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

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

# Summary

This memo is one of the series of policy analysis about autonomous vehicles (AVs) for the Bay Area. It tries to answer how AVs will affect urban land use, and why the Bay Area 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 AV technologies entered a “critical juncture” (Docherty, Marsden, and Anable 2018). In the fields of automation control systems, some critical hardware like processors and sensors have the ability to undertake more complex tasks. Improving software and algorithm are becoming more fledged. According to the third edition definition and taxonomy by SAE (2018), the existing technologies are achieving from the Level 3 - Conditional Driving Automation to Level 4 - High Driving Automation.[[1]](#footnote-22)

*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, holds the only testing permit for driverless testing by California DMV and committed to providing ride-hailing services in Arizona in 2018. In 2019, Waymo announced their Level 4 AV would be assembled in Detroit. Almost all big automakers such as Ford, General Motors, Volkswagen, etc., are investing heavily in this field(Crute et al. 2018). The leading transportation network company (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 research of AVs with lots of energy. Gandia et al. (2019)‘s research found 10580 published papers in this field from 1945 to 2018. Since 2012, the number of articles has exponential growth with a 39% growth rate while 8-9% average growth rate in science. Although a large amount of the studies is from the perspective of systems control, computer science, robotics, engineering, there are more and more articles that start to focus on the AVs’ impact on transportation and Land use (Milakis 2019).

*Governance*: In 2011, the Nevada DMV issued the 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 guidance for Automated Driving Systems (ADS is the definition by SAE). The guidance 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.

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 “breakthrough in movement technology” had reshaped the previous dominated urban form and launched a new era with a “distinctive spatial structure.” We try to answer how AVs could influence the demand for transportation and land use in this memo. The impacts on safety, liability, and other issues will be discussed in other memos.

# The Frameworks of changes

While industry, scholars, and governments realized the high impacts of AV, some research frameworks also imply it is a highly uncertainly evolution rising some involved 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*, which reflected a sequentially 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, travel modes, 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 in 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 cycle* (Wegener and Fürst 2004; adapted by Soteropoulos, Berger, and Ciari 2019) are two helpful complements. These figures can present the relationship between transportation and land use in a clearer manner. AV technology as an exogenous variable will influence travel behaviors in the first ripple and then is reflected in the change of accessibility. The dynamic of accessibility 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-demand model explains 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 the current research agree that AVs will provide more options for travelers with less travel time and larger capacity. According to the results of 37 modeling 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 notice that more available services by AVs may encourage low-occupied vehicle, reduce transit use, and increase VMT. (Taiebat et al. 2018) The tradeoff between higher efficient and higher demand makes the trends of congestion and emission being uncertainty. Overall, these are equalizing and incremental changes in quantities.

However, as a breakthrough technology, the impacts of AVs may not follow some divergent curves and show the polarizing 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 slight change will let it slip to two stable equilibria. But the equilibrium points represent two directions, a vicious circle (low ridership and longer wait time) or a virtuous circle (high ridership and shorter wait time).

To explain this phenomenon, we need to understand the components of travel cost and current options on travel modes. The opportunity cost and transaction cost are significant parts of travel cost. Being late for work, a meeting, or a flight means much higher opportunity loss, which can explain why people hat uncertain and wait time. Similarly, hailing a taxi for each trip or planning carpool every day means the transaction cost are unacceptably expensive. Meanwhile, the available travel modes options are limited. Once choosing transit, the trips often lost 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 AV supported mobility-as-a-services (Maas) proved by TNC introduced a potential solution. For the connected AV’s ‘perfect information’ and automation, Maas could largely reduce the opportunity cost and transaction cost, then, could reduce car ownership. Moreover, It provides a series of options by monetized the values of reliability and flexibility. A hurried passenger may willingly pay $100 for arriving at the airport as soon as possible. A worker may instead get up one hour earlier for a $10 off-peak pass per month.

Maas is a business mode transition in many ways. These round-the-clock services could achieve on-demand ridesharing by real-time matching. Many pieces of research show that the ridesharing level is a critical variable for AVs application (Soteropoulos, Berger, and Ciari 2019). The preset value of rideshare 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 (VOT) 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 previous 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 an economic perspective, all the activities want to minimize the cost and compete for the land close to the city center. *The bid-rent theory* orients 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 Alonso and others (1964)’s land market model, this economic theory is the basis of many land use models.

Some relevant studies conclude that wider urban sprawl might be an output of AVs application (Legacy et al. 2019). In the same way, some studies about parking say that the CBD could be denser for less demand for 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 fewer studies 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 negligible 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 doesn’t talk a lot about what is “a higher degree of the spatial division of labor possible” in AVs era (Hawkins and Nurul Habib 2019).

The theory of *network society* by Castells (2011) and other theories of the information society imply another possible perspective of land use pattern in the AVs era. If the travel demands and supplies can match in real-time 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, may disintegrate. In the long run, the network may control the travel and assign people to a place. People only choose their activities and amenities but don’t care about the actual locations.

# The feedback cycles

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) described the cycle of a “earlier technologies went from invention through take-off and rapid growth to saturation and was eventually superseded by 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 investment and land value return to virtuous incentive circle, there always some drawbacks (Vadali et al. 2018). From the perspective of equality, charging an unmeasurable service is unfair. From the perspective of the market, an unmeasurable trade is inevitable inefficient. The feedback cycle shows a decay process for free rider problem or 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 consumers can freely choose where they live. It assumes that there are enough communities available, the commuting cost is negligible, and there is no externalities or spillover of public goods across towns. Many scholars critique the Tiebout model for its unpractical assumptions. For the same reasons, The Tiebout model is more success in suburban areas. The roads in suburban communities like a club good. There is no free rider problem. All the cost and externalities internalized in property tax.

Entering the AV era, Tiebout model might be applied to the whole urban area. Maas supported by connected AV allows us to measure the road use for each trip. Moreover, Maas provides the opportunity of internalizing all the positive/negative externalities and redefine the boundary of the public good. The theory of local governments competition and the beneficiary pays principle can be fully applied to the new feedback cycle. Under this scenario, transportation becomes an excludable and rivalrous good. The cities or communities compete by investing and improving infrastructure; Transportation service suppliers bid for right-of-way and provide as many as possible options for consumers; Consumers choose the travel services based on their ability and willingness to pay money or adjust their itineraries. The social segregation in Schelling’s model (Schelling 1971) may be more significant and invisible. Bid for mobility may cause problems with 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 policymakers should “bolster transportation demand management, reconsider the right-of-way, and continue to develop transit.” The ideas about road capacities, curve space, and transit, are aimed at first-order changes. “Rethinking the parking standard and requirements” could help better redevelop the urban parking lots saved by AVs. Urban Growth 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 real challenges are how to response the self-reinforcement changes, the new distributions, and the networks never saw before? And how to let AVs leverage the virtuous circle rather than vicious? (Legacy et al. 2019) Pricing through Maas provides a valuable space for policymakers to guide the transportation and land use system to the direction we want. Responding to the promotion of Maas by industry, MTC 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 traveled, vehicle emissions, local levels of congestion and pollution, and availability of public transport alternatives.” SDOT (2017)’s policy wants to “establish a city-owned TNC digital platform to incubate smaller shared AV fleet businesses” in Seattle. Hand (2016) suggests starting some similar pilot projects in Los Angeles.

Other metropolitan areas are on the move. This memo cannot give more quick answers and tries to urge MTC to realize that the AVs’ effects on land use are far beyond what we can understand and respond to. The solid supports should be provided to the relevant research on the interactions between Maas by AVs land use, housing, and urban design, for the better future of the 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.

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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.” [↑](#footnote-ref-22)