitan Planning Organizations*, California Transportation Commission, 2017.

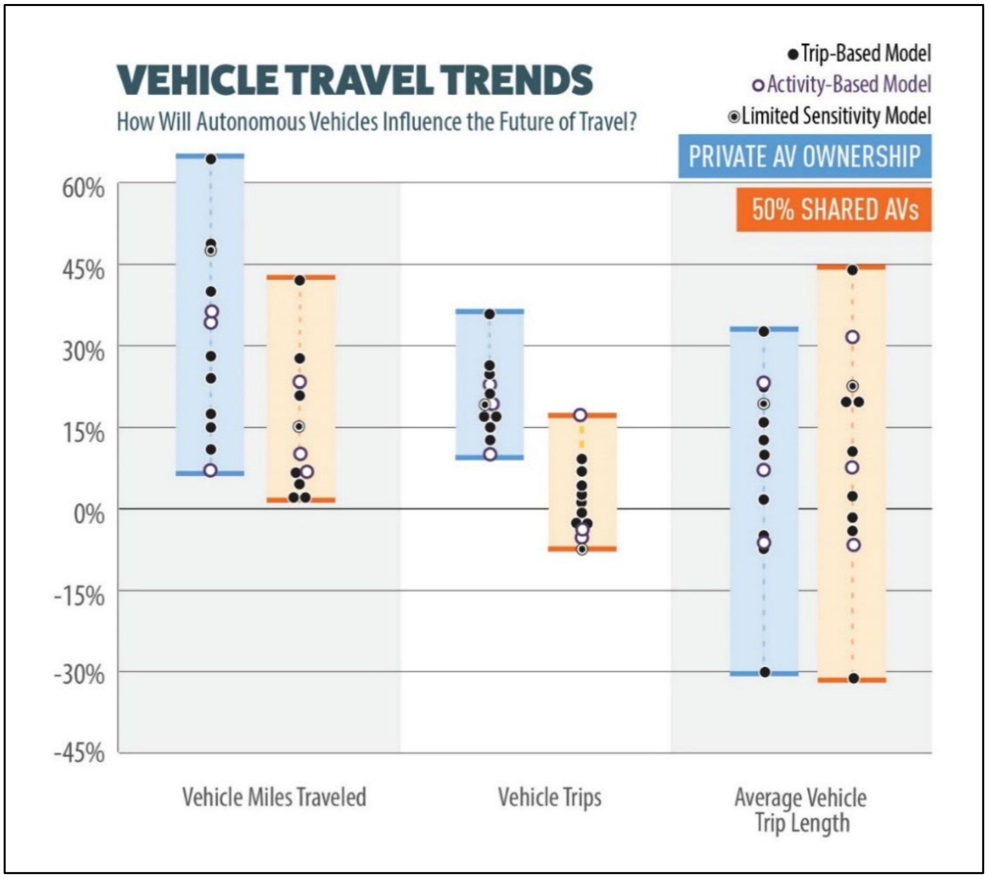

Figure 2: AV Effects on Vehicle Travel
Source: Fehr & Peers, 2019

In comparison to other research we see that these results may be highly relevant. For example, a unique experiment involving the provision of 60 hours of free chauffer service for one week showed a VMT increase of 83 percent for those participating *(24)*. While, this experiment was conducted using a small sample of 13 test subjects from the San Francisco Bay Area it underscores the significance and importance of our modeling.

Effect on Transit Travel

As anticipated, transit ridership decreases in all the scenarios but even more so in the shared AV scenario. This conforms to the current trend in TNC effects on transit ridership discussed earlier. Figure 3 shows the range of effects captured by the models for transit use.

The highlights of the AV effect on transit ridership and transit trips can be summarized as follows:

- Total transit trips declined in all but one of the models. This model had limited sensitivity due to a lack of feedback to trip distribution and mode choice.
- Transit trips declined by similar levels under the shared scenario since drive alone trips were simply shifted to shared ride vehicle trips.

- Short distance transit trips less than 5 miles decreased more than rail and transit trips greater than 5 miles.

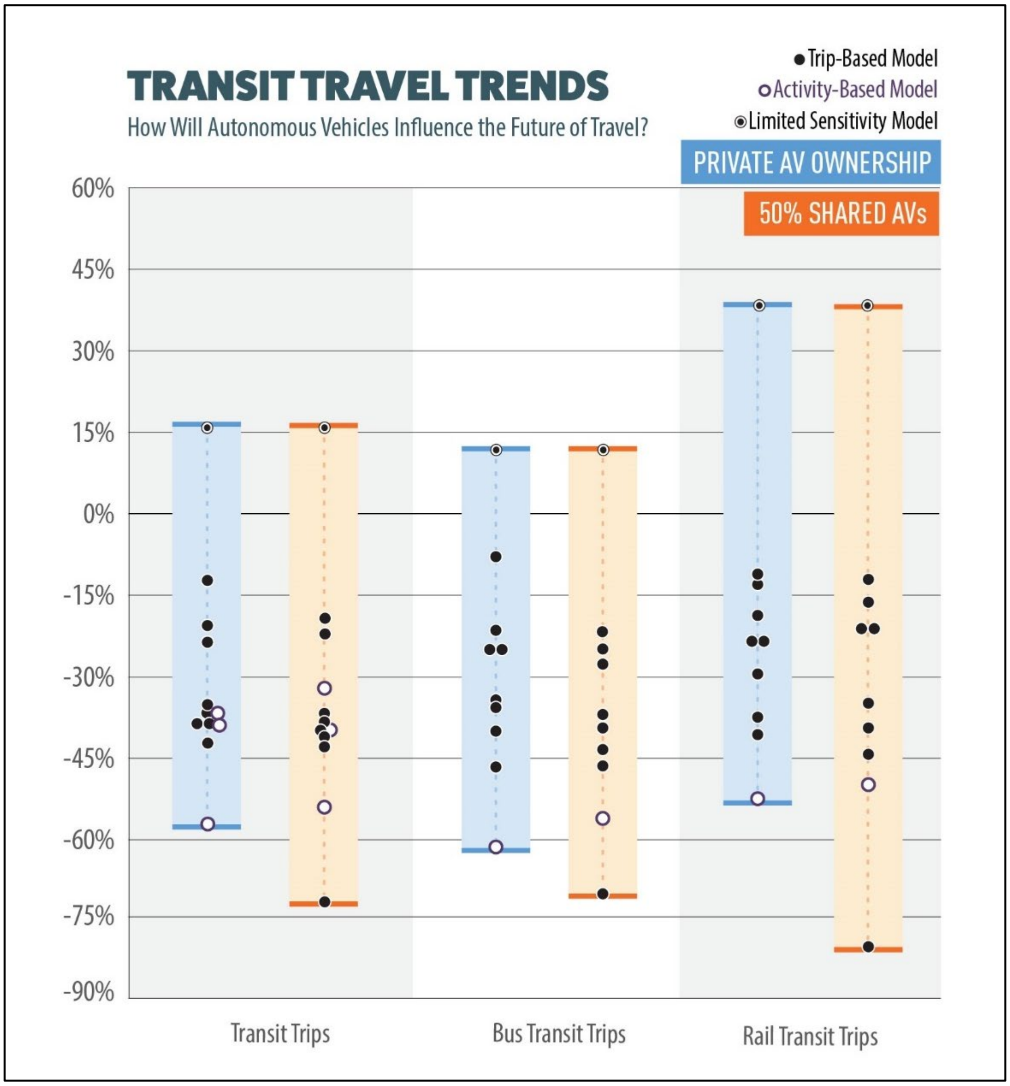

Figure 3: AV Effects on Transit Ridership
Source: Fehr & Peers, 2019

The variations in results among the models may be due to different model strengths and weaknesses rather than real-world variations in effects. They did not capture all induced growth and induced vehicle travel effects as the tests did not account for zero-occupant trips or long-term land use effects. The model tests themselves were designed as ‘stress tests’ to better understand potential effects and level of sensitivity to help inform future research and analysis rather than tests based on a consensus on the likely AV penetration levels, cost and time savings.

OFFSETTING AV IMPACTS

The modeling results are important at framing future behavior and transportation trends, but they also emphasize the policy context. The actions of government can have a dramatic effect on these outcomes. Governments can use policy and regulation to balance the desires of private companies with the public good. With that context in mind, we provide a brief list of potential policy and regulatory responses designed to offset the effects revealed by the modeling tests. In general, the responses include: increasing public transit competitiveness; increasing the occupancy of new mobility vehicles, decreasing their size, and increasing the cost of zero-or-low-occupancy vehicle travel; and using land use policy.

Improving Transit Competitiveness

Decrease in transit ridership is largely attributed to the fact that transit travel times are much slower than automobile travel especially if delivered in a TNC or mobility as a service (MAAS) platform. These discrepancies between transit and disruptive modes will be enlarged by incorporation of AV technology. Some strategies to improve transit travel experiences and travel times in order to keep transit competitive are listed below.

- <u>Increasing frequency and hours of service</u> – Frequency directly influence wait times and provides flexibility to system users to come and go from destinations without having to worry about schedules. The operational hours for transit need to cover most of the day.

- <u>Providing transit-only lanes</u> – Similar to operational hours, in-vehicle travel time on buses needs to be faster to compete with vehicle travel. Transit-only lanes (during peak periods) improve roadway space efficiency and utilization and would lower current in-vehicle travel times.

- <u>Automating transit service</u> – Buses on fixed routes are one of the first opportunities for autonomous vehicle use. Fixed routes are easier to navigate than an open network and the switch to autonomous operations reduces labor costs. Savings could be redirected to expanding core services or improving frequency and service hours. Savings could also be translated into reduced fares, with the possibility of offering free transit service that could stimulate a virtuous cycle of attracting more ridership. If automated operation is combined with technology for matching riders and vehicles, then *autonomous rapid transit (ART)* service could be offered. These could potentially create a destination matching similar to Uber Express Pool that would allow the automated transit vehicles to skip some stations once the vehicle is full thus improving in-vehicle travel times compared to conventional bus or bus rapid transit (BRT).

- <u>‘Right size’ transit demand</u> – TNCs, MAAS, and AVs offer expanded options for demand-responsive and crowd-sourced transit in low- to medium-density areas whether service is provided by the public or private sector. Public agencies could benefit by operating on-demand door-to-door service using a similar platform or by contracting for cost-effective service when traditional fixed-route bus productivity would otherwise be low. Three main components of these services can be described as-

1. *Backbone Service* - Fixed-route, high-frequency rail and bus services operating in exclusive or managed rights-of-way. Examples include commuter rail, metro rail, light rail, streetcar, rapid bus, express and HOV-lane bus, and fixed-route buses in high demand corridors.
2. *Crowd-Sourced Service* - Public or private shuttles and micro-transit operating smaller vehicles in route deviation, demand-responsive services. Examples include casual carpool, university and employer shuttles, and TNC services like Chariot, Via, and Lyft Shuttle.
3. *On-Demand Ridehail* - Private and public door-to-door services following completely flexible routes and guaranteed travel times while attempting to pool several traveler groups. Examples include vanpool, casual carpool, Lyft Line, Waze, and carpool.

- Service performance and equity – a key challenge in ensuring that MAAS and TNC type transit platforms are equitable is that they are market driven. Planners and engineers do not yet know what the implications for more rural and poor areas might be. It could be that they would require subsidy or mandatory service standards for operations, to make sure that private providers maintain safe and reliable service access.

Regulating AVs

In terms of AVs, absent government regulations, initial implementation will likely occur through TNC or MAAS platforms. While AVs offer potential benefits such as reducing collisions, they also make vehicle travel more attractive. Increases in vehicle use could exacerbate current problems associated with congestion and emissions especially if vehicle sizes remain large and occupancy levels remain low. The following actions are intended to minimize adverse effects of greater vehicle use.

- Require AVs to be electric – Using electric power generation would minimize the emissions associated with AV travel.

- Support small or micro-sized AVs–Today's large vehicle sizes (combined with low occupancies) consume substantial physical space, capacity, and green time at signalized intersections. Reducing vehicle sizes improves network performance.

- Manage or price low occupant AV travel– Various studies of AV effects emphasize that the only way to prevent substantial increases in vehicle use (i.e., VMT) is require AVs to operate as taxis carrying multiple passengers. It is important to recognize that vehicle travel on today's roadway networks is characterized by very low seat utilization. A study of seat utilization on I-15 in Salt Lake City, Utah found levels below 35 percent in the peak hour of the peak direction *(25)*. The lack of a market for vehicle travel and associated roadway pricing is directly related to this outcome. Without a change to vehicle travel markets and pricing, AVs could potentially lower existing seat utilization levels due to zero-occupant trips. Building pricing into AV use early can help shift ground transportation towards more efficient travel outcomes.

Managing Land Use

As explained above, new mobility and autonomous vehicles have the potential to contribute to more dispersed land use patterns. Greater land use controls such as those listed below may be necessary to offset undesirable expansion of land use development.

- Urban growth boundaries – AVs and new mobility may extend the distance people are willing to travel between their home and major destinations such as employment and education centers. Urban growth boundaries are one mechanism for directing growth to help minimize undesired expansions of urban area footprints. Land in urban centers presently used for parking could become available for active uses and the cost to develop higher densities and to mitigate their transportation impacts could decline. The potential for denser and central housing, workplaces and services development could help counterbalance the sprawl pressures from increased travel efficiencies.

- Zoning changes – AVs and new mobility may increase development pressure on land areas and parcels that previously were not envisioned for residential development. With housing supply constraints in many major U.S. cities, AVs may extend travel distances as noted above, which could increase demand to build residential homes on parcels originally intended for other uses. Urban policies that reduce required parking at downtown locations could help offset some of this effect.

MODELLING THE REGULATED AUTONOMOUS FUTURE

This section presents the results of modelling some of the countermeasures discussed in the previous section into the regional planning models. Many of these measures will require cooperative public and private efforts, setting in place supportive policies, regulations, financial incentives and infrastructure and making significant private investment to make technology and operational advances possible. The major regulatory measured tested included the following:

- Pricing - Fees and user charges on low occupancy vehicle travel in the form of vehicle-mile charges and congestion pricing.

- Shared-Ride Incentives - Pricing and added efficiencies and right-sized vehicles for pooled door-to-door travel, crowd-sourced micro-transit, enhanced "mobility-as-a-service" options.

- Transit Enhancements - Autonomous transit vehicles to redeploy services in a more demand-responsive fashion to reduce passengers' service access and wait times, speed up origin-to-destination travel times, and reduce fares.

- New Technology Solutions - Autonomous goods movement, local manufacture and 3D printing, optimized deliveries on right-sized vehicles. Drone deliveries and vertical-takeoff-landing (VTOL) transport, virtual reality as a substitute for travel, micro-mobility technology including e-bikes and scooters, and delivery bots.

RESULTS: AUTONOMOUS FUTURE CAN BE OPTIMIZED

The modeling results find that, as shown in Figure 4, adequate countermeasures have the potential to offset the negative impacts that will likely be caused by AVs in the three regions tested.

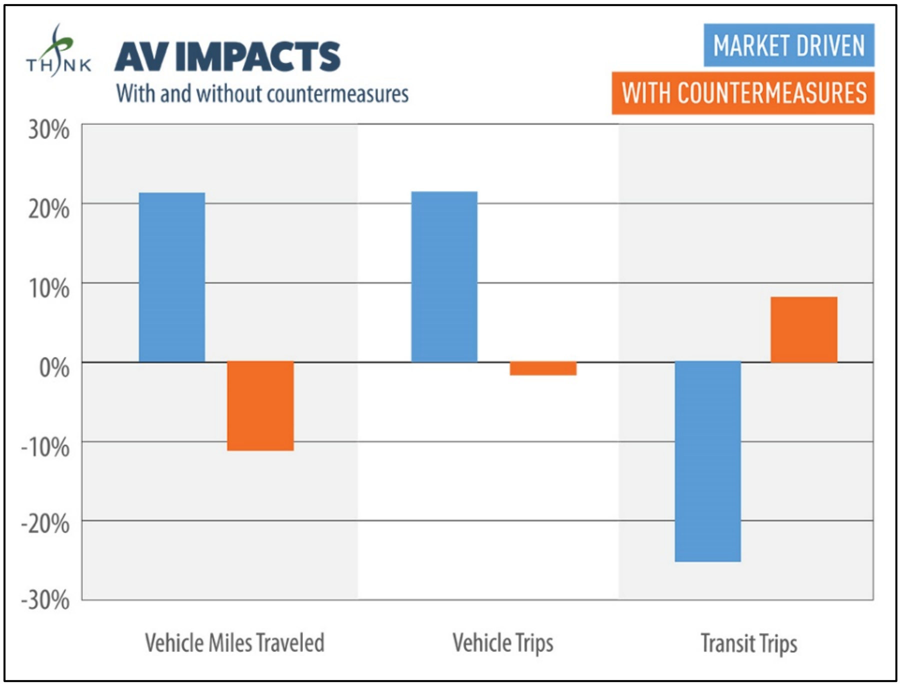

Figure 4: Effects of Countermeasures
Source: Fehr & Peers, 2019

Results can be summarized as follows:

- Without the countermeasures, the regional vehicle miles and trips would increase by an average of between 20 and 25% and transit trips would decrease by about 25% when compared to future conditions with no AVs being available.

- With the full array of optimal strategies, the VMT would decrease by 10 to 15%, trips would decrease by up to 5%, and transit trips would increase by an average 5 to 10% compared with a no-AV future.

LIMITATIONS & NEXT STEPS

Since there is uncertainty related to changes in people's travel choices as AVs become more prevalent, public agencies may consider forecasting potential effects as speculative. While that is not an unreasonable position, waiting for clarity and certainty could cause delays in policy and regulatory responses that would be needed early to avoid undesirable outcomes. This paper demonstrates that existing travel forecasting models are capable of predicting AV effects on travel demand sufficiently to inform early policy response discussions since the potential increase in vehicle travel is a risk to those public agencies already focused on reducing vehicle use and VMT for sustainability purposes. We consider the range of effects measured in current practice models to potential underestimate the size of the effect given the following limitations of our model testing.

- The models did not capture zero-occupant vehicle trips that would occur as AVs travel between different passengers or to final parking locations when not in use.

- Long-term land use changes were not accounted for in these model runs. So, higher levels of VMT are possible.

DISCUSSION

This paper presents evidence from current practice models that AV influence on travel behavior could substantially increase vehicle travel and decrease transit ridership if public agencies do not take policy or regulatory action. This is simply a reflection of how travel behavior preferences embedded in current practice models respond to individual input parameter changes influenced by AVs. This analysis does not consider how the objectives of the private market may amplify these effects given that revenue models for TNC or MAAS depend on the level of vehicle use.

Offsetting these potential undesirable effects is possible but likely requires government actions. While ultimate outcomes are surrounded by uncertainty, public agencies can start to build on the quantitative assessments from this paper and the analysis by others cited in the paper. Public agencies can consider this analysis an important first step in a risk assessment of AV effects. The next step is to recognize that action is likely necessary to achieve desired future outcomes especially in communities already striving to reduce vehicle travel for sustainability purposes.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Ron Milam, Adrita Islam; data collection: Ron Milam, Adrita Islam; analysis and interpretation of results: Ron Milam, Adrita Islam, Kevin Johnson, Jimmy Fong, Kwasi Donkor, Jinghua Xu; draft manuscript preparation: Ron Milam, Adrita Islam. All authors reviewed the results and approved the final version of the manuscript.

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