Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 49 (2020) 44–59

Transportation Research Procedia

www.elsevier.com/locate/procedia

47th European Transport Conference 2019, ETC 2019, 9-11 October 2019, Dublin, Ireland

Impact of Driverless Vehicles on Urban Environment and Future Mobility

Serio Agriesti[b], Fausto Brevi[a], Paolo Gandini[a], Giovanna Marchionni[a], Rahul Parmar[c], Marco Ponti[a], Luca Studer[a]*

[a] *Dep. of Design, Politecnico di Milano, Via Durando 38/A, Milan 20158, Italy*
[b] *Department of Built Environment – Aalto University, Espoo, Finland*
[c] *Dep. of of Architecture Urban planning and construction engineering, Politecnico di Milano, Piazza Leonardo da Vincia 32 Durando 38/A, Milan 20132, Italy*

Abstract

Driverless cars or autonomous vehicles (AV) have become topic of debate in various forums for both governments and academia. A lot of research is focused on the technical aspects dealing with what technologies will be needed in order to achieve completely driverless traffic. Less investigated are the effects that this technology will have on our cities and the future mobility. Autonomy along with electrification and sharing is likely to change the face of individual transport in next three decades. This paper tries to understand and foresee the changes in mobility behavior through a scenario building exercise. Various topics that relate to mobility and cities are analyzed based on available researches. The aim of the research is focus on the way this technology can impact our urban environments and set the base for policy changes at different levels. Planners, Policy and car makers and other new stakeholders need to take a holistic and multi-disciplinary approach in understanding and assessing the effect this technology will have in our lives and cities.

Keywords: Driverless cars, Mobility, Cities, Urban planning, Transportation

---

1. Introduction and context

It is very important to know the context and the playing field in which the research is conducted and designed in order to understand the overall effects of autonomous driving on the urban environment. The research developed is

---

* Corresponding author : Tel: +39 02 – 2399 5848
E-mail address: luca.studer@polimi.it

2352-1465 © 2020 The Authors. Published by ELSEVIER B.V.

10.1016/j.trpro.2020.09.005

not referred to a specific urban environment, but it considers a model city with certain kinds of parameters so to simulate the effects of the autonomous driving and to make them transferable to different case studies. The research is mainly focused on urban areas with some insights on suburban and rural areas connected to the analyzed city. The study is designed on a city in a developed world context, such as the European one. Part of the reason for such categorization is the fact that there aren't many data and direct experiments available for other kinds of cities in different context. Furthermore, these are the kinds of cities that are likely to be front runners in terms of having autonomous technology to be implemented and tested in next few years.

In terms of geography and climate, it is a city which is relatively flat and located inland (i.e. no seaside, mountains, advanced topography and terrains). Also, in terms of climate we assume a climate that normally does not have harsh winters like Oslo but is within the range of Milan, Paris, Hamburg, and Munich etc. Flat terrain and reasonable weather can ease walking and biking in the city. Moreover, the hypothesis is needed to guarantee a steady and continuous Operational Design Domain to the autonomous vehicles. Electrification of vehicles in cold climates is a technological challenge and there might be more innovation in the field in the years to come hence in order to not digress from the aim of the study. The cities with harsh cold winters are not part of the analysis. This is done in order to keep the focus of the work on the urban planning and transportation aspect given the time and resources that were available to synthesize this research.

Some mobility parameters are crucial to define the nature of the cities upon which this analysis can be adapted and replicated. These cities have relatively high car ownership, ranging from 400-600 cars/1000 people (Eurostat, European Comission, 2019). These ownership patterns are in line with many European cities in Belgium, France, Italy and Germany. In terms of modal share, it is assumed that there is a high share on public transportation along with the private car. The mode share on private car and public transportation is around 40% each and the remaining 20% is on slow mobility which includes biking and walking, that is in line with some of the developed European cities that are more likely to adapt policies to initiate AV testing (EPOMM, 2019). These are cities featured by a well-developed and established network for public transportation but with limitations in the way it can grow. Moreover, with the introduction of autonomous vehicles, part of the modal share currently using public transport could shift towards private vehicles in form of either car sharing, ride sharing or just private autonomous vehicles. Also, 20-25% of the modal share is surface transport, meaning buses and BRT system, which might be more affected in terms of ridership due to autonomous vehicles. This kind of impact on public transport will be discussed in the following, with aim of deriving best practices and suggestions to prevent it.

Moreover, in order to get a good idea of the impacts of autonomous traffic in the city it is well known that ring radial cities with a good grid density are ideal for supporting an array of public transportation and expansion of the city to accommodate a higher amount of population and future growth. This kind of cities are the ones more exposed to urban sprawling and therefore the ones on which the impacts of autonomous driving on mobility can weigh the most. Therefore, the analyzed city meets these traits, being also a city with a historic city center component that is mostly commercial-based and has a higher mode share on public transportation than the outskirts. The city is also polycentric in terms of distribution of retail services and transport components. This will allow for a good network of urban arterials, collectors and local roads. In order to further add on to this, the analyzed city is also the place where people from the region and nearby satellite towns commute. The city has a good regional connectivity with the suburban areas and rural areas in proximity.

In terms of readiness index for autonomous driving similar cities and countries usually rank high and hence it is possible to implement necessary policy changes and debates to get the best choice that is appropriate to maximize the benefits arising from the new autonomous means of transportation. New mobility service providers and many stakeholders are usually attracted by cities like the analyzed one, so it is hypothesized that these actors are going to be exploitable in the analyzed scenarios.

2. Revolutions in transport and scenario building

Three revolutions are expected to deeply impact the transportation of the future: Automation, Electrification and Sharing. 'The world is on the cusp of three revolutions in transportation: vehicle electrification, automation, and widespread shared mobility (sharing of vehicle trips). Separately or together, these revolutions will fundamentally change urban transportation around the world over the next three decades.' (Lew Fulton UC Davis, 2017).

These revolutions are the fundamental blocks on which Autonomous driving is going to rest and have an impact on urban areas and the mobility of future. The three revolutions form the basic framework lens of this research and characterize the 3 different scenarios in which autonomous driving/cars will possibly be implemented. The design of these scenarios is the first step to assess their possible impacts on the urban landscape and on the transportation services within the considered cities. The time horizon for the research is taken as next 30 years, which is a relevant time scale for the introduction and assimilation of technology at large scale, especially in the developed world.

The three scenarios range from the most optimistic, from a mobility and collective transport perspective, to the most disruptive and pessimistic scenarios. The scenarios are as follows:

- BAU (Business as Usual) scenario or limited CAV (Completely autonomous Vehicle) scenario: automation is still in its infant stages and will have a very limited mode share in the traffic composition, the components of sharing and electrification also remains minimum. Therefore, no disruption effects arise and most of the mobility needs are met by the same kind of transport as of today. This is a very conservative scenario.
- Private CAV scenario: the traditional car companies take the benefit of the technological revolution; the components of automation and electrification disrupts the way in which transportation is currently organized. All the autonomous vehicles are mostly privately owned and sharing of vehicles is very limited or not desirable. Other researches such as (Mohr, Kaas, Wee, & Möller, 2016) (Lew Fulton UC Davis, 2017) (Lang, et al., 2016) (Römer, Gaenzle, & Christian Weiss, 2016) considered a similar approach to define scenarios.
- Mobility as a service scenario: all the three revolutions in transport are fully realized and synergize with each other. It is an ideal scenario in which the autonomous vehicles are electric and shared among different users (Hensher, 2017) Private ownership of vehicles is very limited and there are arrays of opportunities to use different transport modes to meet the mobility requirement of the population.

It is acknowledged by the authors that the listed scenarios are a continuum rather than discrete steps on the disruption scale. So, it is probable to have cities where two of the three new technologies are fully exploited or cities where an intermediate equilibrium is reached between scenarios. This strong discretization is needed for the analysis carried out in the following paragraphs; the identified impacts can be layered depending on the degree of development of the actual case study.

3. Effects on mobility parameters

The context (type of city) and scenario building exercise forms the framework lens of the work. Based on the assumptions made in these scenarios various mobility parameters are accessed. The aim of this section is to take a deep dive on the effects that automated driving will have on Congestion, Public transportation, Parking, Pedestrian safety and urban sprawl.

3.1. Induced demand and congestion

An introduction of AVs will facilitate a large part of population to take part in an individual mobility behavior. Currently one of the biggest challenges in the field of transport access are individuals with disability, old age and children (Sommers & Weertunga, 2015) .With AVs the negative effect of travelling alone will be curbed to an extent with efficient passenger information system and reliability. Hence, a larger part of the population will be able to take part in daily mobility. This increase in demand of trips can be defined as induced demand, it can be either more people making trips or same amount of people making more trips. Moreover, the time cost of travelling will almost reach zero hence, more people will be willing to take longer trips which they would have avoided if autonomous driving was not available. Users will be able to use their journey time more effectively like reading a book, watching a movie or spending time with family (Mckinsy & Company, 2016) (Nordoff, 2014).

Autonomous vehicles (full automation) can drive and park without human assistance. This will enable a vehicle to be used for multiple trips within the day. In case of a traditional car that is human driven different vehicles or mode of transport will be required but with AVs the trips can be shared. This can be extended to small neighborhoods or employees of a company etc.

But since some of AVs will be shared more, less cars might be needed but they will travel longer distance and each car will be making more trips than in the present context. As a result of MaaS and ridesharing, it is predicted that the number of vehicles on the roads will decrease although the vehicle kilometers travelled (VKT) will likely increase (Godsmark, Kirk, Gill, & Flemming, 2015). These effects will be visible in both scenarios 2 and 3.

There are two main components in traffic that have a direct impact on congestion i.e. car occupancy and fleet size. These two components are interrelated and not mutually exclusive. The higher the car occupancy the lower the fleet size to serve a constant number of trips. Another important component is the turnover factor. It measures the number of the times the same vehicle is used to make trips per unit of time (this can be hourly/daily depending on the context of analysis). Since the traditional cars need drivers they can only work when a driver is available to take the car to places. Then, for a private, traditional vehicle the only times it is used is for personal purposes. Hence 95% of time the car is sitting in a parking lot (Rajasingham). With AVs this will change as more people will be able to use the same vehicle for their mobility needs as stated previously. There are many studies that have tried to simulate and understand the fleet of AVs that will be required to meet the foreseen demand of mobility.

A study done in Ann Harbour, a city with 120,000 residents, finds that only 15% of the vehicles currently needed would be enough to carry out the mobility trips in a day (International Transport Forum, 2015). A study by the (OECD/ITF, 2015) reports that 10% of today's car fleet is needed to cover the existing demand in Lisbon, Portugal. (Bischoff, 2016) Estimate that 10 cars in Berlin can be replaced by one AV. For Singapore, a study came to the result that 30% of the available fleet size would be needed (Spieser, et al., 2014) and a possible reduction of up to 90% of fleet size in the Zurich region has been found in (Boesch, M., Ciari, & Axhausen, 2015). In a recent study done by Carlo Ratti & MIT sensible city lab (Ratti, Santi, Vazifeh, & Resta, 2018) the Taxi fleet required to meet all the mobility needs in New York City is 40% of its original size. One of the more interesting case studies analyzed in Lisbon Portugal by (Forbes, et al., 2015) indicates that if traditional cars were made autonomous and shared 10% of vehicles would be required to deliver transport needs in a day and 30-90% increase in vehicle kilometers travelled due to diversions and repositioning would arise.

In order to conclude and detail the effects, in all the different scenarios of the research it can be said that road capacity will increase even factoring the induced demand since the traffic mixed with AV or even partial automation have demonstrated to regulate the traffic better then all human driver (Pinjari, Augustin, & Menon, 2013). This hypothesis is especially relevant in the long run (which is also the time horizon adopted in this analysis), after the first phase of transition in which the traditional traffic still will have to adapt to the new transport systems. Scenario 1 will experience the worst traffic and congestion in urban areas and highway since none of the three revolutions take effects and increased personal car use will cause more vehicles inefficiently packed on the roads and streets. In Scenario 2 functional road capacity optimization will be more prominent in the highways and motorways around the cities. Cars will have ability to use autopilot and cruise control even with partial automation. Bose and Loannou used simulations to demonstrate that 10 percent semi-autonomous vehicles in the traffic mix (with mixed traffic) can help smooth the traffic from rapid accelerations of human-driven vehicles (Pinjari, Augustin, & Menon, 2013) . The urban areas will be more congested as humans take control of wheel in an urban setting as automation in its easier stages will need human assistance in complex environments. In Scenario 3 the congestion will improve in the short run but more perceivable effect on a city scale will be there with increasing penetration of level 4 and level 5 automated vehicles combined with sharing and efficient use of group vehicles and public transportation.

NHTSA (Sommers & Weertunga, 2015) (Coppola & Silvestri, 2019) defines 5 different level of automation. Level 1 automation includes drivers assistance but all actions are done by the human, level 2 automation includes acceleration, break assistance etc. but under complete human supervision, Level 3 is conditional automation with piloted parking and autopilot mode in controlled and predictable environment but the human is available to take control, level 4 includes complete automation of features but human override still possible in situations needing assistance and level 5 automation include complete autonomy and the car is able to perform all tasks without needing human assistance in any given situation.

3.2. Public Transportation

At first blush, it seems that the key advantage of an autonomous car is freeing the driver’s hands from the steering wheel. The real transformational advantage, however, is that self-driving vehicles might blur the distinction between private and public modes of transportation (Caracciolo, 2017) (Szell, Ratti, & Santi, 2015).

There are two major categories of transport modes that comprise public transport. One is rail transport, and another is road transport. Rail transport includes Metros, Sub urban rails, Light rail transport (LRT) and tram system. Metro and rails have already been optimized to a certain level around the world in terms of using autonomous technologies. In many cities around the world metros are autonomous. One of factors for increased and easier autonomy in metro and rail systems is that it runs on fixed routes. The infrastructure is already put in place and there is no alternative traffic/mode that is going to hamper the smooth functioning of this system, so it is a closed system with limited number of variables. Trams or Light rails (that run within the urban context) on the other hand must constantly deal with mixed traffic from cars, cyclists and pedestrians on the streets. So, there is an additional level of difficulty in terms of technology and implementation that comes with making LRTs and trams autonomous.

Nonetheless, the real disruption that will come from autonomous driving is in road transport that currently includes BRT, Buses, Car sharing, Bike sharing, scooter sharing etc. CAVs will enable efficient sharing of vehicles which will further boost the use of micro-mobility modes as last mile connection especially in scenario 3 under MaaS (DuPuis, Martin, & Rainwater, 2015). It is important to take a deep dive in understanding how public transport on roads will be organized and understand the different modes that will emerge. Some of these new modes will replace ridership from existing ones and others will add an induced demand that will arise from easier availability of multiple transport modes. It is fundamental to understand the effects of CAV (Connected and Autonomous vehicles) technology will have on the buses of today to see them came out as CAV- PTs of tomorrow. Buses, compared to railway, tram, or metro, present the most flexible mode to address on-demand services, as they don’t drive strictly on fixed infrastructure. Some of the effects that CAVs will have on current bus market and regulation are as follows.

Buses are likely to run on long routes and on the routes with high demand. The cities will still need fixed route high frequency transit (Metro and light rail). Buses are one of the most flexible modes of transportation and hence they will be able to survive in the era of increased CAV penetration. So, in term of city planning and design strategies public transport buses that are unmanned is something that is desirable and city governments should push for this option. There will be other modes of transportation that uses CAVs and that is likely to complement unmanned buses. In the following there are some of the expected outcomes. These needs to be tested and simulated as part of the assessment on the ideal city that is being studied:

- Replacing regular fixed routes with more dynamic routing adjusted to local needs (time of the day/week/year)
- Providing more reliable service by connecting all mobility options under one platform (MaaS)
- Using heterogeneous fleets in order to accommodate different kinds of trips vs. standard urban buses or trams with a fixed standard capacity.
- Replacing regular's stops with more dynamic pick up spots that runs deep in the neighborhood. (Giving mobility options to suburban and even rural areas)
- A massive reduction in cost of operation by decreasing the number of humans involved behind the wheel.

One of the most important factors that determines user choice of the mode is the cost that is associated with that mode of transportation. All around the world across all public transport modes the cost of humans to the system can range from 40-60% of total management cost. This cost will drastically decrease once the vehicles are autonomous (Aloni, Optibus). Furthermore, when buses are autonomous the capacity of the system with the same fleet size increases. A study by Princeton University showed that autonomous buses on the bus lanes of the Lincoln Tunnel, connecting New York City to New Jersey, could accommodate over 200,000 passengers per hour, more than five times today’s throughput. This shows how public space and budget can be saved (less road construction, etc. (Lutin & Kornhauser, 2013).

The challenges of implementation of autonomous vehicles as public transport are many. Scalability is one of the issues that will be need effort and planning from different stakeholders involved. Infrastructure requirement at a city-wide scale is something that will need huge investments and new business models in order to support this change.

Removing labor costs from driverless taxi/Uber type services, for example, may increase demand for those services, some of which may come at the expense of public transport although these services are increasingly becoming part of the 'public transport' mix. Similarly, increased personal travel in cheaper driverless shared cars may also reduce demand for Public transport trips. Such circumstances may reduce demand for some types of bus services as we know them today.

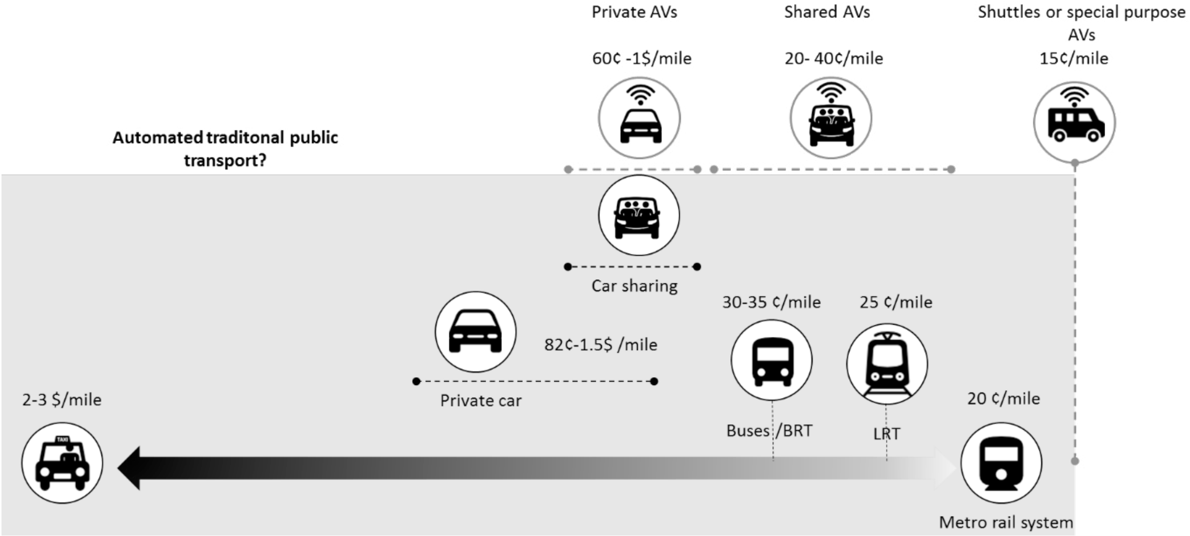

Figure 1: Cost comparison (per mile) for different modes

First definition of cost of AVs for the future was given by (Burns, Jordan, & Scarborough, 2013) that indicates that cost per mile of an AV can be as low as 0.15 cents/mile. Furthermore, (Litman, 2014) introduced cleaning and management costs which were discussed in the previous sections. These costs can increase the operating cost/mile for AVs to somewhere around 0.60-1.00 $/mile. In another estimate done by (Johnson, 2015) the price of shared AVs is equal to 0.44 US$ per trip-mile (operating cost plus 30% profit margin). For purpose-built shared AVs used as pooled taxis, they estimate the price per trip-mile is equal to only 0.16 US$. Less rigorous and detailed, but more transparent estimates are provided by (Stephens, et al., 2016) find the lower-bound cost of fully autonomous vehicles used with ride-sharing to be less than 0.20 US$ per passenger-mile and the upper bound to be 0.30 US$ per passenger-mile. In the study by (Institute of Victoria Transport Policy, 2017), it was found that the total operating cost for Bus and light rail is 0.94 cents/mile and 2.05$/mile respectively. But the revenues from the fare (which the individuals pay) are 0.24 $/mile and 0.19 $/mile. It should be noted that most of the research in the cost domain focusses on American context and hence has been used in this paper even though the context of this research is a European city.

In a study done in Chicago, comparing the costs for Uber and Lyft vs. Public transportation by (Bliss, 2018), it was found that even though ride hailing services cost 4 times more than public transportation majority of people chose ride hailing. Part of the reason being the comfort and users overvaluing the cost of time. So, it can be concluded that even though cost is one of the major factors there are other associated factors which have a huge impact on modal choice. Not all humans are able to think in a logical way and hence, the results might be in favor of personal vehicles with higher cost. There are limited studies that compare the role of cost with ride hailing services and public transportation for European cities which is one of the gaps in research available.

Thus, in Scenario 1 ridership and mode share on public transport in the model city either remains constant or decreases since it can be assumed that public transport in the model city has reached its maximum capacity. In Scenario 2 Private CAVs will take over and no automation occurs in terms of public transport and on the other hand the investments decrease, and the traffic congestion raises to a certain extent. With limited options for the city government for facing the existing problems of congestion PT will not be a very used mode of transportation. Ridership lost in PT will be taken up by either ride hailing services or private vehicles as discussed before. Lower cost of private AVs will take up the advantage on user price that public transport always had. In Scenario 3, which is the favorable scenario, the city government and the local service providers take the benefit of the opportunity of providing good profits as well as spaces for people. So public transport like metros and trams will vanish from low density or low demand areas and will be replaced with high frequency low capacity buses or shuttles that are autonomous. These buses can be used in a dynamic environment and their routes can be changed based on the demand. It is more flexible and cheaper than the conventional mode of public transport. In order to complement this kind of implementation for the public transport, there will be a lot of private and shared CAV services coupled with shuttle services in off peak hours which fill in the gaps in mobility. This scenario represents an ideal mobility ecosystem where many modes can flourish in mutual agreement and cohesion.

3.3. Parking in the future cities

Parking is one of the critical issues in modern cities. A car remains parked more than 95% of time, its average usage being 1.5-2 hours (Rajasingham). Fewer than 17% of household vehicles in the US are in use at any specific time in a typical day (Ticoll, 2015), the percentage is even lower for European cities since a good level of public transport is usually available for commuting. Furthermore, a person spends almost 17 hours a year trying to find a parking spot and as high as 30% of traffic can be a recirculating traffic during the peak hours, this being a matter of concern for traffic planners and mobility experts (Pawel Gora, 2016). It is not usually perceived how much space parking has taken up in our cities; some estimates suggest that in some cities it can be as high as 25-30% (Makinen, 2017) (Gardner, 2011).

One of the main reasons for the problems listed above is the combination of land use development and minimum parking requirements. Minimum parking requirement laws put up a lot of cost on the land that is very valuable to the city and that in the end is underutilized. AVs will give an opportunity to turn this issue of overspending and overdesign into providing public spaces especially in the city centres. It is important to understand the cost and economics associated with parking that will be completely transformed. As mentioned in the previous chapter that with reduction in the fleet size, especially in Scenario 3, the demand for the parking spaces will reduce drastically, as explained in the following chapter. It should be noted that paid parking is also one of the most important revenue streams for the local governments which will be hampered. For example, the Toronto Parking Authority (TPA) operates about 17,500 street parking spaces. It also runs 186 off-street parking lots and garages with 37,500 spaces. In 2014 parking ticket revenue was $105 million (Ticoll, 2015).

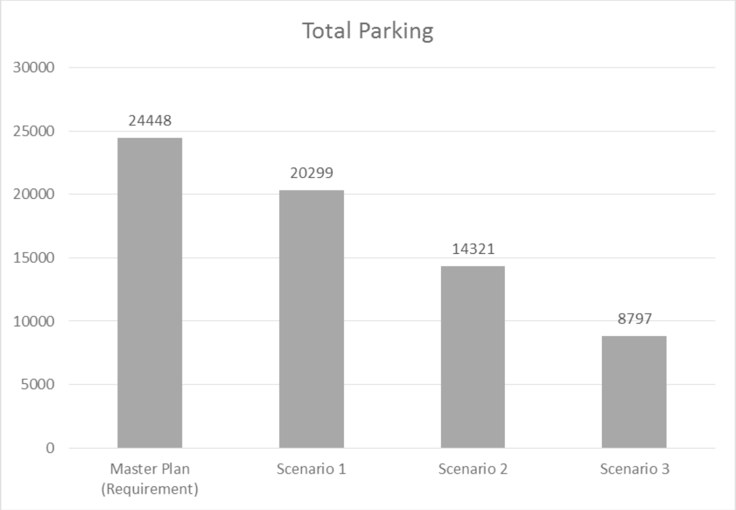

Figure 2: Parking capacity in different scenario - Simulation of a neighborhood with 100,000 people

This is considerable amount of money for the local government that are always in the cash crunch which also has an effect on the level of service the municapility is able to offer to its citizens, this challenge will not be easy to solve and alternate revenue streams have to be thought upon.

In a simulation done for the city of Atlanta, it was found that total of around 25,000 parking places will not be required for an inventory of 500,000 parking spots. The simulation results show that parking land use can be reduced by approximately 4.5%, once the AVs start to serve 5% of the trips within the City of Atlanta in both charged and free parking scenarios. The results also reveal that each AV can emancipate more than 20 parking spaces in the city (Zhang & Guhathakurta, 2016). These positive effects can be envisaged in all the three scenarios.

It becomes important to understand the way in which parking in the cities will be organized after the demand for the parking spaces is reduced. There is another level of efficiency that can be added in the way in which the spaces are distributed in the city. For this purpose, a short simulation is done as part of this paper; the attempt is to calculate the minimum fleet required to meet the demand for trips which was calculated using traditional trip generation model- The final number of trips taken into consideration also has an additional 15% trips as part of induced demand This is a simulation done on a master plan with 100,000 people and parking requirement of 25,000 CPP. This can be a neighbourhood in the considered ideal city. In order to simplify the simulation and understand the effects this approach has been taken.

As it can be seen, in the simulation the fleet size and the parking requirement reduced drastically from 25,000 to 9000. The scenarios coincide as given in the definition above.

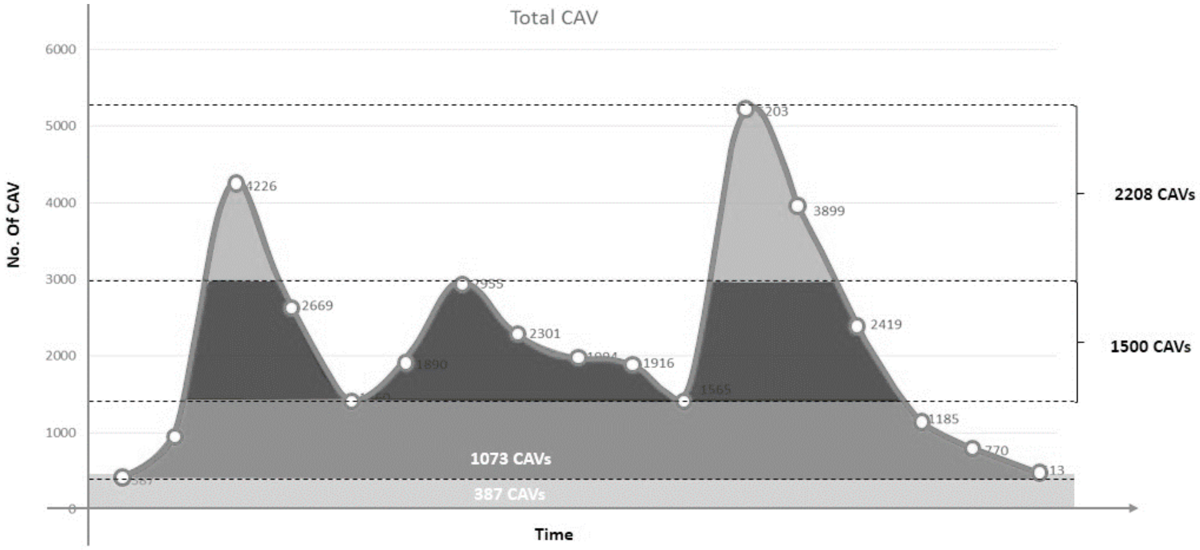

Figure 3: Daily curve for fleet required to meet the demand of trips in the day

This is the demand curve throughout the weekday for Scenario 3. The purpose of this diagram is to understand the effective distribution of parking in the city. It is assumed that this fleet is level 4 and level 5 autonomous vehicle that requires no human assistance. The fleet mix refers to different kinds of fleets of vehicles that are assumed with variable car occupancy.

The fleet type ranges from personalized car with car occupancy of 1.2 to shuttle with car occupancy of 6. Users are distributed in different categories that include Employees, Residents and Tourists. The mobility behaviour (i.e. using shared cars or private car or shared shuttle) depends on user and time of the day, peak hours have more vehicles with higher car occupancy. This fleet will be able to serve the current demand and an additional 15% trips as part of induced demand as mentioned before. In this simulation exercise an attempt was made in order to calculate the active fleet and the passive fleet which will form the basis for parking strategy. Active fleet will be the fleet that is required all throughout the day and it will be in motion most time of the day. Passive fleet on the other hand will only be active during the peak hours of the day and hence can be stored in the areas which is outside the city and can be procured when required. Thus, the space consumption in the city centre and the neighbourhood areas will be much lower than now. So, active fleet needs to be available at a very short notice, simulations can be made based on waiting times and level of service desired. Then there is another type of fleet that will be required during the 2-3 peaks of the demand which means that this fleet can be stored near the city or in the suburban areas depending on the space availability and where the fleet needs to be dispatched. As showed by the diagram, around 1000 CAVs will be active all the times of the day, another 1500 are active in all the peak hours and hence can be stored in the nearby areas and other 2500 or more is only required during the peak hour. But it can be seen that some of the cars will make a longer trip which might range for more than an hour and hence cars which are used in the first part of the peak hour might not be able to make trips in the second part of the hour. Thus, the CAVs from the entire peak hour which lasts two hours needs to be used in order to make the parking spaces. Two-hour time window is considered because some trips as part of assumption are longer than one hour and hence in order to accurately calculate the turnover factor (number of times one vehicle is used in peak hour window) and hence the fleet size. In this exercise it can be seen that there is a strong relationship between the fleet and the parking and the strategy that should be implemented in order to meet the requirements of trips, fleet and parking spaces. Below is the diagram that describes the definition of different types of fleets and their possible location in the city and neighborhood areas. If planned carefully, a lot of space can be freed in the city centre which will bustle with activities that are people oriented.

Figure 4: Parking distribution strategy (For active and passive fleets)

In Scenario 1, the number of parking slots will be optimized in the city to a certain extend. Since car sharing or AV will have limited penetration, reserved parking spaces in the city centres can be envisaged to provide the spaces for these cars. But large parking lots and effective decoupling of parking and land use will only start to happen in Scenario 2 and Scenario 3. Scenario 2 will see some removal of on street parking while on the other hand the demand for big parking structures in the suburban areas will increase, this will have effect on the network that connects the city with the suburbs. The access and ingress to these parking areas will have a considerable impact on the road network and its capacity and as mentioned before some of the reductions in traffic will be compensated by increased traffic/induced demand. In Scenario 2 city centers will be the first ones to get rid of some of the cars from the streets with increased penetration of AVs in the fleet mix. In Scenario 3 the cities will have the opportunity to categorically choose the policies that are people-centric and hence will also integrate the pedestrians and biking areas. Many of the spaces dedicated to cars will be given back to more eco-friendly modes that will be part of the larger mobility mix.

Hence, the dense city centres will have lot of drop offs integrated in the street design that will allow for pickups during the peak hours. These areas will also be served with an integrated mass transit like metros. Thus, cities in general tend to become filled with less cars and to become more walkable as a result of increased AV penetration with increased electrification and sharing of fleet for the purpose of the trip.

3.4. Social impact of AVS

There are many levels at which AVs will impact the human society. Some of these are directly mobility-related while others may bring change in the way in which society and social trends are organized. With the advent of AV, the mobility scenario of different people and age groups is going to increase. People who have a limited access and depend on others will have access to AV. This will provide independent mobility and practical solutions to problems of different user groups. The category of people who will be able to get to move in different ways with a lot more freedom than they enjoy today are old age people, physically impaired people, etc.

In Nishaka Japan, a small rural community 71km away from Tokyo, the local government started testing autonomous vehicles in rural areas. The major population in the town is old age people and this service provides essential mobility options to the people in the community at a cheaper price than traditional vehicles (Tajitsu, 2017). James Welling was born with a permanent movement disorder, a disease affecting 2/1000 people. In his interview 2025AD Driverless communities he mentioned that driverless cars will give wings to people from his community and all other disabled people (Welling). Another example is the following: during few days in August, the parking lot at Perkins School for the Blind morphed into a test zone where a golf-cart-like vehicle transported students and staff members, guided by a laptop. It was a prototype from Optimus Ride, a startup in Cambridge, Massachusetts, that is developing self-driving technologies for electric vehicles (Woyke, 2016). Another interesting design concept is having driverless cars for school going kids. Since in the realm of driverless cars integrate school going children in neighborhoods is very important (Marshal, 2017). These examples indicate that even at decentralized and small-scale driverless cars can have a positive impact for providing mobility to groups that traditionally were dependent on others for mobility and travel.

One of the important aspects of mobility behavior that transcends to societal impact is car ownership. With the advent of AVs, it is probable that less people will be willing to own a car if a shared vehicle is easily available. The trend in past few decades shows that there is a decrease in number of cars owned in the newer generation. Even though the trend shows increased car ownership, the percentage of young people holding a driving license is decreasing in these countries as well at a steady rate. A study by the German ministry of education shows that in 2009 only 34% of students had expenses for a car compared to 54% in 1991 (Kuhnimhof, Buehler, & Dargay, 2011). In the scenarios that are considered in this document the decreasing car ownership trend works in conjunction with Scenario 3 where mobility is like any other service and owning a car is not very important for having a high degree of mobility freedom. On the other hand, in Scenario 2 the ownership of cars and especially the private ownership of car is something that is favored because still the mobility is not detached from the vehicle itself that an individual owns. Employment concerns due to autonomous vehicles have been the center of discussion in many debates. The ones at stake the most are truck drivers (logistic industry) and taxi drivers. It is also to be noted that these two employment sectors will suffer a more direct impact than others but at the same time there are other jobs which require the use of internet and Everyday commute might not be necessary and preferable option or workers and employers alike. There are two contrasting views that are being debated currently associated with trucking and logistic industry. The argument that Uber is putting forward is that the nature of trucking industry should change, which means more trucking activities and hence the employment that is available for people will increase as more people use ecommerce to purchase products. On the other hand, the estimates by famous management consultancies predict a sharp drop in number of jobs. Goldman Sachs, for example, predicted trucker job losses of 25,000 per month as self-driving trucks roll out. McKinsey Global Institute put out a report with the possibility of 1.5 million jobs lost in trucking over the next 10 years. The International Transport Forum proposed that 2 million American and European truckers could be directly displaced by 2030 (Marshal, 2017). Nonetheless, it is not very clear the way in which future in the trucking industry unfolds but one thing is for sure in the long run when AV technology matures and reaches high level of penetration in the transport mix the jobs in the trucking industry are likely to decrease .The cost of operation is one of the important factors when it comes to commercial operations in logistic industry and deliveries without human assistance will be cheaper , it won’t be an economically viable option for logistic industry to keep using humans for delivering goods.

3.5. Pedestrians and human safety

Pedestrians and cyclists are the user groups that are at most risk in case of crashes. Unlike car occupants, pedestrians and cyclists do not have a protective 'shell' that reduces the impact in case of a collision (Vissers, Kint, MSc, & Hagenzieker, 2016). The assumption underlining the deployment of AVs is that the number of accidents will decrease drastically as a result of the on-board software controlling the vehicle more efficiently. While this might be true in the case of complete automation of all fleets, in an intermediate scenario when AVs and human drivers will share the road space this will not be the case and the issues of pedestrian safety become more critical than ever. The (Who, 2015) reports that of all road fatalities worldwide pedestrians make up 22% and cyclists 5%, implying that, as a group, they contribute to over one quarter of all road fatalities worldwide. Pedestrians routinely play the game of chicken. Crossing the street, even at a marked although unsignalized crosswalk, requires an implicit, instantaneous probability calculation: what are the odds of survival? (Millard-Ball, 2017) It is very well known that there is a certain dialogue and communication that always happens with the drivers and pedestrians in case of crossing an unsignalized junction. This communication/behavior is difficult to measure and map into a machine that will be able to understand and communicate the intent. (Lagström & Lundgren, 2015) suggested three major ways in which the AVs will interact with humans. The cusp of this finding is that the pedestrian needs a way of exchanging information with the vehicle in order to feel safe. As for now, one is through gestures (hand signs, waving etc.), second with some infrastructure near the crossing that will communicate the AVs about the status of pedestrian activity in real time and third is wearable devices that communicate with the vehicle directly the location and intent of pedestrians. While these systems offer promise of significantly improving safety, they bring new kinds of safety challenges that must be managed. The most prominent of these challenges is cyber security and the risk of hacking (Zon & Ditta, 2016). Some risks can also be elevated in case of a system shutdown or failure as a result of malfunction of software and system.

There are two major ways in which vehicles can reach complete autonomy. One through gradual automation functions eventually leading to full autonomy (this is what traditional OEMs are planning to follow). This is defined as evolutionary approach. Second approach is instead the revolutionary approach i.e. reaching level 5 autonomy as fast as possible (Google, Uber and Apple are working towards this kind of intervention) (Coppola & Silvestri, 2019) (Corwin, Vitale, Kelly, & Cathles, 2015). There are business decisions that are involved in this for which we will not go in further detail. Partial automation can be a very dangerous situation from a safety point of view. One of the compelling arguments against partial automation is that humans are likely to lose the attention span while sitting ideal and it becomes difficult and potentially dangerous to take control in an emergency.

As journalist Dave Roberts asks: “can we trust human drivers who are inattentive 75 per cent of the time to pay attention the right 25 per cent of the time, and to make the right decisions?” (Zon & Ditta, 2016).

At higher (but still not complete Level 4) levels of automation, designers face the challenge of an “uncanny valley” where the human driver might only be controlling the vehicle 25 per cent of the time, leaving a paradox where the safety technology creates the danger of inattentive and inexperienced drivers. The system will be very difficult to design and to be made safe for humans in driverless dominated environments (Zon & Ditta, 2016).

The technology will become safe, reliable and robust in 99% of situations, toppling the balance in favor of having human drivers out of the driving equation (Moore & Lu). But one of the most important question that arises is: will humans be able to drive once the cars have become safer than human driving? What are the odds and arguments in favor of this situation is something that still needs to be explored in literature.

3.6. Density and sprawl

Driverless cars have a multifaceted impact on our urban environments. As literature suggests, AVs along with electrification can save a lot on fuel cost and carbon emission saving, the real test of this technology will be its impact on sprawl. Density matters, even in a world of zero emissions and zero productive time lost to driving, because it is the means by which we control the human footprint on the larger ecosystem, and it becomes important to critically understand the urban impact of increasing land usage and low-density ecosystems. (Fox, 2016).

Conventional wisdom suggests that high density cities are less impacting in terms of environment factors and it is advisable to be in a walkable high dense neighborhood rather than suburban areas with sprawl. Even in terms of per capita energy demand it is advisable to live in a certain threshold of densities which will help to make and efficient use of resources and services that includes public transportation. (Baojun, 2012) (Cheng) (Newman, 2014).

In the popular debate among planners and policy maker two distinct types of scenarios emerge as a result of autonomous vehicles. One is that Urban sprawl will increase, and the cities will go far beyond what they are in the current situation. Second approach suggests that cities with effective planning and policy framework will establish a denser urban form and more walkable cities. Both scenarios coincide with Scenario 2 and 3 of this research respectively. One approach corresponding to Scenario 2 of this research tends to paint a bleak picture of future condition of transportation, mobility and cities. The fundamental principle of this line of thinking is that cars are owned privately, and sharing is limited, this resulting in lot of individual behaviors that will impact the common resources i.e. our cities. Urban sprawl being the center piece of the arguments that stems from the fact that vehicle miles travelled per vehicles will increase. Historically, new transportation technologies lead to larger metropolitan areas and time saved from mobility gains is used mostly in additional distance between home and workplace. With the increasing comfort for the driverless cars in this line of thinking the "time cost of driving" tends to reach zero and hence the assumption is that the suburban sprawl is going to increase. The people density will decrease, and the road density will increase. This is a way will replicate the advent of suburbanization in the 20th century and hence it will be making the same mistake twice (Fox, 2016). Some might say that it will undo the progress we made on densification of cities after suburban sprawl of 20th century. Other things that will follow will be lot of 0 occupancy vehicles in the traffic mix, entering and exiting the main arterials of the city. This will nullify the positive effects that are gained on efficient traffic management due to autonomous cars as they are more effective in space utilization in the traffic mix. Another important aspect to consider are the utilization and ridership of public transportation. There are two main reasons for decline in PT usage in this scenario. One being reducing cost of personal travel as vehicles become autonomous and second being reduced ridership due to sprawl. As it is known that in order to sustain a PT system a certain amount of density is essential. These two factors reduce the effectiveness of public transportation in this scenario.

On the other hand, Scenario 3 is the most optimistic of them all. This scenario will make use of existing public transportation system and try to integrate AVs through sharing and providing the last mile connectivity. The VMT will be reduced as there will an array of mobility choices that the users will be able to access seamlessly. Policies like dynamic road pricing will ensure higher occupancy in vehicles during the peak hours that will ensure lower fleet size at a city scale hence less parking requirement. The positive effects gained from efficiency in traffic management will multiply with more users choosing healthier mobility options in dense urban settings. The cities become efficient, safe, walkable and dense.

From the various topics discussed in the sections above it can be said that driverless cars are a reality in the near future, and it will in some way or the other impact the way in which we organize our cities. The challenges in the cities all around the world are getting more and more complex. In a system it is said that there is only a certain point to which by amending the rules the system will function, after that point the whole system needs to be reshuffled in order to induce efficiency. Driverless technology is going to change the way in which we organize mobility systems in our cities. In theory the mobility function has remain constant for past 100 years. Even though we have amended the technologies that are used, but in principle, we are still focused around private mode i.e. human driven and collective mode i.e. public transport. Because of its inherent nature these systems have reached its peak point and now there is a need to change the status quo that will make our cities more efficient. Automation coupled with electrification and sharing will transform the face of transport in our cities.

4. Conclusions

The table summarizes the outcomes of this paper. Scenario 3 is a preferred scenario from a mobility and user perspective but at the same time moving towards MaaS will require lot of effort by local government and stakeholders to form partnership that are profitable from an economic standpoint. Scenario 2 and 3 are in a way contrasting results that prefers to keep AVs under private ownership and later shifting away from vehicle ownership to mobility access.

Scenario 2 is a repetition of behavior from the 20th century i.e. planning, and policy based around vehicles/car instead of people. This approach in the past lead to sprawl and suburbanization, with negative effects.

In the research the attempt was to understand the impact that driverless cars will have on the future of mobility. Part of the reason for choosing a model city is the availability of research material, in order to form meaningful and coherent argument. The research tries to give array of possibilities for future that are envisaged as transitional rather than discreet. It can also be looked as progressive scenarios. Scenario 1 represents a slow start at the adaptation of autonomous vehicles. This can be the transition to private ownership for some users and then with effective planning and management of the local government some cities and regions will try to move towards Scenario 3 where mobility is a service rather than a necessity. It is important to note that most critical issues that are related to effective institution management and policies will be prominent in the phase when human driven cars will have to share space with autonomous vehicles. The uncertainty that this area of study faces is the intermediate transition phase. In the next 30 years a lot of experimentation on how to develop and deploy this technology in an effective way needs to be done. This paper focusses on those aspects that have to be thought during the process and it is also an attempt to map the gap in literature that poses in the further work. Most of research done until now focusses on technical and technological aspect of autonomous driving. Only limited research is available and done on the wider scale societal impact that autonomous driving will have on our cities and urban environments. But it would be fair to say that in recent times a lot more attention is given to the mobility aspect of autonomous driving. In this framework, it becomes essential that different stakeholders come together to have a roadmap for effective and efficient implementation of autonomous driving in our cities. When it comes to cities local government is one of the most important and powerful stakeholders that can facilitate an array of possibilities for implementing this technology. There are many steps that the local government can take that will allow effective planning and deployment of AVs. Technology is agnostic and can be used in multiple ways in order to profit different kinds of people. But when the technology and its implementation is market driven then the common people are not ensured the full benefits that can be harnessed. That’s when the local governments need to take charge and allow for a participatory and transparent approach. Driverless vehicles have the potential to impact states and municipalities in a number of ways: traffic congestion and tax revenues may increase or decrease, current public transit options may need to become more competitive, parking needs may decrease and roadway infrastructure may need to be adapted (to name a few). Local governments will need to plan for these many changes. There are many barriers for the implementation of driverless technology. It is important that in the policy making and decision process governments at different hierarchies have different roles to play in order to implement autonomous technology.

There are some challenges that pose a threat to effective deployment of autonomous driving. Scalability is one of the issues that will need a lot of effort and planning. This will be accompanied by local government and private agencies initiating pilot projects to understand in depth the issues that might arise with this automated driving. In this regard many university campuses, expo areas, Theme parks and airports have started implementing driverless shuttles in a controlled environment, this one step forward in raising awareness of future user. This technology poses to have considerable impact on the road infrastructure that includes reducing functional capacities increasing travelling speeds in the urban areas. The reduced cost of private vehicle access (cheaper fuel, time cost of travel tending to zero) that may accompany driverless vehicles may pose a threat to public transport but also provides some possible ways out. Removing labor costs from driverless taxi/Uber type services, for example, may increase demand for those services, some of which may come at the expense of public transport although these services are increasingly becoming part of the ‘public transport’ mix. Similarly, increased personal travel in cheaper driverless shared cars may also reduce demand for PT trips. Such circumstances may reduce demand for some types of bus services as we know them today. A widespread use of driverless cars will have a considerable impact on the revenues of city governments that will be lost in the light of low parking, management of manpower in the transit system (governments might have to completely change the kind of people that will be needed to work).

But despite the challenges there are many steps which can be taken in order to minimize the negative externalities and uncertainties that will arise from automated driving. Local government needs to be proactive at the progress that is being made in the vehicle technology along with different players in the local market. Special attention should be given by the city planning and transport department at all levels in the government. It is important to establish relationship with local stakeholders and service providers. It will be imperative that a good working relationship is established with these local service providers in order to make the best from it. It will be a win–win situation since local governments will have a say in how the technology is going to be implemented along with some revenue stream which might open from the partnerships. It is quite probable that the local government will not be able to sustain their revenue streams that comes from Parking revenues and road traffic violation hence new ways of funding new planning and mobility initiatives needs to be explored. Finally, an update in traditional modelling and data management at local level, change in land use policies to discourage sprawl and an efficient parking management plan are required.

Table 1:Summary of effects vs scenarios

	Scenario 1	Scenario 2	Scenario 3
Induced demand	Congestion increases VMT saturates Functional road capacity decreases due to increasing congestion (1,800 instead of 2,200 for one lane)	Congestion decreases in peripheral roads and increases in the city. VMT increases 15-20% Functional road capacity increases moderately (2,685 vehicles at 50% market penetration)	Congestion reduces VMT increases 15-20%but fleet size decreases 30-50% of original size Functional road capacity increases (3,600 vehicles at 80% -100 % market penetration)
Public transport	Ridership stagnates, mode share remains constant or decreases slightly Poor maintenance and investment in PT	Ridership decreases Mode share on PT decreases due to other cheaper available transport options (Private AV) (less than 15-20% on PT, 70% car) Poor maintenance and investment due to decreases ridership	Ridership increases New modes for mobility add to increasing shared transport mix. (Private vehicle 15%, PT 50-60%, Slow and micro mobility 30 %) More investment in different kinds of shared /public transportation due to integration with MAAS
Social impact of AVs	Private car ownership remains constant or stagnates (400-600 cars/1000 people)	Private ownership of car increases (600-700 cars/1000 people) with cheaper prices for AVs to buy and maintain Disable and old people have chance to be included in mobility mix	Private ownership of cars/vehicles decrease under mobility as a service platform. (150-200 cars/1000 people) Resources are shared Disable and old people have chance to be included in mobility mix
Pedestrian safety	High amount of deaths by accidents of human driver (1 million every year) Pedestrian infrastructure will remain as it is now	Potential risk for soft mobility users with new technology, deaths on accidents reduce. (90% reduction in traditional accident deaths) + 5% deaths caused by new conflicts with AV	Lower risk for soft mobility users as street and city design takes into consideration pedestrian behaviour (90 % reduction in traditional accident deaths)
Density	Sprawl increases first then stagnates due to limitation in times spend on commute.	Cost of commute time almost reaches zero hence sprawl increases with private AV automation	Cities become dense as more activities and transportation are concentrated with connected suburban and rural areas.

Driverless cars are going to hit the markets in more than one way and hence it becomes necessary to steer the deployment in a way that maximizes the benefits that can be harnessed from the technology. The borders between public and private are going to fade away. Governments across the globe are faced with the challenge of providing sustainable mobility solutions to the ever-increasing number of people in the cities. This revolution is a great opportunity for solving some of very complicated problems in urban and transport planning (e.g. last mile connectivity, safety for road users, reducing GHGs, congestion etc.).

References

Alessandrini, A., Campagna, A., Site, P. D., & Filippi, F. (2015). Automated Vehicles and the Rethinking of Mobility and Cities. Transportation Research Procedia 5, 145-160.

Alexander-Kearns, M., Peterson, M., & Cassady, A. (2016). The Impact of Vehicle Automation on Carbon Emissions. Retrieved June 29, 2018, from https://www.americanprogress.org/

Aloni, Y. (Optibus). Dynamic Scheduling for the Autonomous Public Transportation Era.

Agriesti, S., Gandini, P., Marchionni, G., Paglino, V., Ponti, M., Studer, L. (2018). Evaluation approach for a combined implementation of day 1 C-ITS and truck platooning. IEEE Vehicular Technology Conference, 2018-June.

Baojun, Y. (2012). Planning strategies for liveable high density cities. Urban Solutions (1), 76-79.

Bischoff, J. M. (2016). Simulation of City-wide Replacement of Private Cars. Procedia Computer Science, pp. 237-244.

Bliss, L. (2018). The High Cost of Saving Travel Time. Retrieved June 28, 2018, from https://www-citylab-com

Boesch, M., P., Ciari, F., & Axhausen, K. W. (2015). Required autonomous vehicle fleet sizes to. Transportation Research Board 95th.

Böhm, M., Studer, L., Mans, D. (2010). Toolkit for sustainable decision making in ITS deployment. 17th ITS World Congress

Bondorová, B., & Archer, G. (2017). Does sharing cars really reduce car use? Transport & Environment.

Bresciani, C., Colorni, A., Costa, F., Lue, A., Studer, L. (2018). Carpooling: Facts and new trends. International Conference of Electrical and Electronic Technologies for Automotive, Automotive 2018.

Burns, L. D., Jordan, W. C., & Scarborough, B. A. (2013). Transforming Personal Mobility. New York: The Earth Insitute, Columbia University.

Böhm M., Studer L., Mans D., “Toolkit for sustainable decision making in ITS deployment”, in 2010 17th ITS World Congress.

Caracciolo, M. (2017). MIT Professor Carlo Ratti: Looking Towards the Future of “Sensible”.

Cheng, V. (n.d.). Understanding Density and High Density.

Coppola, P., & Silvestri, F. (2019). Autonomous vehicles and future of mobility solutions. In P. Coppola, & D. Esztergár-Kiss, Autonomous vehicles and future mobility (pp. 1-15). Rome, Italy: Elsevier.

Corwin, S., Vitale, J., Kelly, E., & Cathles, E. (2015). The Future of Mobility- How transportation technology and social trends are creating new business ecosystem. United Kingdom: Deloitte University Press.

DuPuis, N., Martin, C., & Rainwater, B. (2015). City of Future - Technology and Mobility. Washington, USA: National league of Cities.

EPOMM. (2019, August 31). TEMS - The EPOMM Modal Split Tool. Retrieved from epomm: http://www.epomm.eu/tems/index.phtml

Eurostat, European Commission. (2019). Transport statistics at Regional Level. Brussels: European Commission.

Fagnant, D. J., Kockelman, K. M., & Bansal, P. (2015). OPERATIONS OF A SHARED AUTONOMOUS VEHICLE FLEET. Transportation Research Record (2563), 98-106.

Forbes, I., Buchanan, P., Crockart, M., Choa, C., Dedring, I., & Gheerawo, R. (2015). Driverless cars and the city. London: Urban land institute.

Fox, S. J. (2016). Planning for Density in a Driverless World. North-eastern law university.

Gardner, C. (2011, December 12). Old urbanist. Retrieved October 4, 2017, from We Are the 25%: Looking at Street Area Percentages and Surface Parking: http://oldurbanist.blogspot.it/2011/12/we-are-25-looking-at-street-area.html

Godsmark, P., Kirk, B., Gill, V., & Flemming, B. (2015). Automated Vehicles: The Coming of the Next Disruptive Technology. Ottawa: The Conference board of Canada.

Greenblatt, J., & Saxena, S. (2015). Autonomous taxi could greatly reduce greenhouse gas emissions for US light duty vehicles. Nature Climate Change, 5, 860-863.

Greenblatt, J., & Shaheen, S. a. (2015). Automated Vehicles, On-Demand Mobility, and Environmental Impacts. Curr Sustainable Renewable Energy Rep, 74–81.

Hensher, D. A. (2017). Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change?

Institute of Victoria Transport Policy. (2017). Transportation Cost and Benefit Analysis II – Vehicle Costs. Victoria.

International Transport Forum. (2015). Urban Mobility System Upgrade How shared self-driving cars could change city. Paris: OECD/ITF.

Issac, L. (n.d.). How local governments can plan for driveress vehicles. WSP Parsons Brinckerhoff.

Johnson, B. (2015). Disruptive Mobility - A scenario for 2040. Barclays Investment bank.

Kuhnimhof, T., Buehler, R., & Dargay, J. (2011). A New Generation: Travel Trends among Young Germans and Britons. TRB.

Lagström, T., & Lundgren, V. M. (2015). AVIP - Autonomous vehicles´ interaction with pedestrians. Gothenburg: Chalmers University of Technology.

Lang, N., Rüßmann, M., Mei-Pochtler, A., Dauner, T., Komiya, S., Mosquet, X., & Doubara, X. (2016). Self-Driving Vehicles, Robot-Taxis, and the Urban Mobility Revolution. Boston, USA: Boston Consulting Group.

Lew Fulton UC Davis, J. M. (2017). Three Revolutions in Urban Transportation. UC Davis, ITDP.

Litman, T. (2014). Autonomous Vehicle Implementation Predictions Implications for Transport Planning. Victoria Transport Policy Institute.

Lutin, J. M., & Kornhauser, A. L. (2013). Application of Autonomous Driving Technology to Transit - Functional Capabilities for Safety and Capacity. New Jersey: Princeton University.

MADRIGAL, A. C. (2018). Could Self-Driving Trucks Be Good for Truckers? Retrieved May 19, 2018, from https://www.theatlantic.com/technology/archive/2018/02/uber-says-its-self-driving-trucks-will-be-good-for-truckers/551879/

Makinen, A. K. (2017, April 17). The real Problem with having 800million parking spaces. Retrieved October 4, 2017, from Parkman: http://blog.parkman.io/problem-with-too-many-parking-spaces

Marshal, A. (2017, November 1). Who’s ready to put their kid on a self-driving school bus? Retrieved March 21, 2018, from Wired: https://www.wired.com/story/self-driving-school-bus/

Mckinsy & Company. (2016). Automotive revolution –. Mckinsy & Company.

Millard-Ball, A. (2017). Pedestrians, autonomous vehicles and cities. Journal of Planning Education and Research, 27, October.

Mohr, D., Kaas, H.-W., Wee, D., & Möller, T. (2016). Automotive revolution –perspective towards 2030. Visual Media Europe, McKinsey & Company.

Moore, M., & Lu, B. (n.d.). Autonomous Vehicles for Personal Transport: A technology assessment. Caltech.

Newman, P. (2014). Density, the Sustainability Multiplier: Some Myths and Truths with Application to Perth, Australia. Perth: Curtin University Sustainability Policy.

Nordoff, S. (2014). Mobility 4.0: Are consumers ready to adopt Googles self-driving car. Delft: Delft University of technology.

OECD/ITF. (2015). Urban Mobility System Upgrade: How shared self-driving cars could change. Paris: OECD Publishing.

Pawel Gora, I. R. (2016). Traffic models for self-driving connected cars. Transport research Procedia, 2207-2216.

Pinjari, A. R., Augustin, B., & Menon, N. (2013). Highway Capacity Impacts of Autonomous Vehicles: An Assessment. South Florida: Centre for urban Transport Research, University of South Florida.

Römer, M., Gaenzle, S., & Christian Weiss. (2016). How Automakers can survive the Self - Driving era. India: A.T. Kearney Inc.

Rajasingham, D. (n.d.). Driverless vehicles - Opportunities and challenges in new networked world. Commonwealth bank of Australia.

Ratti, C., Santi, P., Vazifeh, M., & Resta, G. (2018). Minimum Fleet, MIT sensible city labs. Retrieved July 10, 2018, from http://senseable.mit.edu/MinimumFleet/

Schito, P., & Braghin, F. (2012). Numerical and Experimental Investigation on Vehicles in Platoon. SAE Int. J. Commer, 5(1), 63-71.

Schwieterman, J., & Livingston, M. (2018). Uber Economics - Evaluating the monetary and non-monetary trade-offs of TNC and Transit Service in Chicago. Chicago: Chaddick institute for Metropolitan Development.

Sommers, A., & Weertunga, K. (2015). AUTOMATED VEHICLES: ARE WE READY? Main Roads Western Australia.

Spieser, K., Ballantyne, K., Treleaven, R. Z., Frazzoli, E., Morton, D., & Pavone, M. (2014). Systematic Approach to the Design and Evaluation of Automated Mobility-on-Demand. Road Vehicle Automation, 229–245.

Stephens, S., T., Gonder, J., Chen, Yuche, & Lin, Z. (2016). Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles. United states: National Renewable Energy Lab. (NREL), Golden, CO (United States).

Studer, L., Paglino, V., Gandini, P., Stelitano, A., Triboli, U., Gallo, F., Andreoni, G. (2918). Analysis of the relationship between road accidents and psychophysical state of drivers through wearable devices. Applied Sciences (Switzerland) Volume 8, Issue 8.

Szell, M., Ratti, C., & Santi, P. (2015). Trip sharing in the era of self-driving cars. New York: Marron institute of urban management.

Tajitsu, N. (2017, September 12). Japan trials driverless cars in bid to keep rural elderly on the move. Retrieved March 21, 2018, from Reuters: https://www.reuters.com/article/us-japan-elderly-selfdriving/japan-trials-driverless-cars-in-bid-to-keep-rural-elderly-on-the-move-idUSKCN1BN0UQ

Ticoll, D. (2015). Driving Changes: Automated Vehicles in Toronto. Toronto: UTTRI, University of Toronto.

Vissers, L., Kint, M. S., MSc, I. v., & Hagenzieker, P. M. (2016). Safe interaction between cyclists, pedestrians and automated vehicles. Hague: SWOV Institute for Road Safety Research, The Netherlands.

Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. Transportation Research part A: Policy and Practice, 86(February), 1-18.

Welling, J. (n.d.). Driverless cars are my lifeline. (2. -T. community, Interviewer)

Who. (2015). Global status report on road safety. Geneva: World Health Organisation.

Woyke, E. (2016, October 12). The Blind Community Has High Hopes for Self-Driving Cars. Retrieved March 21, 2018, from MIT technology review: https://www.technologyreview.com/s/602555/the-blind-community-has-high-hopes-for-self-driving-cars/

Zhang, W., & Guhathakurta, S. (2016). Parking spaces in the age of shared autonomous vehicles: How much parking will we need and where? Atlanta: Georgia Institute of Technology.

Zhu, H., & Yang, Z. (2011). Simulation of the aerodynamic interaction of two generic sedans moving very closely. IEEE, 2595-2600.

Zon, N., & Ditta, S. (2016). Robot take the wheel. Toronto: Mowat centre, Ontario Voice on Public Policy.