Policy Memo

Autonomous vehicles and land use

June 11

To: Scott Haggerty, chair of governing Commission of Bay Area Metropolitan Transportation Commission

From: Shen Qu, Policy Advisor

Date: 6/11/2019

RE: How Bay Area should be planning for autonomous vehicles?

Summary

This memo is one of the series of policy analysis about autonomous vehicles for Bay Area. It trys to answer how the autonomous vehicles will affect urban land use, and What the MPO and cities should be planning to seize this opportunity and address the challenges.

Background: the current and projected status of AVs.

Technology: The history of exploring autonomous vehicles can date back to late 1950s (Milakis 2019). Since DARPA ran the Grand Challenge in 2004, the autonomous vehicle technologies entered a "critical juncture." (Docherty, Marsden, and Anable 2018) In the fields of automation control systems, some critical hardwares like processors and sensors are having the ability of undertaking more complex tasks. The improving softwares and algorithm are becoming more fledged. According the third version of definition and taxonomy by SAE (2018), the existing technologies are achiving from the Level 3 - Conditional Driving Automation to Level 4 - High Driving Automation.[1]

Industry: Since 2009, Google had conducted a series of tests for AVs over 10 million miles on real-world roads in California, Texas, and other states. Waymo, a company founded by Google, hold the only testing permit for driverless testing by California DMV and committed to providing a ride-hailing services in Arizona in 2018. In 2019, Waymo announced their Level 4 AV will be assembled in Detroit. Almost all big automakers such as Ford, General

[1] SAE defines the concept of AV as ADS-DV (ADS-Dedicated Vehicle), "A vehicle designed to be operated exclusively by a level 4 or level 5 ADS for all trips within its given Operational Design Domain (ODD) limitations." ADS means "The hardware and software that are collectively capable of performing the entire Dynamic Driving Task (DDT) on a sustained basis, regardless of whether it is limited to a specific ODD; this term is used specifically to describe a level 3, 4, or 5 driving automation system."

Motors, Volkswagen, etc., are investing heavily in this field.(Crute et al. 2018) The leading transportation network companys (TNC) like Uber and Lyft are making up a term of Mobility-as-a-service (Maas) to change current travel modes by AVs.

Academia: Many scholars start working on the reaserch of AVs with lots of energy. Gandia et al. (2019)'s reserch found 10580 published papers in this field from 1945 to 2018. Since 2012, the number of articles have an exponential growth with 39% growth rate while 8-9% average growth rate in science. Although a large amount of the research are from the perspective of systems control, computer science, robotics, engineering, there are more and more articls that start to focus on the AVs' impact on transportation and Land use (Milakis 2019).

Governavce: In 2011, the Nevada Department of Motor Vehicles issued a first license to google's experimental AVs. Currently, "33 states have passed legislation related to AV." "15 states enacted 18 AV related bills." (NCSL 2019) From 2016 to 2018 the U.S. Department of Transportation (U.S.DOT) and the National Highway and Transportation Safety Administration (NHTSA) published three federal guidences for Automated Driving Systems (ADS is the definition by SAE). The guidances advocate industry, state and local government to support the AVs' development. (NHTSA 2019) California is playing a leading role in this field. Until January 2019, California DMV has issued AV Testing Permits (with a driver) to 62 companies on public roadways.

Unveiling the future: Muller (2017) introduces the four stages in the spatial evolution of the American metropolitan. Form Walking-Horsecar Ear to Electric Streetcar Era, Recreational Auto Era, and Freeway Era. The four-stage model shows that each "break through in movement technology" had reshaped the previous dominated urban form and launched a new era with a "distinctive spatial structure." There are some indications that a new era might be dawning. We try to answer how AVs could influence demand for transportation and land use. This memo will focus on the crutial response for land use. The topic of safety, liability, and other issues will discussed in other memos.

The Framworks of changes

While industry, scholars and governments realized the high impact of AV, some research frameworks also imply it is a highly uncertainly evolution rising up some complex issues such as coupling, resonance, or agitation. Milakis, Van Arem, and Van Wee (2017) arrange many substantial implications of AVs by a structure of *ripple effect*, whcih reflected a sequantially spreading process. Land use is placed in the second-order that is affected by the factors in the first-order including travel cost, travel time, vehicle use, capacity, trvael modes, and etc. The flaw of this structure is that the ripple effects model emphasizes the diffusion characteristic of the AV technology and cannot describe the feedback effects. The changes of urban form and land use will influence the travel behavior and traffic in the first-order too.

The *Diamond of Assembly* (Levinson and Krizek 2018 Chapter.12) and the *feedback cylce* (Wegener and Fürst 2004; adaped by Soteropoulos, Berger, and Ciari 2019) are two helpful complements. These figures can present the relationship between transportation and land use in a more clear manner. AV technology as a exogenous variable will influence travel behaviors in the first ripple, and then is reflected in the change of accessiblity. The dynamic of accesessibility will interact with land use and forms a new cycle.

The history of 'the four stages' (Muller 2017) tells us, if AVs being a breakthrough force, many previous models, methods, and arguments may be different or even fail. Under the two kinds of the framework above, we will review the classical theories about transportation and land use, following the sequence of the first order, second order, and feedback cycle.

The first order

The utility maximization problem: As the core of consumer theory, the supply and demand model explaines the relationship between the price (travel cost) and the quantity (VMT). When price changed or the curve shifted, the market-clearing equilibrium point will reach a new one. In estimating the impact of AVs on travel consumption, most of current research agree that AVs will provide more options for travelers with less travel time and larger capacity. According the results of 37 modelling studies from 2013 to 2018, The application of AVs means the lower price and higher service qualities, which will induce more and longer trips, produce more total VMT (Soteropoulos, Berger, and Ciari 2019). At the same time, these research noice that more available services by AVs may encourage low-occupied vehile, reduce transit use, and invrease VMT. (Taiebat et al. 2018) The tradeoff between higher effecient and higher demand makes the trends of congestion and emission being uncertaint. Overall, these are equalising and incremental changes in quantities.

However, as a breakthrough technology, the impacts of AVs may not follow some divergent curves and show the polarising characteristics. For example, the *prospect theory* of value and gains shows a logistic curve. (Levinson and Krizek 2018, 6) When coming to the relationship of bus ridership to wait time, the curve shows the initial point is not stable. (Levinson and Krizek 2018, 83) A slightly change will let it slipe to two stabel equilibria. But the equilibrious points represent two direction, a vicious circle (low ridership and high wait time) or a virtuous circle (high ridership and low wait time).

To explain this phenomenon, we need understand the components of travel cost and current options on travel modes. The opportunity cost and transaction cost are the significant part of travel cost. Being late for work, a meeting, or a flight means much higher opportunity loss, whcih can explain why people hat uncertaint and wait time. Similarly, hailing a taxi for each trip or planning carpool everyday means the transaction cost are unacceptable expensive. Meanwhile, the available travel modes options are limited. Once people choosing transit, their trips often lost the reliability and flexibility. They also have few options on the transit quality, such as speed, headway, and routes. Thus, people choose to own a private car to control the high opportunity cost and transaction cost. Now we know why the initial point is not stable.

The practices of mobility-as-a-services (Maas) proved by TNC introduced a potential solution. For the connected AV's 'perfect information' and automation, Mass could largely reduce the opportunity cost and transaction cost, then could reduce car ownership. Moreover, It provdes a series of options by monetized the values of reliability and flexibility. A hurried passenger may will pay $100 for arriving the airport as soon as possible. A worker may will get up one hour earlier for a $10 off-peak pass per month.

This is a business mode transition in many ways. These round-the-clock services could achieve on-demand ridesharing by realtime matching. Many research show that the ridersharing level is a critical variable for AVs application. The preseting value of ridershare could drastically change the simulating results of the models. What's more, travel time could become a positive factor in transportation models. The value of time as a large part of travel cost may decrease and even could turn to a productive gain (Singleton 2019). Although scholars are discussing how significance the time cost will change, that would like a suddenly switching lanes rather than a gradual process. We should realize the impacts of AVs may keep accelerating until all the energy released and should reset the prvious equations with new parameters and even new distributions.

The second order

As shown in Milakis, Van Arem, and Van Wee (2017)'s ripple effect, the first-order changes triggered by AVs are not about land use. But these forces will push the land use changes forward. An essential reason is that the travel cost is positively correlated with distance. From the technical perspective, *the gravity model* for measuring accessibility considers the mass of place and distance (travel time) as the determinative factors. From the economic perspective, all the activities want to minimize the cost and compete for the land close to city center. *The bid-rent theroy* oriented form Thünen (1826)'s model, which derived from the utility maximization through introducing the spatial variables. From the 'concentric zone model' by Burgess (2008), to Christaller (1933)'s central place theory, and to Alonso and others (1964)'s land market model, this economic theory is the basis of many land use models.

The relevant research conclude that wider urban sprawl might be an output of AVs application (Soteropoulos, Berger, and Ciari 2019). In the same way, the research about parking say that the CBD could be more dense for less demand of parking lot (Fagnant and Kockelman 2015). However, these inferences build on the theories of spatial economic equilibrium. The underline assumptions are the functions remain the same and the incremental changes happen on values and parameters. There are less research from the theories of spatial polarisation (Pred 1966).

Hagerstrand (1970)'s *action-space theory* proposes "action spaces are limited by three types of constraints: capacity constraints, coupling constraints, and institutional constraints." While the growth of capacity is still incremental, the matching cost might be negligitable in AVs era. The *theory of time and travel budgets* by Zahavi, Beckmann, and Golob (1981) and Downes and Emmerson (1985) agree that "longer trips make more dispersed locations." But existing literature don't talk a lot about what is "a higher degree of spatial division of labour possible" in AVs era (Hawkins and Nurul Habib 2019).

The theory of *network society* by Castells (2011) and other theory of the information society imply another possible perspect of land use pattern in the AVs era. If the travel demands and supplies can match in realtime and generate as many as possible options for customers, the 'space of places' also could become the 'space of flows.' The traditional forms, including cores, clusters, and corridors will be disintegrated. In the long run, The network may control the travel and assign people to a place. People only choose their activities and surrounding environment but don't care about the actual locations.

The feedback cylce

In this section, we try to explore what changes may happen on land use feedback cycle brought by the AVs technology. From the temporal dimension, the theory of long waves by (Kondratieff 1926) and (Schumpeter 1939) discribed the cycle of a "earlier technologies went from invention through take-off and rapid growth to saturation and was eventually superseded by a more advanced technology." From the spatial dimension, the changes triggered by AVs may like a "cyclical sequence of agglomeration and deglomeration phases" (Van den Berg et al. 1982).

Although many funding tools try to combine the transportation investiment and land value return together to incentive virtuous circle, there always some drawbacks (Vadali et al. 2018). From the perspective of equalty, charging an unmeasurable service is unfair. From the perspective of market, an unmeasurable trade is inevitablelly inefficient. The feedback cylce shows a decay process for free rider problem, or for delay of demand response. Pricing by demand-supply mechanism becomes infeasible.

Tiebout model contributes a non-political solution to optimal public goods provision (Tiebout 1956). The "foot voting" by the mobile residents motivates the competition between communities. The primary assumptions Tiebout model relied on are that conusmers can freely choose where they live. It assumes that there are engough communinties available and commuting cost is negligible. there are not externalities or spillover of public goods across towns. Many scholars critique Tiebout model for its unpractical assumptions. For the same reasons, Tiebout model is more success in suburban areas. The roads in suburban communities like a club goods. There is no free rider problem. All the cost and externalities internalized in property tax.

Entering the AV era, Tiebout model might apply to whole urban area. Maas suppored by connected AV allows us to measure the road use for each trip. Moreover, Maas provide the oppotuinity of internalizing all the positive/negative externalities and redefine the boundary of public good. The theory of local governments competetion and beneficiary pays principle can be fully applied on the new feedback cycle. Under this scenario, transportation become a excludable and rivalrous goods. The cities or communities compete by investing and improving infrastucture; Transportation suppliers bid for road license and provide as many as possible options for consumers; Consumers choose the travel services based on their ability and willingness to pay money or change their itineraries. The social segregation in Schelling's model (Schelling 1971) may be more significant and invisible. Bid for mobility may cause problems about equality. But, as Levinson and Krizek (2018) say, “prices create choices, and choices are fair.” (p.248)

The policy options

As Crute et al. (2018) suggested, In response to the changes by AVs technology, the policy makers should “bolster transportation demand management, reconsider the right-of-way, and continue to develop transit.” These types of method are aimed at the first-order changes. “Rethinking the parking standard and requirements” could help better redevelop the urban parking lots saved by AVs. Urabn Groth Boundary is also a ready-made tool for mitigating sprawl. In the face of those gradual changes, existing theories and policy tools are sufficient to cope with them (Zmud et al. 2018).

The true challenges are how to response the selfreinforcement changes, the new distributions, and the networks never seen before? And how to let AVs leverage the virtuous circle rather than vicious? (Legacy et al. 2019) The solution of Maas provides a valuable space for policy-makers to guide the transportation system in the direction we want. Responding to the promotion of Maas by industry, government should advocate “a simpler, smarter and fairer system of road user charging”(Barrett, Wedderburn, and Belcher 2019). The London government is launching a new scheme of “charging drivers on a per-mile basis based on distanced travelled, vehicle emissions, local levels of congestion and pollution, and availability of public transport alternatives.” Hand (2016)‘s suggests to start some pilot projectsin Los Angele. SDOT (2017)’s policy want to “establish a city-owned transportation network company digital platform to incubate smaller shared AV fleet businesses” in Seattle. Other metropolitan areas are on the move. This memo cannot cover all the AVs’ issues and try to urges MTC to realize that the AVs’ effects are far from the transportation itslef such as road capacities, parking lots, and curve space. The substantial supports should be provided to the relevant research on land use, housing, and urban design, for the future of Bay Area.

Notes

The concept of *Public good* helps to understand the cyclical process. Transprotation infrastructure is the semi-public good. Except toll road, this system is non-excludable. But the congested sections in the peak hour are rivalrous. Fuel taxs partly reflect the amount of use of road, but can not adjust the spatial distribution. Even the congestion charging like London, is still a binary intervention (Yes or no). Some research conclude that the success of pricing policy depend on political support. [] But the research don’t realize that the current charging plan cannot effectively and accurately reflect the use of transprotation infrastructure.

such scheme would reflect the true impact of individual vehicle journeys. be integrated with London’s wider transport system and be accessible via an app and digital platform. This would allow Londoners to compare, plan and pay for all journeys in one place. Ultimately it would encourage drivers to leave their cars at home when possible, by providing them with alternative travel options.

References

Alonso, William, and others. 1964. "Location and Land Use. Toward a General Theory of Land Rent." *Location and Land Use. Toward a General Theory of Land Rent.* Cambridge, Mass.: Harvard Univ. Pr.

Barrett, S, M Wedderburn, and E Belcher. 2019. "Green Light: Next Generation Road User Charging for a Healthier, More Liveable, London." www.centreforlondon.org/publication/road-user-charging/.

Burgess, Ernest W. 2008. "The Growth of the City: An Introduction to a Research Project." In *Urban Ecology*, 71–78. Springer.

Castells, Manuel. 2011. *The Rise of the Network Society.* Vol. 12. John wiley & sons.

Christaller, Walter. 1933. *Die Zentralen Orte in Süddeutschland: Eine ökonomisch-Geographische Untersuchung über Die Gesetzmässigkeit Der Verbreitung Und Entwicklung Der Siedlungen Mit Städtischen Funktionen.* University Microfilms.

Crute, Jeremy, William Riggs, Timothy Stewart Chapin, and Lindsay Stevens. 2018. "Planning for Autonomous Mobility." PAS Report 592. American Planning Association.

Docherty, Iain, Greg Marsden, and Jillian Anable. 2018. "The Governance of Smart Mobility." *Transportation Research Part A: Policy and Practice* 115. Elsevier: 114–25. https://doi.org/10.1016/j.tra.2017.09.012.

Downes, JD, and P Emmerson. 1985. "Urban Travel Modelling with Flexible Travel Budgets." *Crowthorne: Transport and Road Research Laboratory.*

Fagnant, Daniel J, and Kara Kockelman. 2015. "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations." *Transportation Research Part A: Policy and Practice* 77. Elsevier: 167–81.

Gandia, Rodrigo Marçal, Fabio Antonialli, Bruna Habib Cavazza, Arthur Miranda Neto, Danilo Alves de Lima, Joel Yutaka Sugano, Isabelle Nicolai, and Andre Luiz Zambalde. 2019. "Autonomous Vehicles: Scientometric and Bibliometric Review." *Transport Reviews* 39 (1). Taylor & Francis: 9–28. https://doi.org/10.1080/01441647.2018.1518937.

Hagerstrand, T. 1970. "What About People in Spatial Science." *Regional Science Association* 24: 7–21.

Hand, Ashley Z. 2016. "Urban Mobility in a Digital Age - a Transportation Technology Strategy for Los Angeles." www.urbanmobilityla.com/.

Hawkins, Jason, and Khandker Nurul Habib. 2019. "Integrated Models of Land Use and Transportation for the Autonomous Vehicle Revolution." *Transport Reviews* 39 (1). Taylor &

Francis: 66–83. https://doi.org/10.1080/01441647.2018.1449033.

Kondratieff, ND. 1926. “Die Langen Wellen Der Konjunktur. Archiv Fuer Sozialwissenschaft Und Sozialpolitik.” *Tuebingen* 56 (3): 537.

Legacy, Crystal, David Ashmore, Jan Scheurer, John Stone, and Carey Curtis. 2019. “Planning the Driverless City.” *Transport Reviews* 39 (1). Taylor & Francis: 84–102. https://doi.org/10.1080/01441647.2018.1466835.

Levinson, David M, and Kevin J Krizek. 2018. *Metropolitan Land Use and Transport: Planning for Place and Plexus*. Routledge. https://doi.org/10.4324/9781315684482.

Milakis, Dimitris. 2019. “Long-Term Implications of Automated Vehicles: An Introduction.” Taylor & Francis. https://doi.org/10.1080/01441647.2019.1545286.

Milakis, Dimitris, Bart Van Arem, and Bert Van Wee. 2017. “Policy and Society Related Implications of Automated Driving: A Review of Literature and Directions for Future Research.” *Journal of Intelligent Transportation Systems* 21 (4). Taylor & Francis: 324–48. https://doi.org/10.1080/15472450.2017.1291351.

Muller, Peter O. 2017. “Transportation and Urban Form.” In *The Geography of Urban Transportation, Fourth Edition*, edited by G. Giuliano and S. Hanson, 57–85. Guilford Publications. https://books.google.com/books?id=J3GnDQAAQBAJ.

NCSL. 2019. “Autonomous Vehicles | Self-Driving Vehicles Enacted Legislation.” National Conference of State Legislatures. 2019. http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

NHTSA. 2019. “Automated Driving Systems.” National Highway; Transportation Safety Administration. 2019. https://www.nhtsa.gov/vehicle-manufacturers/automated-driving-systems.

Pred, Allan Richard. 1966. *The Spatial Dynamics of Us Urban-Industrial Growth, 1800-1914: Interpretive and Theoretical Essays*. MIT press.

SAE. 2018. “Taxonomy and Definitions for Terms Related to Driving Automation Systems for on-Road Motor Vehicles.” J3016. SAE International.

Schelling, Thomas C. 1971. “Dynamic Models of Segregation.” *Journal of Mathematical Sociology* 1 (2). Taylor & Francis: 143–86.

Schumpeter, Joseph Alois. 1939. *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. McGraw-Hill New York.

SDOT. 2017. “New Mobility Playbook.” Seattle Department of Transportation. newmobilityseattle.info/.

Singleton, Patrick A. 2019. “Discussing the ‘Positive Utilities’ of Autonomous Vehicles: Will Travellers Really Use Their Time Productively?” *Transport Reviews* 39 (1). Taylor & Francis: 50–65. https://doi.org/10.1080/01441647.2018.1470584.

Soteropoulos, Aggelos, Martin Berger, and Francesco Ciari. 2019. "Impacts of Automated Vehicles on Travel Behaviour and Land Use: An International Review of Modelling Studies." *Transport Reviews* 39 (1). Taylor & Francis: 29–49. https://doi.org/10.1080/01441647.2018.1523253.

Taiebat, Morteza, Austin L Brown, Hannah R Safford, Shen Qu, and Ming Xu. 2018. "A Review on Energy, Environmental, and Sustainability Implications of Connected and Automated Vehicles." *Environmental Science & Technology* 52 (20). ACS Publications: 11449–65. https://doi.org/10.1021/acs.est.8b00127.

Thünen, JH von. 1826. "Der Isolierte Staat." *Beziehung Auf Landwirtschaft Und Nationalökonomie.*

Tiebout, Charles M. 1956. "A Pure Theory of Local Expenditures." *Journal of Political Economy* 64 (5). The University Press of Chicago: 416–24. https://doi.org/10.1086/257839.

Vadali, Sharada, Johanna Zmud, Todd Carlson, Karin DeMoors, Rick Rybeck, Steven Fitzroy, Naomi Stein, and Mark Sieber. 2018. *Guidebook to Funding Transportation Through Land Value Return and Recycling.* Project 19-13. https://doi.org/10.17226/25110.

Van den Berg, Leo, Roy Drewett, Leo H Klaasen, Angelo Rossi, and Cornelis HT Vijverberg. 1982. "Urban Europe: A Study of Growth and Decline." Elmsford NY/Oxford England Pergamon Press 1982.

Wegener, Michael, and Franz Fürst. 2004. "Land-Use Transport Interaction: State of the Art." *Available at SSRN 1434678.* https://doi.org/10.2139/ssrn.1434678.

Zahavi, Yacov, Martin J Beckmann, and Thomas F Golob. 1981. "The Umot/Urban Interactions."

Zmud, Johanna, Tom Williams, Maren Outwater, Mark Bradley, Nidhi Kalra, Shelley Row, National Cooperative Highway Research Program, Transportation Research Board, and National Academies of Sciences, Engineering, and Medicine. 2018. *Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 2: Guidance.* Washington, D.C.: Transportation Research Board. https://doi.org/10.17226/25332.