Autonomous vehicles: Pedestrian heaven or pedestrian hell?

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May 2017

STRC | **17th Swiss Transport Research Conference**
Monte Verità / Ascona, May 17 – 19, 2017

ETH Zürich

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May 2017

Abstract

Autonomous vehicles are an emerging technology that will play a significant role in shaping transport systems in the decades to come. Consequently, implications are anticipated for societal issues ranging from transport safety to congestion, from energy consumption to the allocation of public and private lands. Driverless technology will undoubtedly influence other transport modes, too.

With this in mind, the implications for pedestrians have hardly been researched. If the introduction of driverless cars could ultimately result in the disappearance of on-street parking spaces and in crossing streets without so much as glancing towards approaching cars, this could potentially mean that walking becomes much more attractive. At the same time, one could imagine the opposite outcome if society decides that the ability of being picked up and dropped off at any front door or location imaginable renders walking as a state-supported transport mode superfluous.

The purpose of this paper is to discuss the impact of autonomous vehicles on pedestrian transport in all its aspects, including the range of possible outcomes, interdependencies, and opposing effects. With the state-of-the-art of pedestrian transport research as a starting point, how can the needs of pedestrians be taken into consideration when fully autonomous vehicles become ubiquitous in daily life?

Keywords

pedestrians, autonomous cars, autonomous vehicles, urban planning, transportation policy

1 Introduction

Autonomous vehicles (AV) are an emerging technology that over the last few years has been implemented in advanced testing programs on public roads. The most well known projects are run by Google, Tesla Motors and Uber. The technology is alternatively referred to as referred to as a driverless car, autonomous car or self-driven car. Estimations of when self-driving capability will be the standard in cars range from as early as 2030 (Levinson and Krizek, 2015) to 2040 - 2060 (Litman, 2014).

Legislation for autonomous cars has been passed in a number of countries to allow them on public roads for testing purposes. Self-driving cars were allowed to be legally operated in the U.S. state of Nevada as early as 2011. In policy documents, levels of automation have been defined representing increasing levels of autonomy of the vehicle. This article concerns only the highest level of automation, so-called fully autonomous vehicles (NHTSA-Level 4 (National Highway Traffic Safety Administration, 2013) / SAE-Level 5 (Society of Automotive Engineers, 2014)) which is expected to eventually prevail.

Since the topic is now widely discussed in media and popular culture, it is hardly surprising that many speculative articles on the effect of self-driving cars can be found in popular science magazines and websites (Grabar and Doezema, 2016, Hurley, 2017, Lee, 2014, Plumer, 2014). The two potential benefits of autonomous vehicles mentioned most in the literature are the reduction of accidents and traffic congestion (Forrest and Konca, 2007, Plumer, 2014, LaFrance, 2015).

One issue that is far less clear is the economic and societal effects. Generally speaking experts seem to be divided in two camps. Some believe that car ownership and consequently car use will increase because of the increased accessibility and utility of private vehicles. This scenario would possibly lead to more urban sprawl and the total time spent per person in vehicles. The latter seems obvious since the opportunity cost of time spent in vehicles is drastically lower when, similarly to public transport, time can be spent on other activities while “driving”.

The other "camp" argues shared mobility will drastically increase, eventually displacing actual ownership. This would lead to a decrease in total car usage which could lead to cars being the most efficient transportation mode for commutes and short to average distances in general. (Lee, 2014, Forrest and Konca, 2007). Plumer (2014) suggested a list of arguments used by either side of the discussion.

Apart from the safety aspect, the discussion largely seems to ignore the direct and indirect effects driverless cars will have on walking and cycling, the so-called active transportation modes. One could just as easily envisage a future streetscape perfectly suited for walking – with drastically reduced noise levels and exhaust emissions, and far less space reserved for parking – as a dystopian image where walking is seen as completely dispensable because one can be picked up within seconds by a vehicle at any time.

The aim of this paper is to explore the various effects autonomous cars could have on pedestrian activity and walking attractiveness. First an overview is given of existing literature relevant to this topic. Then the positive and negative effects are presented in a structured way. In the final part of the paper two scenarios are presented, roughly corresponding to the two lines of argument mentioned above.

2 Literature on pedestrians' interactions with autonomous vehicles

Walking- or pedestrian-related literature on autonomous vehicles focuses almost exclusively on the safety aspects of self-driving cars (Chen *et al.,* 2017, Rangesh *et al.,* 2016, Navarro *et al.,* 2016). Other literature focuses on the related topic of ethical implications of having a machine decide what to do in case of unavoidable collisions (Zhao *et al.,* 2016, Fleetwood, 2017, Lin, 2016, Bonnefon *et al.,* 2016). Among the most ambitious ideas are adhesive layers applied to cars to prevent pedestrians from being flung around (Woolf, 2016) or equipping cars with a display to inform pedestrians of the vehicle's intentions (Clamann *et al.,* 2017).

Regarding the effects autonomous vehicles will have on walking attractiveness, the literature is scarce. International Association of Public Transport (2017) carried out a SWOT analysis for autonomous vehicles and used this to give policy recommendations to increase shared mobility. Meyer *et al.* (2017) simulated the effects autonomous vehicles could have on the accessibility of municipalities. They argue that self-driving cars favor urban sprawl and may render public transport largely superfluous. The latter effect would naturally have large implications for the total trips or legs undertaken on foot.

Millard-Ball (2016) employs game theory to research the interactions between pedestrians and self-driving cars. In particular, he finds that cars will be risk-averse, therefore allowing pedestrians to "behave with impunity". He argues that this could cause a shift towards pedestrian-oriented urban neighborhoods. Forrest and Konca (2007) paint a particularly positive picture with timeshared cars prevailing, congestion in cities completely disappearing,

Table 1: Potential positive and negative effects of AV on pedestrians

Area	Potential (dis-)advantage of AV	Impact on the Transport System	Implication for Pedestrians	Positive for pedestrians?
Safety	AV are less error prone than human car drivers, hence fewer accidents occur	Traffic related fatalities and injuries are reduced	Walking becomes safer and thus more attractive	
	AV can detect pedestrians crossing the street earlier and independent of the ROW	As cars will stop or slow down to let pedestrian cross at every location pedestrian crossings are not needed any more	The separating effect of streets is reduced as pedestrians can cross everywhere and cars will stop	
		To prevent pedestrians from abusing the ability of AV to stop at every location, pedestrians are physically blocked from crossing the street at every location to allow an efficient car flow	pedestrians have to take longer detours to cross streets even if no traffic is present. Walking therefore gets less attractive	
Interaction	The communication between the car driver (now a computer) and other road users is more difficult	Rules for communication have to be set up, so that AV "understand" the behaviour of other road users.	Pedestrians need to be trained to properly communicate with AV	
		AV have the ability to understand humans and can react to them in an easy understandable manner	Compared to today, when drivers are usually hardly visible behind the windscreen, pedestrians can better understand the intention of cars	
	AV must detect other road users, determine their reaction and plans and adapt to them	AV have similar rights than today's car drivers. In certain cases other road users get more rights than today, as autonomous vehicles can react better to the surrounding	Crossing streets and walking in shared areas is easier and safer for pedestrians.	
	To allow for a high road capacity and to use the advantages of AV, other road users are banned from the road and allowed only to cross at dedicated areas.	The streets are physically separated into car and non-car areas. Other road users have to adapt to the needs of AV	Pedestrians are further forces to sidewalks and dedicated crossings. The barrier effect of car roads increases.	
Parking	AV are usually shared and do not need parking space within cities and other areas with constricted space. Today's parking space can be used for other purposes	Unused road space can be used for other transport means or non-transport related uses. The public space becomes more attractive.	Pedestrian facilities are wider and do not have to be shared with other transport users (i.e. bikes). The attractive city spaces makes it more comfortable to walk and more shops are available within a short distance	
	AV are mainly privately owned and parked at the destination. As the search for a free parking spot is done by the car, it is more attractive to drive into crowded city centres.	The parking traffic is increased, parking lots are heavily used and more space has to be dedicated to parking	The hindrance of parking cars is increased, the walking environment gets less attractive	
Short trips	the use of AV is easy and they are available everywhere. It is convenient to use AV also for short trips.	pickup areas for AV are present everywhere. As pedestrian facilities are less used their size and quality is reduced. In some areas sidewalks are abolished to provide space for pickup areas	Is it far more convenient to use AV also for short trips than walking there. The quality of the walking environment is strongly reduced walking is only done by people not able to use AV and for recreational purposes outside the city centres. Everyday walking is not needed any more	
	In dense areas, the streets and parking areas are reduced to provide capacity only for local traffic. Other traffic is prohibited and routed around the cities on streets with higher capacity than today.	City centres and other areas with heavy use are released from heavy car traffic but transformed into livable urban spaces, it is more convenient to use walking and bikes for short trips.	Even within the city centres, a pleasant walking environment is available, which increases the amount of walking trips done. Short trips can be easily done by foot.	

Table 2: Potential positive and negative effects of AV on pedestrians (cont.)

Area	Potential (dis-)advantage of AV	Impact on the Transport System	Implication for Pedestrians	Positive for pedestrians?
Accessibility	As no driving licence is needed, almost all people can use AV.	People with disabilites can be provided with the acess to AV, hence other means of transport do not have to provide access for all any more. Only the economically most efficient way of transport will provide barrier free acess.	The role of walking as the only mean of transport which is available for all mobile people is diminished. For cost savings, some walking areas are not designed barrier free, as all trips can be made using AV	
		In regions with challenging topographies, AV can be used as an additional transport possibility. As the vehicle can also be used for only one direction, the AV can for example be used to get uphill whereas the other direction is done walking.	Pedestrians with disabilities can also cover longer trips and unknowns areas, as AV are available as alternative and backup.	
	The time spend in AV can be better used, hence it is equally convenient to also drive longer distances. In addition, the travel speed will be increased due to better road usage of autonomous and connected vehicles.	Cities will be more widespread, the population density decreases. Shops and other facilities orient themselves more towards car users	Less activities are within walking distance, city centres will be less attractive for businesses. The share of walking will be reduced.	
Environmental impact	AV are expected to be electrically driven, which reduces noise and pollution. In addition, the connection between vehicles and the autonomous driving will lead to less energy consuption due to efficient driving and less congestion.	The environmental impact of car traffic will be considerably reduced.	The air quality and noise levels will be improved. Thus the quality of the surrounding for pedestrians will be improved	
	The higher convenience of AV will lead to more use of cars and longer travel distances. Thus the air and noise pollution will be increased.	The negative environmental consequences (except accidents) will be increased.	More car traffic will lead to a worse environmental quality for walking	
Traffic	Car sharing and car pooling is widespread, which leads to considerably less cars on the streets.	Streetspace can be used for other transport means, as the demand for space for cars is considerably reduced.	More space is available for pedestrians which makes walking more attractive.	
	Cars are still mainly privately owned. Apart from additional and longer trips, cars are also used for unattended good transport.	Congestion and the number of cars is similar to today or even worse	The walking environment is dominated by cars	
Lane width	AV can operate within smaller lane widths, as they can follow precicely a predefined track	less roadspace is needed for cars	Space can be used to improve the pedestrian areas	
Traffic speed	AV can operate at higher speeds as reduced reaction times an V2V connections need less safety margins	To allow higher walking speeds, car lanes have to be better separated from other traffic	crossing car lanes is more difficult for pedestrians, the barrier effect increases. Walking is declining	
	As the flow of car gets more efficient, the maximum speeds can be reduced while keeping or reducing the travel times.	The severity of accidents and traffic pollution is reduced	The walking environment gets better due to less noise and easier road crossings	

More on the topic of pedestrians and walk- and bike-friendliness, Bucheli (2016) and Bikeleague (2014) both presented visions and discussions about the implications that autonomous vehicles could have for pedestrians. They conclude, similarly to Sammer and Beckmann (2016) and Schweizerischer Bundesrat (2016), that politics and spatial planning can have a strong impact on how autonomous vehicles will influence the urban form and pedestrian transport.

Based on own analyses, supplemented by additional literature, an overview was compiled in Tables 1 and 2 looking at all possible positive and negative effects autonomous cars might have on pedestrian activity and the walk-friendliness of public spaces. In the following sections these insights will be used to sketch two possible scenarios for pedestrians as they might be created by the increased use of self-driving vehicles.

3 Scenario 1: Pedestrian "heaven"

In this scenario, autonomous vehicles are used in a way which leads to a significant increase in the attractiveness of walking.

To reduce the separating effect of streets with motorized traffic, AV travel within cities and other populated areas with a low speed and enable pedestrians to cross the road safely and comfortably. Due to optimizations based on car-to-car communication and computer technologies, travel times for cars are even shorter than they used to be. In addition, most AV are shared, and thus significantly fewer cars are present in the streets, further reducing travel time and the aforementioned barrier effect.

Reduction of the number of cars as well as more precise driving of AV result in narrower and fewer lanes. On-street parking spaces have almost vanished; what remains are pick-up zones in strategically planned locations. The available space can now be used to build comfortable bike paths and walkways. In addition, sidewalk cafés and other non-traffic uses of the streets are enabled or extended. This provides an attractive streetscape which promotes walking. In addition, the usage of electric vehicles and lower speeds will result in less noise and air pollution, which also improves the quality of walking.

For disabled people the situation improves considerably. First, AV will provide services where other transport means do not offer a viable solution. In addition, pedestrians in general do not have to take heed of cars anymore, as they are always aware of the pedestrians and will give them the right of way. This obviously provides great benefits for the visually impaired.

The most important mechanism driving the improvements of the walking environment in this scenario is the reduction of cars due to AV being a shared service. This will lead to less space demand for parking and driving cars, which then can be used to design pedestrian friendly environments. More space will be available for pedestrians, and the barrier effect of roads is significantly reduced.

4 Scenario 2: Pedestrian "hell"

In this scenario, the breakthrough of autonomous vehicles result in pedestrian transport becoming dispensable and ultimately disappearing.

AV have several benefits compared to today's cars. Almost everyone can use them, parking is easier, as the car can independently find a suitable parking space and the time in the vehicle can be better used. This leads to AV used more often and for longer trips. The better time usability leads to AV becoming office spaces and recreation areas. Everyone who can afford it has a private car, which is regularly sent out by itself to pick up goods from stores. A sharp increase in the number of cars result in a higher demand of parking spaces and road space within cities.

As the car is always available and can be sent to every location, walking is not needed any more. Only people not able to afford AV still walk in populated areas. For recreational walking, people use their AV to go to the countryside or other more remote scenic locations. With the decreasing share of walking, pedestrian infrastructures are reduced or removed to provide space for the increasing car traffic. To increase the efficiency of the AV, pedestrian street crossings are limited to specific places. Physical barriers prevent pedestrians from entering the roads, which further increases the road capacity.

In this scenario, the increase in car traffic due to the benefits of AV will be the key factor. This increase will put more pressure on the distribution of street space towards roads for cars. Other transport means will be less important and therefore less space will be provided for them. Walking for transport is not needed any more, recreational walking is done outside the crowded city centers.

5 Conclusion

The crucial point determining the impact of autonomous vehicles on pedestrians appears to be the question whether vehicles will be mainly shared or kept private in the future. In the first case, the considerable decrease in the number of cars will outweigh the increase in car trips due to the benefits of autonomous driving. In the latter case, more cars will be present in the streets, and in addition each will on average drive longer distances. As the space occupied by road infrastructure is one of the most important limitations in city centers, less space for cars result in more space for pedestrians and non-traffic usages, which increase the quality of the walking environment.

At this point in time it is impossible to predict the exact consequences autonomous vehicles will have on pedestrian activity, in particular in urban environments. The two scenarios described above should be considered thought experiments on what could happen if the initial implementation of the technology kicks off a number of developments that might be hard to stop once set in motion. Obviously a mix of elements of both scenarios seems more likely than either extreme.

Two factors especially will have a large impact but are of yet difficult to estimate: To what extent will drivers be prepared to let go of the (for many desirable) feeling of being in charge of the vehicle and to what extent will car owners accept shared ownership or even fleets that are completely controlled centrally. The consequences to traffic safety on the one hand and public space (in the form of disappearing parking spaces) on the other could be enormous. If the general public and by extension policy makers are to have an influence in these matters, planning and lawmaking for future scenarios should be started right now. The aim of this paper is to facilitate public discussion about which outcomes are desirable.

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