The impacts of autonomous vehicles on urban road infrastructures

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Autonomous vehicles are leading to a significant revolution in road transportation systems, with enormous challenges to mobility through several vectors, e.g., economic, legal, social, psychological, and technological. This paper deals with the expected impacts of autonomous vehicles on road infrastructures of old urban centres.

Introduction

Autonomous vehicles (AVs) are vehicles that can move automatically and independently of human intervention. There are five automation levels associated with these vehicles: Levels 1–5. Levels 4 and 5 are the highest levels of automation, corresponding to a complete automated driving system (SAE International 2016). The penetration of AVs in road traffic will be a major revolution in road transportation in general (Bunghez 2015, Meyer et al. 2017). Besides the uncertainty inherent in predictions, it is consensual that AVs will affect future mobility and accessibility through several vectors, e.g., economic, legal, social, psychological, and technological (Bunghez 2015, Litman 2018, Meyer et al. 2017). Most critical aspects of AVs implementation are currently related to either technology developments or road environment interactions that are generally complex and present additional risks and costs (Hulse et al. 2018, Rathore 2016). In the case of urban environment, the relationships between AVs and users (e.g., motorcyclists, cyclists, and pedestrians), equipment (e.g., barriers, signals, and other urban furniture), and infrastructure design (e.g., bus stops, parking areas, pedestrian zones, and street features) become more important to avoid issues with safety, efficiency, and performance (Duarte and Ratti 2018, Hulse et al. 2017, Montanaro et al. 2017). The particularities of old urban centres (e.g., high volumes of road users, high density of equipment, and reduced and irregular infrastructure geometry) lead to additional impacts on AVs and on the need for significant transport policies and planning to be accounted for by municipalities (Fagnant and Kockelman 2015, Metz 2018). This paper has the objective of making a reflection on the expected impacts of autonomous vehicles in road infrastructures of old urban centres in terms of planning and design, traffic management, equipment, users, and environment.

Methodology

A case study of an old urban centre was selected to model different realisations of AVs and consequently to overcome the impossibility and complexity of analysis in real conditions (Lang et al. 2017). The historical centre of downtown Lisbon was chosen, considering that its main characteristics are very representative of old cities of the south of Europe, with typical planning and design. This area, called "Baixa Pombalina," is the main tourism, shopping, and banking district of the city, characterised by intense vehicle and pedestrian traffic, with an enormous impact on traffic congestion and air pollution (Velez, 2018).

The model of this area was performed using PTV Visum software and considering the following transportation modes: private vehicle (car), AV, public bus (bus), and pedestrians (walking). The model considered different scenarios of AV penetration: Scenario 1 corresponded to the current traffic flows related to private and public transport modes (cars and buses); Scenario 2 was characterised by the total removal and replacement of the car mode, i.e., the transportation system consisted of AVs, with the same permissions as the car mode, and buses; Scenario 3 consisted of the total sharing of the same route between the AVs and the car mode, i.e., the AVs circulating in mixed traffic; in Scenario 4, the AVs mode was only allowed to travel in a special lane (in parallel with the bus lane), not crossing the same lane as the car mode. Only over ground modes of transport were considered in the model, regarding that in this area there are two underground subway lines. Velez (2018) describes the network (links, nodes, zones, and connectors) in more detail and demands a model of the case study zone.

The model intends to point out the challenges of AVs in the road infrastructures of the case study zone at different relationship levels: planning and design, traffic

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management, equipment, users, and environment (Figure 1).

Road infrastructure

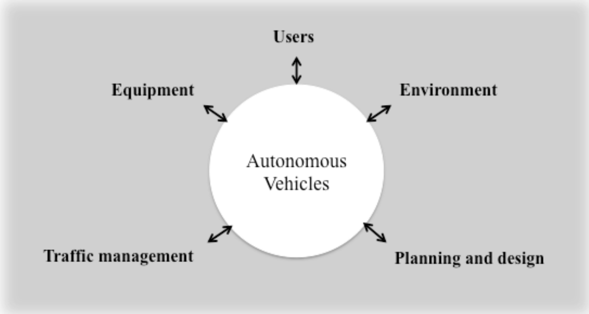

Figure 1. Relationships between AVs and urban road infrastructures

Source: Authors' own compilation

Results and discussion

Planning and design changes to road infrastructures will be necessary in order to ensure the efficiency and safety circulation of AVs in urban centres.

Two perspectives of including AVs in the traffic of urban centres can be implemented: the AVs have a shared or taxi function with the ability to pull over and safely pick up or drop off passengers and then return to the traffic flow with a new route; the AVs have a valet capability, and after leaving the passenger and avoiding wasting time for its user, will have to find a parking place and pick up its user again at the end of the workday. In both cases, unless the street layout is suitable for executing these maneuvers without disrupting the normal traffic flow, specific zones should be created for this purpose. This could be more critical in the case of intermodal interfaces.

AVs can move more accurately in narrower lanes. However, in a mixed traffic scenario, vehicles with a human driver will be conditioning. The presence of AVs will increase the street capacity, mainly due to the low speed and reduced headways of vehicles (more effective in platoons) in the traffic flow. AVs can also be managed with more efficiency in intersections and can perform curves with reduced curvature radii. However, the ability to detect the vehicles in proximity continues to be important. This will require the navigation and communication systems to be perfectly functioning, leading to a central physical and digital system that manages this information.

If an exclusive AV lane is intended, similar to a bus lane, it would be necessary to adapt the existing number and width of lanes on the street. Additional difficulties can emerge from this. It may be unacceptable to take away public space, limiting or even preventing the creation of an AV lane in that way. If it is decided that AVs will share the bus lane, problems and collisions with human drivers may occur, because there is no physical barrier, only a formal one (which is often not respected by other drivers).

Looking at the relationship between AVs and road infrastructure, a radical scenario characterised by completely closing roads off to regular car traffic, except for AVs or cars with a minimum of Level 3 autonomy, could induce great inconveniences and may appear as the most prudent scenario. In the short or medium term, depending on the importance and representativeness of services, businesses, housing, the enormous movement of people and goods, and the sweeping renewal of the car fleet by the residents, this could represent a huge inconvenience to the citizens and a profound economic impact with enormous negative repercussions.

For example, lanes for platooning on the freeways are stipulated. However, in an urban environment, the creation of isolated streets or neighborhoods that are exclusively for AVs can be considered. In these cases, a physical barrier to divide pathways should be created. To guarantee the current volumes of traffic, and regarding a long-term scenario, the need to replicate the infrastructure specifically for AVs seems reasonable.

In contrast, in a scenario where human and nonhuman drivers coexist or even vehicles with varying degrees of autonomy (Level 0 to 5), the possibility of collision is real, because humans have disruptive behaviors, and even the vehicles themselves have different capacities and degrees of autonomy. Moreover, to ensure the coexistence of these completely different types of drivers, a near duplication of the infrastructure or a substantial reinforcement of the existing one would be necessary to guarantee safe conditions for AVs.

The implementation of platooning on AVs driving could be very harsh on the road surface. The inexistence of a lateral wheel wander can induce significant damages to the road surface structure. The construction and maintenance of road surfaces that are more resistant to permanent deformations deserve more attention.

Classical traffic management will be changing with AV implementation, due to the need for connectivity between vehicles and infrastructures. Traffic signs, marks, and lights will undergo a great evolution, and change and will need to become more digital. Vertical signals would be redundant, complemented by a central traffic control system to support the navigation and communication with AVs. An irregular road network may be confusing for AVs and may result in collisions with other modes. The lines on the pavement surface need to be perfectly defined and in good condition to achieve the allocation and correct movement in the respective lanes. It is essential that the road surface is in perfect condition and that the horizontal markings are maintained regularly.

Numerous and diversified equipment (barriers, signals, and other urban furniture) in the proximity of AVs lanes should be analysed in order to always guarantee the efficiency and safety of the AVs. In a scenario in which electric cars are highlighted, as is already happening in several cities, it would be a good idea to associate parking spaces with charging points for vehicles.

Old urban centres are characterised by having several road users (motorcyclists, cyclists and pedestrians) in conjunction with traffic vehicles. The AVs could be circulating in dangerous conditions, because the road is shared with human drivers (vehicles, motorcycles, cyclists, heavy trucks, buses), and there is still a considerable number of pedestrians on the nearby pavements. With a great number of warning signals given by the various moving elements, the AVs would probably reduce their speed, and may even stop completely, potentially leading to an eventual accident. To avoid this situation, using physical barriers between vehicles and pedestrians can minimize the scale of alert.

The use of AVs as shared vehicles or as a taxi service leads to a significant reduction of the total number of vehicles circulating in the urban centres. This reduction and the fact that AVs will probably be mainly electric, will contribute to the general reduction of air pollutant emissions in urban centres, substantially improving the air quality.

The various scenarios modelled in the case study have confirmed general benefits on the AVs implementation in urban centers. There was a general tendency for the increase of AVs speed in congested traffic in Scenario 2. For the case of mixed traffic (Scenario 3), an increase of speed in both transport modes was obtained. For Scenario 4, AVs had a significant decrease in speed due to the AV corridor. Regarding CO2 emissions, the modelling has showed the most significant decrease, at 83%, in the case of Scenario 2.

The difficulty in implementing AVs in urban environments is still a reality. Changes and improvements to infrastructure will be necessary for the integration of AVs. While on the one hand it is difficult to change the existing infrastructure to create sharing conditions, it is even more difficult to guarantee safety for various participants. In the current state of technology, it would be a challenge to guarantee operational levels in mixed traffic, without too much caution also becoming a reason for congestion. Moreover, there would be a need for a strong initial investment in a digital infrastructure that guarantees centralised traffic management, making the navigation and communication of the vehicles in the city possible. The scenario that would allow for a greater space, for the benefits of AV to stand out, would be in an exclusive scenario for its movement, which for now is very difficult, if not practically impossible.

Conclusions

The current knowledge about AVs is still cause for uncertainty about the implications that AVs will have on the future of mobility and accessibility. However, technical advances that are in progress may predict major changes in the near future. It is expected that most of the current legal, social, psychological, and technological issues will be overcome soon.

In the particular case of old urban centres, the presence of AVs will have a positive impact on road infrastructures: the reduction of traffic congestion, the improvement of air quality, and the increase of traffic safety and infrastructure capacity. All these benefits are aligned with fundamental societal goals, such as decarbonisation or an inclusive and circular economy.

Despite the intention to objectively clarify the adaptations needed for road infrastructure for the use of AVs, this is still a difficult task at present. However, it is possible to confirm that the major changes in infrastructure will be at a digital level, not only in the physical infrastructure. In fact, the urban road infrastructures will be more digital, more connected to and from AVs, through intelligent traffic coordination at street intersections, and vertical and horizontal digital signals. The existence of a traffic management system will allow the aggregation and orientation of the various vehicles in a single stream of traffic. In fact, the connectivity of vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) allow for optimization of the traffic flow in comparison with the current reality.

These infrastructure changes will require public investment and planning. Because a period of adaptation of the market to the AVs is foreseen, it is also considered that there will be a redundancy in the infrastructure that will allow the coexistence of both AVs and nonautonomous cars. However, regarding the technological requirements of AVs to monitor the surrounding environment, the need for a well-maintained road network will be essential. In this sense, it is expected that in urban areas the adaptation may take some time, due to the greater fear of integrating the AVs into a more problematic environment.

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