# Road infrastructure requirements to accommodate autonomous vehicles

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# ROAD INFRASTRUCTURE REQUIREMENTS TO ACCOMMODATE AUTONOMOUS VEHICLES

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## Abstract

In the last few years, an increasing amount of research has been dealing with the development of autonomous vehicles (AVs). With the increasing deployment of the AVs on the roads over the years it is necessary to adapt road infrastructure to accommodate them. This paper gives an insight into the impact of AVs on the road infrastructure such as horizontal and vertical alignment, and dimensions of cross section elements. The implementation of the AVs into the road network will not depend just on the preparation of road infrastructure but also on the future development of vehicle automation and the proportion of AVs according to conventional vehicles (CVs) into the vehicle fleet. Therefore, according to AVs proportion into the fleet, three different scenarios for road infrastructure upgrades are given. Finally, the advantages and disadvantages of the introduction of AVs regarding the requirements for existing and future road infrastructure are discussed.

*Keywords: autonomous vehicles, road, infrastructure, integration of AVs*

## 1 Introduction

European Union promotes sustainable development for over 20 years. Sustainable development is defined as balanced development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. European Commission brings a Strategic Plan for the period 2021-2024 with the vision of a sustainable, safe, fair, and prosperous future for people and the planet. The current European Union R&I Framework Programme Horizon Europe for 2021-2027 is supposed to accelerate the achievement of climate and digital goals, while the European higher goal is to achieve climate neutrality by 2050. One of the Horizon Europe Mission is climate-neutral and smart cities [2]. Smart mobility, e-mobility, smart parking, and autonomous mobility solutions are an integral part of smart cities [3].
Autonomous vehicles (AVs) are the future of transportation. An autonomous vehicle is a self-driving car, a vehicle capable of sensing its environment and operating without human involvement which means that a human passenger is not required to take control of the vehicle at any time, nor is a human passenger required to be present in the vehicle at all. These vehicles are equipped with sensors like RADAR (Radio Detection and Ranging), LIDAR (Light Detection and Ranging), ultrasonic sensor and wheel speed sensor, cameras, GPS (Global positioning system) whose purpose is to register, collect, analyse, and share data about the surrounding environment [4]. The environment in which these vehicles will operate should be standardised, unambiguous and very active, to provide real-time data. Six levels of driving automation are defined to understand the need for human intervention and improvement of technology of automated systems (Table 1) [5]. As the level of automation increases the responsibility for performing driving task shift from driver to the vehicle [6].

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**Table 1** Classification of driving automation [6]

| No | Level Name | Driving task | | Response to failure | Operation area |
|---|---|---|---|---|---|
| | | Lateral & longitudinal control | Monitor surroundings | | |
| | | Driver perform part or all of the driving task | | | |
| 0 | No driving automation | Driver | Driver | Driver | N/A |
| 1 | Driver assistance | Driver & System | Driver | Driver | Limited |
| 2 | Partial driving automation | System | Driver | Driver | Limited |
| | | System perform the entire driving task | | | |
| 3 | Conditional driving automation | System | System | Driver & System | Limited |
| 4 | High driving automation | System | System | System | Limited |
| 5 | Full driving automation | System | System | System | Un-limited |

Still unknown is the time when level 5 vehicles will penetrate the market with proven reliability and regulatory approval by governments [3]. The prediction shows that around 2030s AVs fleet proportion will reach 20 %, and by 2050s it will reach 50 % when in 2070 AVs will be only vehicles on the road [6]. With the increasing deployment of AVs on the roads it is necessary to review, update and develop policies and guidelines for road infrastructure.
Several European countries fund research projects, tests, and demonstrations, explore regulatory aspects and set strategies and action plans for autonomous mobility (Table 2) [1].

**Table 2** Research projects in Europe [7]

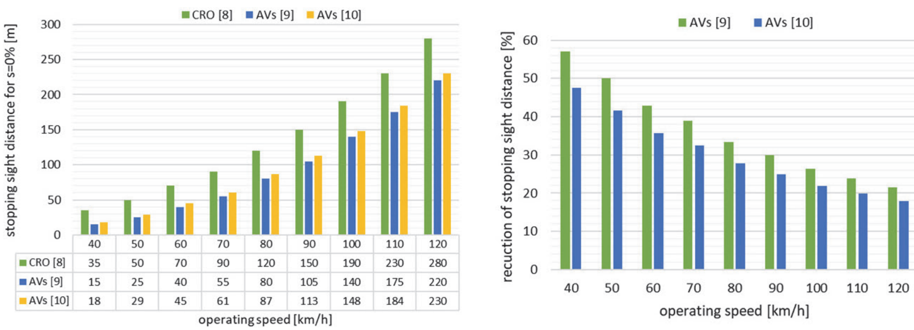
| Project | Dates | Countries | Description | Funding |
|---|---|---|---|---|
| DiREC | 01/09/2021 – 31/08/2023 | UK, Netherlands, Sweden, Finland | Digital Road for Evolving Connected and Automated Driving | CEDR |
| FRONTIER | 01/05/2021 – 30/04/2024 | Belgium, Greece, UK | Next-generation traffic management for empowering CAVs integration | EU H2020 |
| ESRIUM | 01/12/2020 – 30/11/2023 | Austria, Finland, Italy, Hungary, Spain | EGNSS-based digital map of road damages and safety risks for smarter, safer and greener road infrastructure usage | EU H2020 |
| DIGEST | 01/10/2020 – 30/09/2022 | Germany, Austria | The DIGEST project aims at developing and validating an integrated digital twin for the road traffic system | MS |
| Accurate | 01/09/2020 – 31/08/2023 | Spain, France, Germany | Next generation positioning OBU for enabling highly automated driving | Fundamental Elements, EUSPA |

# 2 Road infrastructure requirements

To enable integration of AVs, from a system of CVs to a mixed traffic system of AVs and CVs, and finally to a system of only AVs, upgraded road infrastructure will be required in the different driving environments - urban and suburban. Urban spaces are more observed in the earlier phases of deployment of AVs, while the infrastructure in suburban areas will reach its upgrade with the majority of AVs in the road network.
In the following text, the main road infrastructure requirements for AVs are described and compared with current road design standards from Croatia [8].

## 2.1 Main design parameters

Main design parameters according to the Croatian rulebook [8] are relevant vehicle speeds, friction coefficients, cross slope, and stopping sight distance. Three relevant vehicle speeds are considered: design speed, operating speed, and speed defined by a traffic sign. None of these speeds is expected to change with AVs on the roads and the AVs are supposed to obey the speed limits set by the traffic signs.
According to [8], stopping sight distance represents the sum of distance travelled during the reaction time and distance travelled during the braking. Reaction time for the human driver is 2 seconds. When it comes to AVs, the vehicle will react faster. According to [9], reaction time could be reduced to 0,2 s, but [10] suggests the time of 0,5 s. Consequently, with the reduction of the reaction time, stopping sight distance will be also reduced. Fig. 1 presents the comparison of stopping sight distances for different reaction times, the ones prescribed by Croatian regulations [8] (for CVs), and the ones predicted in previous research [9,10] (for AVs), for 0 % grade. As it can be seen from Fig. 1, the stopping sight distances for AVs could be significantly reduced compared to those for CVs, especially at lower operating speeds.
The impact of friction coefficients and cross slope on the road infrastructure for AVs was not analysed in the previous research.




| | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
|---|---|---|---|---|---|---|---|---|---|
| CRO [8] | 35 | 50 | 70 | 90 | 120 | 150 | 190 | 230 | 280 |
| AVs [9] | 15 | 25 | 40 | 55 | 80 | 105 | 140 | 175 | 220 |
| AVs [10] | 18 | 29 | 45 | 61 | 87 | 113 | 148 | 184 | 230 |

**Figure 1** Stopping sight distance: a) for different reaction times for CVs and reduced for AVs; b) reduction of its length

## 2.2 Horizontal alignment

According to [8], horizontal alignment consists of straight segments and horizontal curves. Long straight segments are not recommended for use as they can make a driver feel tired and the driver can be disturbed by the blinding lights of the vehicles from the opposite direction of travel. Their application is allowed in justified cases and restricted to a maximal length of the value of design speed multiplied by 20 [8]. When it comes to AVs, this limitation can be relaxed because of their self-driving ability, i.e., a human passenger is not required to take control of the vehicle [10].

Minimal horizontal curve radius depends on the design speed, cross slope, and coefficient of side friction [8]. As stated in the previous chapter, in the AVs era design speed is not supposed to change in future, and the cross slope and friction coefficients are not observed in existing literature as the parameters that could affect the driving style of AVs.

## 2.3 Vertical alignment

According to [8], a minimal crest curve radius depends on the required sight distance between the vehicle (driver's eye) and the invisible part of the obstacle on the other side of this curve. The height of the driver's eye is set to 1,0 m from the ground, and the height of the invisible part of the obstacle depends on the operating speed (0,25 – 0,20 m). The requirement for the minimal sag curve's radius is at least half of the radius of the adjacent crest curve.
AVs will use LIDAR technology and the driver's eye will be replaced with the sensor. The position of the sensor could vary from one manufacturer to another. According to [10], in the Waymo vehicle (a self-driving car by Google) the height of this sensor is set to 1,84 m. This value includes the height of the vehicle which is 1,56 m and the height of the sensor which is 0,28 m. The height of the obstacle is not supposed to change.
Consequently, with the AVs on the roads, the minimum radii of the crest and sag curves can be reduced due to the following reasons: firstly because of the increase in driver's eye/sensor's height, and secondly due to the reduced length of stopping sight distance.
Fig. 2 presents the comparison of the minimum crest curve radii, according to Croatian regulations [8] (for CVs), and reduced crest curve radii derived from new reaction time of 0,5 s, and new driver's eye/sensor's height of 1,84 m given in [10] (for AVs). Stopping sight distance was calculated with a 4 % grade. As it can be seen from Fig. 2, the crest curve radii for AVs could be significantly reduced compared to those for CVs, especially at lower operating speeds. Tangent grade values were not analysed in the previous research.

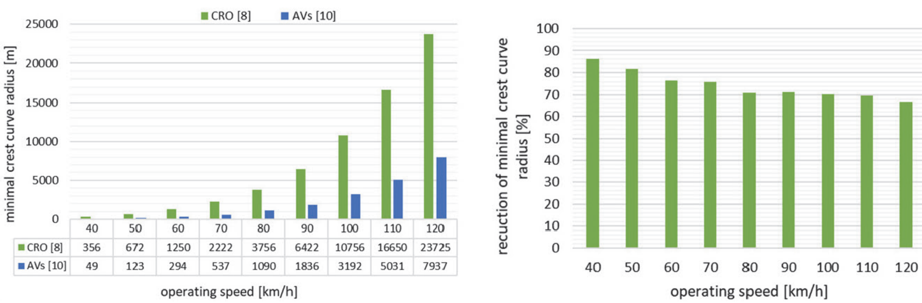



**Figure 2** Crest curve radii: a) for CVs and reduced for AVs, b) its reduction

## 2.4 Cross section

With the higher deployment of AVs, it is expected to have special AV dedicated lanes on the roads in the early stage, while in later stage CVs and AVs will travel together along the new road infrastructure. According to the Croatian rulebook [8], lane width depends on the design speed (2,75 - 3,75 m). As stated in [10], multiple studies in the literature predict that the minimal value of lane width for AVs can be reduced up to 2,4 m. This follows the data from [9], that travel lanes in which buses and big trucks do not run can have lane width reduced to 2,4 - 2,7 m. It is also stated that 20-25 % of reduction in current lane width can be done [9].
Fig. 3 presents separate lane for AVs and the comparison of the lane widths prescribed by [8] and lane widths for AVs reduced for 20 % [9], with the minimum of 2,4 m [10].

Finally, cross-sectional dimensions are expected to change in the future because of the reduction in lane width. By using the Lane-Keeping-System (LKS), which enables AVs to operate continuously in the middle of the lane, the required lane width could be reduced because of reducing safety lateral width used to enable safety buffer between vehicles [11].

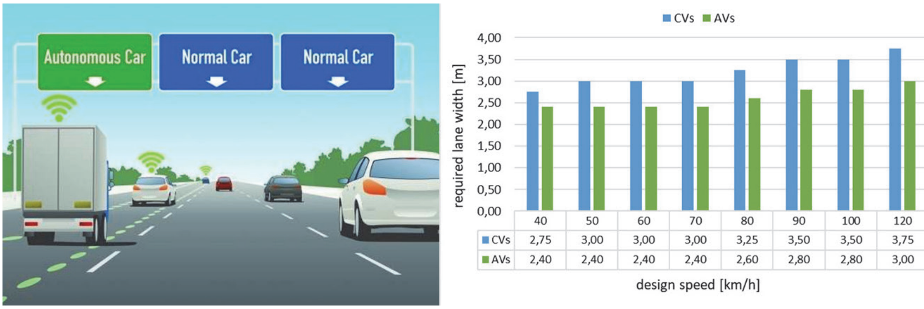



**Figure 3** Lane width for AVs: a) separate lane for AVs [12; b) comparison of the lane widths prescribed by [8] and reduced lane widths for AVs [9-10]

## 3 Integration of AVs into the road network

The implementation of the AVs into the road network will depend not just on the preparation of road infrastructure, but also on the future development of vehicle automation and the proportion of AVs according to CVs into the vehicle fleet. Based on timeline prediction and the upgrade standard, a three-phase transition plan is proposed [6], shown in Table 3. For each phase, it assigns different road infrastructure upgrade work.

**Table 3** A three-phase transition plan [6]

| Phase | Start time | AVs proportion | Upgrade standard |
|---|---|---|---|
| 1 | now | <20 % | maintenance |
| 2 | The 2030s | 20-50 % | segregation |
| 3 | The 2050s | >50 % | simplification |

Phase 1 is ongoing and should end sometime in the 2030s when level 2 automation become dominant. Today, all road policies are suitable for automation level 0, no driving automation. Upgrade standard of this phase includes maintenance of existing road infrastructure for the safe operation of the CVs and building digital communication facilities to support vehicles with a lower level of automation [6]. As the number of AVs in the vehicle fleet increases, the safety of the system will grow. A major increase in safety will happen with the reach of 25 % of AVs in the fleet. Traffic congestion will reduce with the reach of 5 % of AVs in the fleet. The reduction of vehicles could be expected due to sharing vehicles, increased mobility for elderly or underaged or disabled users as well as economic benefits. These are benefits that will be seen despite no significant change in the environment [11].
Phase 2 is the most complex stage with mixed level vehicles on road. In the first place, governments must release new laws and regulations to define rights and especially responsibility in accidents [6]. It is likely that driver liability will decrease, while road authority or manufacturer liability will increase [13]. Then, new road facilities must be built to reduce conflicts between AVs, CVs, and other passengers to ensure safety. Flexible design such as building AVs compatible parking spaces is required [6]. Furthermore, AV dedicated road infrastructure will increase the benefits experienced by AV users. The segregation will ensure

fast travel times and could improve efficiency. On the other hand, with the restriction of lanes to general traffic and by allowing only AVs to use them, overall capacity could be negatively impacted [11]. Above all, existing facilities such as road signs and traffic signals must remain in this phase [6].

Phase 3 starts with the majority of level 5 vehicles on road. Some scientists predict that in this phase unmanned busses and shared driverless taxis will be cruising around, so the number of privately owned vehicles will decrease. Transportation pollution will be reduced as electric vehicles or other clean-energy-powered vehicles will grow rapidly. It could be expected that the road infrastructure will become simpler, making the road less complex. For instance, multiple road markings and traffic signals could be replaced by a single digital communication beacon, very few or no parking spaces appeared in the city centre, most service stations replaced by charging stations etc. [6]. All of this could be considered as a benefit but establishing a system with these infrastructure requirements could be a challenge. The system requires fundamental change and an entirely new road system to be built [11].

## 4 Discussion and conclusions

The implementation of the AVs into the road network will depend on the future development of vehicle automation, the proportion of AVs and CVs in the vehicle fleet and the preparation of the existing road infrastructure. The existing infrastructure is expected to change through three transition phases which will differ considering the proportion of AVs and CVs in the traffic network. A review of previous research from the subject area was made and the parameters which may directly influence the geometric design of future road infrastructure for AVs were analysed.

It was concluded that the values of relevant vehicle speeds, friction coefficients and cross slope should not change and that the stopping sight distance could be notably reduced due to the shorter reaction times (0,2 s, 0,5 s) compared to the reaction time given in current Croatian regulations (2 s). For example, for an operating speed of 40 km/h stopping sight distance could be reduced up to 57 %, and for an operating speed of 120 km/h up to 21 %. This could affect the horizontal and vertical visibility, as well as the values of vertical curve radii. Another parameter that could affect the values of vertical curve radii is the position of the AVs sensor (1,84 m), which is planned to be higher than the driver's eye (1 m). Consequently, the minimum crest curve radii could be significantly reduced compared to those given in Croatian regulations: for an operating speed of 40 km/h the value of this radius will be reduced up to 86 %, and for an operating speed of 120 km/h up to 67 %. Cross-sectional dimensions could be also reduced because of the planned reduction of the lane width which could amount up to 25 %. All these changes may lead to a better adjustment of the road alignment to the topography and the reduction of earthworks during the construction process.

However, the question is how will this "simplification" of the road infrastructure affect the driving mode of CVs and AVs with a lower levels of driving autonomy, as well as the traffic safety of human drivers, passengers, cyclists, and pedestrians. As mentioned before, this last (third) transition phase, with "simplified" road infrastructure and the majority of level 5 AVs on road, is expected to be the most challenging for road designers and other traffic experts. In the light of all the above, in further research, the influence of the road infrastructure for fully autonomous AVs on the driving mode of other vehicles in the traffic network and the traffic safety of other traffic participants should be analysed.

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