EXPLORING THE EFFECT OF AUTONOMOUS VEHICLES ON TRANSIT RIDERSHIP

Amin Mohamadi Hezaveh
University of Tennessee, Knoxville
311 JD Tickle Building, TN 37996
Phone: (385) 259-5148
amohamad@vols.utk.edu

Candace Brakewood
University of Tennessee, Knoxville
320 JD Tickle Building, TN 37996
Phone: (865) 974-7706
Email: cbrakewo@utk.edu

Christopher R. Cherry
University of Tennessee, Knoxville
321 JD Tickle Building, TN 37996
Phone: (865) 974-7710
Fax: (865) 974-2669; Email: cherry@utk.edu

Word count: 5,178 words text + 2 tables/figures x 250 words (each) = 5, 678 words

Submission Date: 11/15/2018

ABSTRACT
Autonomous Vehicles (AV) are a new mode of transportation that provide the ability to communicate with other vehicles and intelligent road infrastructure. Although several studies have shown the potential benefits of fully AVs on mobility and safety, its effect on the overall transportation system is generally not well understood. One mode that could be heavily affected by AVs is public transit. In this study, we establish a framework based on the four-step travel demand model to explore the potential effects of AVs on ridership. By reviewing the current literature on AVs and breaking down the four-step model, the likely results are a reduction in transit ridership with the probable migration of travelers from public transit toward using AVs. Extra comfort and privacy of AVs, compared to public transit, could increase the relative utility of AVs, which ultimately could lead to travelers shifting from transit toward AVs. Low costs of Shared AVs (SAV) and microtransit AVs have the potential to adversely impact transit ridership by attracting travelers from traditional public transit services. AVs also remove mobility barriers for captive riders, which may cause migration of a portion of these travelers toward AVs or micotransit. In contrast, AVs could increase the capacity of existing roads and reduce delays at intersections, which could benefit public transit by cutting in-vehicle and out-of-vehicle travel times, which would positively impact ridership. In summary, the overall effects of AVs on transit are unclear and require significantly more research, but this framework begins to shed light on this emerging issue.

Keywords: Public Transit; Autonomous vehicles

INTRODUCTION

Autonomous vehicle (AV) technology has the potential to transform road transportation in the coming years (*1*). Several studies indicate that autonomous vehicles may impose both negative and positive externalities on the transportation system (*2*). In order manage AVs' externalities, particularly minimize the negative externalities, researchers, policymakers, and practitioners need to study the impacts of AVs, particularly their effects on other elements of the transportation system such as roads, parking, and public transit (*3-5*). Widespread adoption of AV technology in automobiles has the potential to have widespread effects on other modes of transportation. This paper focuses on developing a conceptual framework to assess the potential impacts of fully autonomous cars on public transit systems by identifying changes in the relative utility between modes of transportation.

According to the Society of Automotive Engineers (SAE), vehicles can have six levels of automation (*6*). The first level has no automation, and the driver is fully in charge of driving tasks. As the level of autonomy increases, the driving responsibilities transfer from a human driver to the vehicle. Eventually, in Level 5, when full automation takes place, the vehicle can drive without a human driver or any occupants. Level 5 vehicles will likely make fundamental changes in the transportation system both on the supply and demand side. Connected and autonomous vehicles (CAV) will be able to communicate with other vehicles in the transportation system as well as road infrastructure. This ability will enable AVs to perform based on real-time data of the surrounding traffic conditions, which could increase the efficiency and reliability of autonomous vehicles (*7*).

Shared autonomous vehicles (SAV) or autonomous taxis are another forms of AVs that have the potential to provide low-cost on-demand services for those who cannot afford an AV (*6; 8-10*). These services may play a substantial role in transportation systems by providing convenient last-mile solutions, which could facilitate multimodality (*10*). Microtransit is also a hybrid of AVs and transit system. Microtransit is similar to current services such as taxis and ridesharing (e.g., Uber, and Lyft) (*6; 9; 11*) with the aim of maximizing the utilization rate of autonomous vehicles.

Although there is skepticism about the positive impacts of AVs on transportation systems (*6*), one needs to consider that AVs may provide independent mobility to non-drivers, reduce the stress of driving, and could eventually be a solution for congestion, traffic operations, safety, and pollution problems (*8; 9; 12-16*). Due to the unique characteristics of AVs, many studies predict fundamental changes in travel behavior of road users. These changes in travel behavior may significantly influence individual trip rates and lengths as well as mode choice.

One of these transportation modes is public transit, which is typically reliant on subsidies and regulations particularly in areas with low density. Compared to personal vehicles, public transit has several benefits for society (*17; 18*). Public transit can improve mobility and transportation system resilience; and it can reduce congestion, emissions, and fuel consumption. It also provides affordable transportation alternatives for low-income neighborhoods (*17; 18*). Most public transit service is characterized by four features – it consists of regularly scheduled vehicle trips, is open to all paying passengers, with the capacity to carry multiple passengers whose trips may have different origins, destinations, and purposes (*19*). Broader definitions of public transportation services also include other related forms of shared transportation services. For example, paratransit is a form of transit with flexible routes and scheduled particularly for those who are unable to use the regular, fixed route transit service that serves their region (*20*). Ridesharing (e.g., hire and drive) and taxis (e.g., hail or phone-taxi) are other forms of paratransit (*21*). These services are available for-hire and usually require reservations in advance.

AVs have the potential to change traveler behavior, and it is expected that these changes will affect the performances of public transit and paratransit. Also, one may expect that changes in travel behavior and heavy investment in intelligent transport infrastructure necessary for AVs will substantially affect service efficiency, service effectiveness, and financial information, and therefore, affect transit ridership. However, the extent and magnitude of AV effects are not known (*8; 22*).

Many of these attributes, such as financial indices and fleet size, are subject to exogenous factors such as the availability of local and state funds, which reflect local/state policies. Others such as service effectiveness and service efficiency are a function of transit demand or policy (i.e., number of an unlinked passenger trip). A handful of studies have evaluated the potential impact of AV technologies on various aspects of transit service, including changes in technology used in public transit, effects on transit stakeholders, land use, infrastructure, and reductions in delay (*22-26*); however, to the best of our knowledge, no prior studies have investigated the changes in transit ridership due to the emergence of AV technology in automobiles. Reductions in transit ridership could adversely affect operations of transit agencies, particularly in terms of revenue. Understanding the potential effects of AVs on travelers' behavior may help public transit agencies to develop solutions to prevent or minimize potential adverse effects, such as drops in transit ridership.

This study aims to qualitatively evaluate potential changes in public transit ridership due to the emergence of fully AVs (Level 5) on roads. Although there are many metrics to evaluate the future of public transit, this study focuses on changes in the transit ridership. In order to evaluate the effects, it is essential to develop a framework that is sensitive to changes in the transportation system to forecast travel demand.

ASSUMPTIONS

In order to evaluate the possible effect of AVs, there is a need to make many strong assumptions regarding changes in the factors influencing both transportation supply and demand. In this study for the sake of developing a framework, we assume that AVs are fully autonomous (Level 5) and are able to communicate with other AVs and intelligent road infrastructure. Moreover, AVs have large enough market penetration to have impacted the majority of travel decisions in an urban area. Likewise, there are no significant changes in sociodemographic variables. In addition, there are no major changes in transportation infrastructure except those that are necessary for the performance of the connected autonomous vehicles.

FOUR-STEP MODEL FRAMEWORK

Although several methods and frameworks have been designed to forecast transportation demand, we use a traditional four-step travel demand model. The four-step model consists of trip generation, trip distribution, mode split, and traffic assignment (or route choice, at the individual vehicle level) (*27; 28*). The trip generation model describes the frequency of origins or destinations of trips in each zone based on trip purposes as a function of sociodemographic variables, land use, and household demographics. The trip distribution model matches trip makers' origins and destinations based on the relative attractiveness in each pair of origins and destinations. Mode choice provides information about the transportation mode that trip makers use to travel between their desired origin and destination. This model is often based on the concept of utility (i.e., a traveler chooses the alternative that maximizes his/her utility function (*28*)). The utility is calculated based on the travelers' sociodemographic characteristics and attributes of available alternative modes for the traveler. The fourth step is traffic assignment; it is different from the previous three steps because it relies highly on the quality and availability of transportation infrastructure and is sensitive to changing performance based on congestion. In this step, travel demand loads are assigned to links in the transportation network based on the principles of the equilibrium (*29;*

30). FIGURE 1 shows the traditional four-step model.

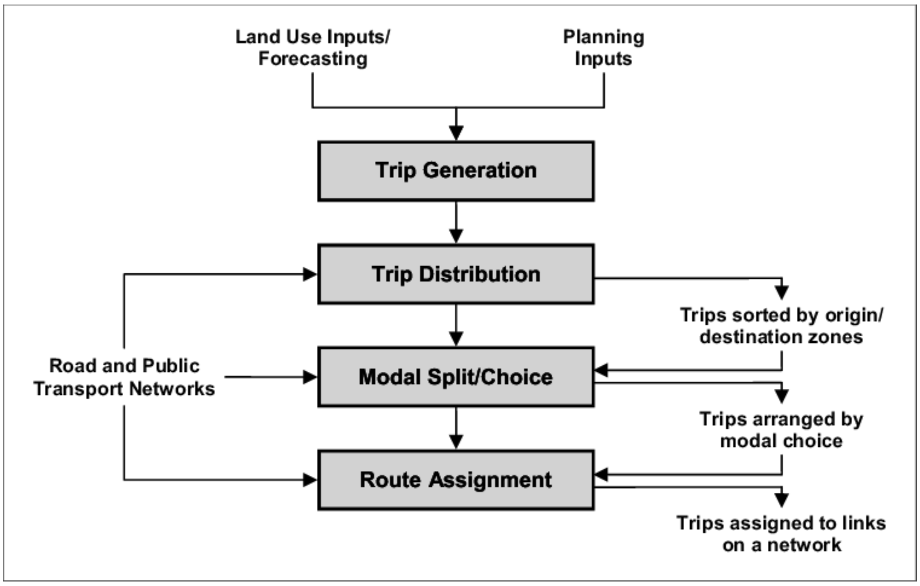

FIGURE 1 Traditional four-step model, adapted from Evans, Burke and Dodson (*31)*

The primary factors that affect transit demand will be investigated for each step of the traditional 4-step travel demand model. This section examines how AV characteristics could impact each of these steps and their resulting effects on transit demand.

Trip Generation

Once full automation is possible, Level 5 AVs will be able to provide mobility to those formerly unable to drive. The disabled, elderly, unlicensed, and perhaps even children will realize newfound independence, thus likely increasing trip-making rates (*8*). While some of these trips would likely have occurred by other modes (e.g., public transit, cycling), AVs should help eliminate a mobility barrier for these individuals. Hence one may expect higher trip rates for these groups of individuals.

Furthermore, convenience and comfort are two of the main factors that affect trip generation (*28*), and it is likely that the perceived burden of in-vehicle travel time will fall as former drivers are freed to pursue other tasks, while reducing driver stress and increasing comfort (e.g., (*9; 32; 33*)). These factors should increase both the convenience and relative utility of AVs in comparison to the other modes of transportation. It also improves user experiences and individuals' willingness to travel more and could eventually yield higher trip-making rates.

Additionally, the ability to communicate between AVs and infrastructure could yield more efficient traffic flows and transportation system operations, leading to an effective system capacity increase (*15; 34; 35*). Bearing in mind that travel time is one of the main factors in travelers' perception of cost (*36*) and equilibrium between supply and demand curve in transportation, we may see a shift in the supply curve that leads to an increase in travel demand. An elasticity-rebound effect would likely be seen in response, with other vehicles filling up the newly added capacity. Simply put, as the cost of travel falls due to faster travel times, more people will travel (*37*). Although the additional capacity may be realized without adding new lanes, it still increases and therefore has the potential to increase travel demand.

Using similar principles, AVs could change monetary travel costs, thus impacting trip generation. AVs might drive more efficiently than conventional vehicles, AVs could relocate while unoccupied to cheaper or free parking (*11*) and shared AV (SAV) travel could be cheaper than taxis (*9; 11*) or eventually even household-owned vehicles (*38*). Yet fuel costs may increase, and the cost of the vehicle could be higher from added electronics and possibly larger sizes. SAV users may also take fewer trips since the fixed cost of the vehicle would be embedded in the marginal price of the trip (*11*). That is, the cost of a year's worth of trips via SAVs might be cheaper than by a personally owned vehicle, but once the vehicle has been purchased, marginal trips could be cheaper than if taken by SAV (*17*). Reductions in travel cost also have the potential to increase trip rates.

In summary, while there is a good deal of uncertainty surrounding many of these trip generation outcomes, the majority of these factors point towards AVs leading to an anticipated increase in trip-making rates. Therefore, one can anticipate that these trips are likely to be taken by AVs rather than other modes of transportation.

Trip Distribution and Land Use

Many of the CV- and AV-related factors impacting trip generation could similarly affect the trip distribution. As was mentioned in the previous section, due to the increased convenience of AVs in comparison to current modes of transportation, one may expect a reduction in sensitivity to in-vehicle travel time. As a result, travelers would be willing to spend more times in vehicle; therefore, they would be willing to travel more often as well as farther distances. Improvement in system efficiency also provides additional capacity that could enhance the aforementioned effect. If AVs' passengers are willing to travel long distances and spend more time in vehicles, one may expect an expansion of cities (i.e., urban sprawl) where housing costs are cheaper. Urban sprawl has negative impacts on transportation systems – increased VMT, total network travel times, and increased fuel consumption and emissions are among these negative externalities. This problem could be more concerning in regions with weak land use regulations.

One study found that density (and trip intensity) was key to SAV success and particularly crucial for ridesharing applications that increase average vehicle occupancy and therefore cut travel costs (*39*). Therefore, one may conclude that SAVs could encourage higher urban density, while non-shared AVs would encourage sprawl (*40*). Indeed, this may lead to simultaneous densification of cities and exurban expansion (*41*).

In summary, urban sprawl is a function of SAV and AV market penetration and highly relies on land use regulations and urban economics. Regardless of land use regulations, AV features could increase the willingness of individuals to travel farther to destinations. In the case of urban sprawl and considering geographical coverage of public transit, it is likely that public transit route lengths may increase to cover longer distances. Bearing in mind increases in route lengths and increases in the number of stations, one may expect longer in-vehicle travel times. As a result, the relative utility of public transit may decrease compared to AVs, SAVs, and microtransit. This change could adversely affect transit ridership.

Mode Split

Since AVs provide unique characteristics for their users, one may expect the highest impact on mode shift and changes in the distribution of travel mode choices. AVs will introduce a new travel mode option for many. The emergence of AVs could broadly change road users' choice for travel (*22*).

Transit users can be categorized into two distinct classes – captive and choice riders (*42; 43*). The first group, captive users, have few other competitive alternatives rather than public transit. This could be due to lack of driving ability, individuals' financial situations, or travel distances that make alternatives unrealistic. In the case of captive users who lack driving abilities, it is possible that many of them shift from public transit, cycling, or walking toward AVs (*8; 9; 44*) to gain more independence, increase their privacy, security level, or reduce their travel time.

In contrast, the choice rider may use public transit to engage in activities other than driving. This group of travelers may be more sensitive to changes in the system, and its characteristics such as comfort, convenience, safety, and reliability may be more important to them compared to captive riders (*43*). Public transit offers these benefits to transit riders. However, fully AVs may also offer these advantages to occupants. As a result, the relative utility of public transit could decline in comparison to AVs. Moreover, due to the lower occupancy rate in AVs, the level of privacy, comfort, and security may be higher than public transit, which is an advantage for AVs. Therefore, one may expect a shift from public transit's choice riders toward AVs.

Microtransit may also be affected by AVs. Microtransit services could also be used as low-speed demand-responsive connector/feeders to line-haul mass transit systems, potentially resulting in increased transit usage (*45*). On the other hand, they can perform as a main mode of transportation for road users to commute between their origin and destination.

Travel cost is also an important factor in travelers' mode choice. One of the main premises of AVs is lower cost of transportation due to effective use of transportation assets and infrastructure (*22*). As a result, the cost of travel in the transportation system is expected to decline (*6; 8*). There are several estimates of travel costs in the future, and they are all in agreement that self-driving vehicles will be cheaper than owning a personal vehicle (*22*). Litman (*9)* compared the operations cost of autonomous and human-driven vehicles and concluded that public transit should be slightly cheaper than AVs and slightly higher than AV rideshare. Although one needs to bear in mind low AV rideshare rate results from high vehicle occupancy (three to six passengers) (*46*), which may not always be the case particularly in lower density areas.

Considering the similar cost of AVs, SAV, and public transit, one may conclude that choice rider travelers are likely to switch from public transit toward AV personal modes in order to gain more utility by reducing their travel time (both in-vehicle and out of vehicle travel time) and more comfort and increase their privacy level. This mode shift from public transport toward AVs could be large, particularly in cases that public transit travel times are not competitive with personal vehicles (*22*). In addition, shared AVs have the potential to reduce vehicle ownership (*47; 48*); this reduction may encourage individuals who do not have a car to use public transit as an alternative to SAVs.

In summary, the majority of the AV mode-choice impacts on the transportation system indicates that the relative utility of AVs will increase in comparison to public transit. This could adversely affect public transit ridership by mode shift, particularly from choice riders.

Traffic Assignment

Several studies showed that connected AVs are able to communicate with other vehicles on the roads and transportation infrastructures to boost their mobility by avoiding delays on roads, especially at intersections (*15; 34; 49-52*). Moreover, due to special characteristics of AVs (such as platooning), operational road capacity of the existing road could increase since AVs are able to travel closer together (*53; 54*). This could lead to shorter travel times for AVs if the added operational capacity exceeded the increases in AV-induced demand. Public transit could also benefit from extra capacity, which could lead to shorter in-vehicle travel times and better reliability.

Likewise, re-entry and intersection delay are two of the main sources of delay in public transit (*55*). Connected vehicles could enable public transit to minimize or effectively eliminate (in some cases) these delays by using transit signal priority (TSP) (*56*).

As it was stated earlier, the additional capacity of the road could have a secondary effect that increases travel demand. This additional demand on roads has the potential to adversely cancel out the mobility advantages of AVs and impose additional congestion to the transportation system, which could negatively impact network travel time. Additional delay could adversely impact transit reliability and schedule adherence.

AVs could improve mobility if travel demand does not change drastically; in this situation, public transit could benefit from a reduction in travel time and improving the relative utility of public transit.

SUMMARY

Autonomous vehicles have the potential to transform personal vehicles and significantly alter the entire transportation system. Table 1 and Table 2 show a summary of key elements pertaining to the effects of AVs on transit ridership for each stage of four step model. Taking all of the outcomes together, it seems likely that the negative impacts on public transit ridership may outweigh the positive ones, suggesting a possible decrease in overall public transit ridership.

1 **Table 1 Factors Influencing Transit Ridership (Trip Generation and Trip Distribution)**

Four step model Stage	Changes	Description	Effect on the transit system	Effect on transit ridership
Trip generation	Increase in-vehicle convenience and comfort	Reduce the perceived burden of travel time	Increase trip rates, excessive travel demand could cause more congestion, which increases transit delay	Negative effect
	Remove mobility barrier and provide accessibility for all users (e.g., disabled)	Enable road users to drive by themselves	Captive riders may shift toward new modes such as SAV or microtransit	Negative effect
	Higher speed and improved mobility	Reduce delay and increase road capacity by using real-time data	Increase travel demand; excessive travel demand could cause more congestion. a secondary effect is that travel time decreases for public transit	Both positive and negative
	Travel cost	Reduction in travel costs by reducing in-vehicle travel time; increase productivity in a vehicle.	Increase travel demand; people traveler use AV as a mode to commute. A secondary effect is that travel time decreases for public transit	Both positive and negative
Trip distribution	Increase in-vehicle convenience and comfort	Reduce the perceived burden of travel time by engaging in other activities, reduce driving stress	Longer trips and Urban sprawl Longer transit routes which end up with more stops and longer routes for public transit	Negative effect
	Shared AVs	Increase utilization rate of AVs; affordable for those who cannot purchase AVs.	Increase population density, a dense network, density has a positive impact on ridership	Positive effect

Table 2 Factors Influencing Transit Ridership (Modal Split and Traffic Assignment)

Four step model Stage	Changes	Description	Effect on the transit system	Effect on transit ridership
Modal split	Increase in privacy and comfort	Better in-vehicle experience by reducing driving stress, engaging other activities, and increase travelers' privacy level compared to public transit	Increase AVs utility and decrease in relative utility of public transit	Negative effect
	Remove Mobility barrier and provide Accessibility for all users (e.g., handicapped)	Travel independence for those who are not able to drive without others help	Increase AVs utility and decrease in relative utility of public transit; new option for a portion of captive riders	Negative effect
	Delay Reduction	Reduce vehicle travel time and unnecessary delays by using real-time information	Decrease public transit in-vehicle time and increase the relative utility of	Positive effect
	Microtransit	A new form of Transit; a hybrid form of AV and Transit	Could be used as demand responsive connector feeder for mass transit. Also could be used as a competitive mode for public transit.	Both positive and negative
Traffic assignment	Increase capacity of existing roads	Shorter travel time: reduce in-vehicle travel time, better schedule adherence	Increase road capacity, which leads to shorter in-vehicle travel time and improvement in schedule adherence	Positive effect
	TSP – speed at intersections	Reduce delay at the intersection by prioritizing public transit movement	Decrease both in-vehicle and out of vehicle travel time, improvement in schedule adherence which increase the relative utility of public transit	Positive effect
	Re-entry delay this is speed (in the lane)	Get back to main traffic sooner	Decrease both in-vehicle and out of vehicle travel time, improvement in schedule adherence which increase the relative utility of public transit	Positive effect

CONCLUSIONS AND FUTURE RESEARCH

Previous studies have indicated that AVs could provide safe, comfortable, and convenient transportation to road users. Moreover, due to the connectivity and communication with other vehicles and intelligent transport infrastructure, it is expected that they will provide enhanced mobility in comparison to the human-driven vehicles. Improvements in mobility could decrease public transit delay, which could eventually improve transit operations and perhaps improve its competitiveness. Additionally, AVs introduced in paratransit modes to the transportation system could play both as a competitor and feeder to public transit.

Breaking down the four-step model indicates that public transit could benefit by reduced travel times on the network due to higher roadway capacity due to AVs and reductions in delay of re-entry and at intersections. Additionally, extra road capacity could help public transit to improve their adherence to schedules. These changes are likely to have a positive impact on public transit ridership by increasing the relative utility of public transit. However, one needs to consider that the additional capacity on roads could be occupied by excessive demand, which leads to excessive congestion and eventually increases both in-vehicle and out-of-vehicle travel time.

Due to the lack of drivers in the autonomous vehicles, formerly transit captive riders may be able to use AVs on their own. As a result, these groups may switch from other transportation modes (e.g., public transit, bicycle) to AVs. This could be also the case for choice riders if AVs deliver higher privacy levels, speed, and comfort at similar prices to public transit. As a result, choice riders may consider AVs or SAVs as an alternative for their commutes.

There are many areas for future research, such as the role of AV-related policy and legislation on public transit ridership. Notably, the future of public transit is not fully reliant on AV technology and travelers' behavior; yet it may be shaped by policy initiatives emerging from legislative and administrative actions of various levels of government (*22*). It is necessary to explore the current and future policies and legislation and how they may shape the future of public transit. Moreover, considering the history of public transit and how it has evolved to its current form, one may expect changes in public transit services once AVs become a widespread reality. In summary, transportation planners, policymakers, and transit agency leadership need to prepare for the coming of AVs and plan for their future effect on transit systems.

CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Amin Mohamadi Hezaveh, Candace Brakewood, Christopher Cherry; data collection: Not Applicable; analysis and interpretation of results: Amin Mohamadi Hezaveh, Candace Brakewood, Christopher Cherry; draft manuscript preparation: Amin Mohamadi Hezaveh, Candace Brakewood, Christopher Cherry. All authors reviewed the results and approved the final version of the manuscript. The authors also would like to express their gratitude to Dr. Daniel J. Fagnant for his contribution in the study design.

REFERENCES

1. NHTSA. *Automated Vehicles for Safety*. https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.
2. NCHRP. NCHRP 20-102(1): Policy and Planning Actions to Internalize Societal Impacts of CV and AV Systems into Market Decisions.In, 2016.
3. Kockelman, K., P. Avery, P. Bansal, S. D. Boyles, P. Bujanovic, T. Choudhary, L. Clements, G. Domnenko, D. Fagnant, and J. Helsel. Implications of connected and

automated vehicles on the safety and operations of roadway networks: A final report.In, 2016.

4. Levinson, D. Climbing mount next: the effects of autonomous vehicles on society. *Minn. JL Sci. & Tech.,* Vol. 16, 2015, p. 787.
5. Milakis, D., B. Van Arem, and B. Van Wee. Policy and society related implications of automated driving: a review of literature and directions for future research. *Journal of Intelligent Transportation Systems,* Vol. 21, No. 4, 2017, pp. 324-348.
6. Litman, T. *Autonomous vehicle implementation predictions*. Victoria Transport Policy Institute, 2017.
7. Talebpour, A., and H. S. Mahmassani. Influence of connected and autonomous vehicles on traffic flow stability and throughput. *Transportation Research Part C: Emerging Technologies,* Vol. 71, 2016, pp. 143-163.
8. Fagnant, D., and k. Kockelman. Preparing a Nation for Autonomous Vehicles Opportunities, Barriers and Policy Recommendations.In, Eno Center for Transportation, 2013.
9. Litman, T. Autonomous vehicle implementation predictions implications for transport planning.In, Victoria Transport Policy Institute, 2015.
10. Krueger, R., T. H. Rashidi, and J. M. Rose. Preferences for shared autonomous vehicles. *Transportation Research Part C: Emerging Technologies,* Vol. 69, 2016, pp. 343-355.
11. Fagnant, D., and K. Kockelman. D*ynamic ride-sharing and optimal fleet sizing for a system of shared autonomous vehicles*.In, *Transportation*, 2016.
12. Walker, J., and C. Johnson. Peak Car Ownership: The Market Opportunity of Electric Automated Mobility Services.In, Rocky Mountain Institute, 2016.
13. Keeney, T. *Mobility-As-A-Service: Why Self-Driving Cars Could Change Everything*. http://research.ark-invest.com/.
14. Arbib, J., and T. Seba. Rethinking Transportation 2020–2030: The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries.In *RethinkX Sector Disruption Reports*, RethinkX California, US, 2017.
15. AERIS. Eco-Approach and Departure at Signalized Intersections: PreliminaryModeling Results. Presented at Fall/Winter Webinar Series, 2013.
16. AERIS. Eco-Traffic Signal Timing Application: Preliminary Modeling Results. Presented at Fall/Winter Webinar Series, 2014.
17. Litman, T. *Evaluating public transit benefits and costs*. Victoria Transport Policy Institute British Columbia, Canada, 2015.
18. Walker, J. *Human transit: How clearer thinking about public transit can enrich our communities and our lives*. Island Press, 2012.
19. Walker, J. *Human transit*. Walker, Jarrett, 2011.
20. Koffman, D. *Improving ADA complementary paratransit demand estimation*. Transportation Research Board, 2007.
21. Kirby, R. F., K. U. Bhatt, M. A. Kemp, R. G. McGillivray, and M. Wohl. Para-transit: neglected options for urban mobility.In, Urban Inst., Washington, DC (USA); Urban Institute, 2100 M Street NW, Washington, DC 20037, 1974.
22. Polzin, S. E. Implications to public transportation of emerging technologies. *National Center for Transit Research*, 2016.
23. Nikitas, A., I. Kougias, E. Alyavina, and E. Njoya Tchouamou. How Can Autonomous and Connected Vehicles, Electromobility, BRT, Hyperloop, Shared Use Mobility and Mobility-As-A-Service Shape Transport Futures for the Context of Smart Cities? *Urban Science,* Vol. 1, No. 4, 2017, p. 36.
24. Lutin, J. M. Not If, but When: Autonomous Driving and the Future of Transit. *Journal*

of Public Transportation, Vol. 21, No. 1, 2018, p. 10.
25. Lazarus, J., S. Shaheen, S. E. Young, D. Fagnant, T. Voege, W. Baumgardner, J. Fishelson, and J. S. Lott. Shared Automated Mobility and Public Transport.In *Road Vehicle Automation 4*, Springer, 2018. pp. 141-161.
26. Polzin, S. E. Just Around the Corner: The Future of US Public Transportation. *Journal of Public Transportation,* Vol. 21, No. 1, 2018, p. 5.
27. McNally, M. G. The four step model. *Center for Activity Systems Analysis*, 2008.
28. Kanafani, A. Transportation demand analysis. 1983.
29. McNally, M. G. The four-step model.In *Handbook of Transport Modelling: 2nd Edition*, Emerald Group Publishing Limited, 2007. pp. 35-53.
30. SHEFFI, Y. *urban transportation networks*. 2017.
31. Evans, R., M. Burke, and J. Dodson. Clothing the Emperor?: Transport modelling and decision-making in Australian cities.In *Proceedings of State of Australian Cities National Conference 2007*, 2007.
32. MacKenzie, D., Z. Wadud, and P. Leiby. First Order Estimate of Energy Impacts of Automated Vehicles in the United States.In *Poster presentation at the 93rd annual meeting of the Transportation Research Board, Paper*, 2014. pp. 14-2193.
33. Gucwa, M. Mobility and Energy Impacts of Automated Cars.In *Presentation at Automated Vehicles Symposium*, 2014.
34. AERIS. Combined Modeling of Eco-Signal Operations Applications. Presented at Summer Webinar Series, 2014.
35. Chang, J., G. Hatcher, D. Hicks, J. Schneeberger, B. Staples, S. Sundarajan, M. Vasudevan, P. Wang, and K. Wunderlich. Estimated Benefits of Connected Vehicle Applications: Dynamic Mobility Applications, AERIS, V2I Safety, and Road Weather Management Applications.In, 2015.
36. Connors, R. D., and A. Sumalee. A network equilibrium model with travellers' perception of stochastic travel times. *Transportation Research Part B: Methodological,* Vol. 43, No. 6, 2009, pp. 614-624.
37. Cervero, R. Induced Demand: An Urban Metropolitan Perspective. 2001.
38. Burns, L. D., W. C. Jordan, and B. A. Scarborough. Transforming personal mobility. *Earth Island Institute, Columbia University*, 2013.
39. Fagnant, D. J., K. M. Kockelman, and P. Bansal. Operations of a Shared Autonomous Vehicle Fleet for the Austin, Texas Market. *Transportation Research,* Vol. 28, 2015.
40. Yigitcanlar, T., G. Currie, and M. Kamruzzaman. Driverless vehicles could bring out the best–or worst–in our cities by transforming land use. *The Conversation*, 2017.
41. Economist. *If autonomous vehicles rule the world from horseless to driverless.* Economist. http://worldif.economist.com/article/11/what-if-autonomous-vehicles-rule-the-world-from-horseless-to-driverless. Accessed 13 January 2016.
42. Cervero, R. Transit pricing research. *Transportation,* Vol. 17, No. 2, 1990, pp. 117-139.
43. Zhao, J., V. Webb, and P. Shah. Customer loyalty differences between captive and choice transit riders. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2415, 2014, pp. 80-88.
44. Silberg, G., R. Wallace, G. Matuszak, J. Plessers, C. Brower, and D. Subramanian. Self-driving cars: The next revolution. *White paper, KPMG LLP & Center of Automotive Research*, 2012.
45. USDOT. Accessible Transportation Technologies Research Initiative. Presented at U.S. Department of Transportation, 2015.
46. Bösch, P. M., F. Becker, H. Becker, and K. W. Axhausen. Cost-based analysis of autonomous mobility services. *Transport Policy,* Vol. 64, 2018, pp. 76-91.

47. Martin, E., and S. Shaheen. Impacts of Car2Go on vehicle ownership, modal shift, vehicle miles traveled, and greenhouse gas emissions: an analysis of five North American Cities. *Transportation Sustainability Research Center, UC Berkeley*, 2016.
48. Shaheen, S. A., E. W. Martin, A. P. Cohen, N. D. Chan, and M. Pogodzinski. Public Bikesharing in North America During a Period of Rapid Expansion: Understanding Business Models, Industry Trends & User Impacts, MTI Report 12-29. 2014.
49. Miller, K., L. G. Drumwright, A. Kostreba, A. Lam, M. Mercer, T. Ryan, J. Schneeberger, and D. Wesolek. Applications for the Environment: Real-time Information Synthesis (AERIS): Applications state of the practice assessment report.In, 2011.
50. Pindilli, E. Applications for the Environment: RealTime Information Synthesis (AERIS) Benefit-Cost Analysis. *Prepared by United States Department of Transportation, Federal Highway Administration Office*, 2012.
51. AERIS. Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results. Presented at Fall/Winter Webinar Series, 2014.
52. USDOT. AERIS Operational scenarios and applications.In, 2014.
53. Fernandes, P., and U. Nunes. Platooning of autonomous vehicles with intervehicle communications in SUMO traffic simulator.In *Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on*, IEEE, 2010. pp. 1313-1318.
54. Tientrakool, P., Y.-C. Ho, and N. F. Maxemchuk. Highway capacity benefits from using vehicle-to-vehicle communication and sensors for collision avoidance.In *Vehicular Technology Conference (VTC Fall), 2011 IEEE*, IEEE, 2011. pp. 1-5.
55. Group, K. Transit capacity and quality of service manual. 2013.
56. Yang, K., S. I. Guler, and M. Menendez. A transit signal priority algorithm under connected vehicle environment.In *Intelligent Transportation Systems (ITSC), 2015 IEEE 18th International Conference on*, IEEE, 2015. pp. 66-70.