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 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.

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 autonomous vehicles 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 real estate 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 AV on travel consumption, most of current research agree that AV will provide more options for travelers with less travel time and larger capacity []. These means the lower price and higher service qualities, which will induce more and longer trips, produce more overall VMT []. At the same time, other research noice that more available services by AV may encourage low-occupied vehile and reduce transit use. [] The tradeoff between higher effecient and higher demand makes the trends of congestion and emission being uncertaint. Overall, these are incremental changes in quantities.

However, as a breakthrough technology, the impact of AVs may not follow some divergent curves. 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 than travel cost, 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. Moreover, It provdes a series of options by monetized the cost 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. Many research show that the ridersharing level is a critical variable for AV application. The preseting value of ridershare could drastically change the simulating results of the models. []

As shown in Milakis, Van Arem, and Van Wee (2017)'s ripple effect, these changes triggered by AVs are not about land use. But they are the direct forces pushing the land use changes forward. And the changes may 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 change the prvious equations on parameters and even distributions.

The second order

The bid-rent theroy: this theory oriented form von [Thünen]'s model, which derived from the utility maximization through introducing the spatial variables. The essential reason is that the travel cost is positively correlated with distance. All the activities want to minimize the cost and compete for the land close to city center. From the 'concentric zone model' by [Burgess] to [Alonso]'s land market model, and to the gravity model for measuring accessibility, this economic theory is the basis of many land use models. The relevant research conclude that urban sprawl might be an output of AV application. [] In the same way, the research about parking say that the CBD could be more dense for less demand of parking lot. However, these inferences build on the assumptions that the functions remain the same. the incremental changes happen on values and parameters.

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. selfreinforcement. The changes triggered by AV may like a process of convolution and iteration, Is AV will leverage the vicious or virtuous circle?

The concept of *Public good* also helps to understand this topic. 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. From the perspective of equalty, charging an unmeasurable service is unfair. From the perspective of market, an unmeasurable trade is inevitablelly inefficient. Pricing by demand-supply mechanism becomes infeasible. Although many funding tools try to combine the transportation investiment and land value return together to incentive virtuous circle, there always some drawbacks. [] The feedback cylce becomes a decay process for free rider problem, or for delay of demand response.

Here we have to think about the *Tiebout model*. As a positive political theory model, (Tiebout 1956) contributes a non-political solution to optimal public goods provision which known as "foot voting". Through competition between communities, the mobile residents "vote with their feet". The primary assumptions Tiebout model relied on are that conusmers can freely choose where they live. It assumes that there are engough commuinties 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.

Therefore, the theory of local governments competetion and beneficiary pays principle can inspire us to conceive the new feedback cycle. 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. 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. As Levinson and Krizek (2018) say, "prices create choices, and choices are fair." (p.248) Entering the AV era, Tiebout model might apply to whole urban area. As simulated by social ecological models, the social segregation may be more significant.

Behavior and land use (Soteropoulos, Berger, and Ciari 2019)

(Hawkins and Nurul Habib 2019)

long-term effects (Milakis 2019)

(Fagnant and Kockelman 2015)

The policy options

This solution of Maas also provides a valuable space for policy-makers to guide the transportation system in the direction we want.

Above analysis are inference base on exsiting theories and research.

It's hard to conduct empirical studies of Land-use Tansport interaction under the AV technology.

The stated preference, reveled preference, simulation by models

- The response for these incremental changes:

The ripple effects

"Mobility-as-a-Service may cause a decline in car ownership. If average vehicle occupancy for on-road time decreases, total VMT will increase." (Taiebat et al. 2018) Time cost may decrease (Singleton 2019) cut off labor cost, the change of parking, affected by travel demand and behavior

the change on road capacities, parking lots, curve space.

- The response for these shifting changes:

Heavy property and light property.

feedback cycles produce

housing, urban design,

- The recommended initiative changes:

Research: Identifies the benefits and costs of these possible outcomes.

round-the-clock services.

full ridesharing by realtime matching

the impact on land use,

The long-term influences include the reconstructure of urban forms and spatial distributions.

use cost and transaction costs - full match

deals fail

adjusting, adapting, guiding

(Legacy et al. 2019)

Presents policy and planning options for mitigating or otherwise addressing the possible land use effects.

designating pilot area

Discusses how the MPO and cities may need alter the tools and analyses they use to consider AVs.

Zoning, Division, and partion, not uniform

Conclusion

overestimated and under estimate

from link to node

CA should play a leading role. responsibility

Notes

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