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PARTICIPATION OF AUTONOMOUS VEHICLES IN REAL-LIFE TRAFFIC: AN ASSESSMENT OF THE BEHAVIOUR OF ROAD USERS

Vladislav Kondratovič, Jurgita Rimkuvienė, Donatas Čygas
Vilnius Gediminas Technical University, Faculty of Environmental Engineering, Department of Roads, Lithuania

Abstract

Self-driving vehicles, also known as autonomous vehicles (AVs) are gradually making their way into real-life scenarios. In Lithuania, there has been significant progress in the field of transport, particularly in the development of autonomous car technology within the road transport sector. A legal framework has been established to define the conditions and processes for the participation and testing of AVs in public traffic. However, integrating AVs into real-world environments necessitates a deeper analysis of the changing interactions between autonomous technologies and human-driven vehicles. This is crucial for identifying potential trends and consequences of such interactions. Drivers commonly make various mistakes due to distractions, fatigue, inexperience, and other factors. In traffic scenarios where two or more vehicle units or road users participate, each must consider the others to avoid potentially dangerous situations. In traffic involving AVs, communication with other road users becomes more challenging. This is not only due to the complex technical aspects of autonomous systems but also factors such as the absence of eye contact, which hinders the prediction of the intentions of all road users and the execution of safe manoeuvres on a case-by-case basis. This article explores the interaction between AVs and other road users. It assesses the significance of different infrastructure elements for AVs traffic, which influences the successful integration of AVs into real traffic alongside human-driven vehicles.

Keywords: road infrastructure, autonomous vehicle, real-life traffic

1 Introduction

The integration of AVs into real traffic marks an era of transformation in the field of transportation. This technological leap, while promising to improve travel efficiency and safety, also introduces a new dynamic in the interaction between AVs and other road users. Analysing and evaluating these interactions is crucial for the efficient and safe integration of AV into the overall transportation system.

The interaction between AVs and other road users represents a complex and multi-layered system, demanding multidisciplinary solutions. This encompasses the development of AV technology, the adaptation of road infrastructure, the study of people's behavior in various situations, the establishment of appropriate legal and regulatory measures, ensuring road safety for all users, and building public confidence. Australian scientists [1] have discussed the multifaceted challenges and opportunities in transitioning to autonomous transport, ranging from engineering and politics to urban planning, and shifting towards a more adaptive approach for environmental and social acceptance. As AV technology continues to evolve, it is imperative to address all relevant aspects comprehensively to ensure the safe and efficient integration of AVs into real traffic. Recent studies indicate that the main factors influencing public opinion on the development of autonomous vehicles are safety, reliability, and economic benefits. The analysis of AV reliability has raised serious concerns about their ability to adhere to road traffic rules without failure. For instance, there was a 99.94% probability that AVs would not comply with at least one traffic rule over a 20-minute driving period, raising concerns about road safety [2]. These studies also highlight the economic and environmental benefits of AVs, such as increased road throughput, reduced emissions, and safer travel by decreasing the number of accidents caused by human errors [3].

One of the primary challenges in developing AV technology is ensuring their ability to make real-time decisions, akin to a human driver. The decision-making process in AVs is critical, encompassing a wide array of complex interrelated components, including sensors, information processing units, algorithms, and control systems.

The integration of AVs into the road network depends not only on the development of road infrastructure but also on the evolution of vehicle automation and the ratio of AVs to conventional vehicles in traffic. Researchers have proposed three different scenarios for upgrading road infrastructure based on the AV share in the vehicle fleet. They discuss the advantages and disadvantages of deploying AVs, considering the requirements of existing and future road infrastructure [4].

AVs are equipped with advanced sensory systems and software algorithms that enable them to recognize and respond to various objects in the environment. The accuracy and reliability of these technologies, along with the proper development of the infrastructure, are vital to ensuring the safe interaction of AVs with other vehicles and road users. Despite state-of-the-art technological advances, AVs still face challenges in complex traffic situations. These include understanding the behaviour of human drivers and operating in areas with intense pedestrian movement, necessitating the adaptation or maintenance of appropriate infrastructure. Researchers emphasize the need for continuous innovation in AV sensor systems and software to address the challenges of a dynamic and unpredictable traffic environment [5].

The necessity for AVs to understand and interact with existing road infrastructure is crucial for their successful deployment. M.M. Rana and K. Hossain highlight in their research that AVs must be adapted to the infrastructure primarily designed for driver-controlled vehicles [6]. This indicates that AV systems should be capable of accurately interpreting road signs, signals, and markings.

Moreover, the road infrastructure itself may require enhancements to better accommodate AVs. As noted by Lengyel, Tettamanti, and Szalay, integrating AVs into real traffic necessitates a parallel evolution of road infrastructure to ensure compatibility and safety [7]. This could involve implementing intelligent transportation systems, upgrading transportation infrastructure, and optimizing traffic management mechanisms to foster an AV-friendly environment.

In conclusion, the relationship between AVs and road infrastructure is dynamic and continually evolving. The way vehicles interact with the road environment, the need to adapt existing infrastructure for autonomous driving, and the broader impact of AVs on traffic efficiency, safety, and sustainability must be meticulously examined.

Despite significant advances in AV technology, considerable challenges remain in their practical application within real traffic. This study aims to address these gaps by developing an assessment model that identifies and analyses key components of the road ecosystem critical to AV traffic. The model will focus on benchmarking, assessing how different elements of the traffic system interact with AVs. This model will not only enhance our understanding of the compatibility of the current road ecosystem with AVs but also provide valuable insights for making informed decisions about the smoother integration of AVs into real traffic.

2 Compilation of the list of components for the study and its evaluation

2.1 Compilation of the list of components

After conducting a review of existing scientific literature, it was determined that the main elements of the road infrastructure ecosystem influencing the integration of AVs into traffic include not only road design components and a good internet connection but also proper road maintenance [8]. It has also been noted that AV performance necessitates a reliable understanding of road markings and traffic signs [9].

To create an evaluation model for several ecosystem components, which would allow the determination of the most crucial components for AV traffic, a list of several ecosystem elements was compiled:

1. Standard road signs are conventional, non-electronic signs that provide information, warnings, and rules about road traffic. They are essential for both human drivers and AVs to comply with traffic safety requirements and navigation. For AVs, the legibility and visibility of these signs are crucial.
2. Static and dynamic digital road signs are road signs that provide drivers with dynamic information, adapting to traffic conditions, weather, or emergency situations in real-time. The AV’s ability to read them and respond to changing signals is vital.
3. Horizontal road markings are white or other coloured lines, arrows, inscriptions, and symbols on the road surface that dictate certain traffic modes and orders. These markings provide important instructions regarding lane divisions, turns, and directions of traffic flows. Clear and well-maintained road markings are essential for AVs to accurately detect lanes and positions.
4. Delineator posts are traffic control devices used on roads and highways to indicate road boundaries and edges, and in some cases, traffic lanes. For AV traffic, these visual markers are necessary to define the driving path and are used as an important additional source of information to ensure accurate vehicle localization and manoeuvring.
5. Urban planning significantly impacts traffic flow and road safety. Urban design must meet specific requirements for autonomous navigation, such as dedicated lanes or zones, sensor-friendly infrastructure, and integration with smart city systems. Effective urban planning can increase the efficiency and safety of AVs by facilitating their interaction with conventional vehicles and other road users.
6. Digital virtual road infrastructure is a digital representation of the physical road environment, crucial for advanced AV navigation. This includes detailed maps, traffic flow data, and environmental conditions. A reliable and constantly updated digital infrastructure is essential for AVs for accurate route planning and obstacle avoidance, especially in challenging urban conditions.
7. Road maintenance strategy is a long-term plan for permanent road maintenance works to ensure safe traffic and the expected lifespan of the road and its structures. Regular and effective road maintenance is vital for safe driving conditions, ensuring that road conditions remain optimal for AV sensors and algorithms, and reducing the risk of breakdowns or crashes due to infrastructure issues.
8. The impact of AV “platooning” on infrastructure – “Platooning” refers to a group of AVs traveling closely together at high speeds, improving traffic flow and fuel efficiency. This component examines how “platooning” affects road infrastructure, such as road deterioration and the need for wider lanes or dedicated corridors.

The main reason for selecting the listed components is their direct impact on the efficiency and reliability of AV technology. AVs rely extensively on external cues from the road environment to navigate safely and efficiently. Additionally, the chosen components reflect the dynamic and ever-changing traffic environment, which is crucial since AVs need to adapt to traffic changes in real-time. The selection of components was driven by the necessity to understand and optimize the complex interactions between AVs and their operating environment, ensuring safe, efficient, and sustainable integration of AVs into the road ecosystem.

2.2 Component estimation using the Kendall Method

The list of described 8 components was presented to experts for evaluation, asking them to determine the significance of the presented components with points. The experts were selected based on their work experience (no less than five years), position at their workplace (division level and higher) and academic degrees (Master's degree and higher) in fields related to the study, without regard to gender or age. The expert group consisted of professionals working in Lithuania in the areas of innovation, Intelligent Transport Systems (ITS) and Cooperative Intelligent Transport Systems (C-ITS), electronic communications, as well as AV legislation and policymaking. Individually interviewed experts (hereafter referred to as E1-E13) provided their assessments of the importance of several ecosystem components (hereafter referred to as Q1-Q8) for AV traffic, using their personal expertise, experience, qualifications, and intuition. These assessments are presented in Table 1. The evaluation values for each component were determined using an 8-point scale. If the evaluated component is deemed the least important for AV traffic, then it is assigned 8 points, and if the component is considered the most important, it is assigned 1 point, with the points for the other components allocated accordingly.

Table 1 List and description of components

	(Q1)	(Q2)	(Q3)	(Q4)	(Q5)	(Q6)	(Q7)	(Q8)
Expert (E1)	5	6	4	7	8	1	3	2
Expert (E2)	4	3	6	2	7	8	5	1
Expert (E3)	3	2	5	4	8	7	6	1
Expert (E4)	3	4	6	2	5	7	8	1
Expert (E5)	1	4	7	3	8	6	5	2
Expert (E6)	3	8	4	2	6	7	5	1
Expert (E7)	4	3	6	8	7	5	1	2
Expert (E8)	2	8	5	3	7	6	4	1
Expert (E9)	3	1	5	4	7	8	6	2
Expert (E10)	3	2	8	5	6	7	4	1
Expert (E11)	6	7	4	2	8	5	3	1
Expert (E12)	3	7	6	2	4	8	5	1
Expert (E13)	3	4	6	2	7	8	5	1

One of the simplest methods applicable – Kendall method [10]. This method is logical and easily applicable in practical calculations [11].
Kendall concordance coefficient [10] is linked with the sum of rank of each factor R_j and with regard to respondents or experts:

$$R_j = \sum_{i=1}^{n} R_{ij} \quad (j = 1, 2, ..., m) \tag{1}$$

The mean rank of each factor $\overline{R}$ is obtained dividing the sum of ranks assigned thereto by number of factors:

$$\overline{R} = \frac{\sum_{j=1}^{m} R_j}{m} \tag{2}$$

where:
R_{ij} – rank given by expert i to factor j
n – number of experts (i = 1, 2, ..., n)
m – number of factors (j = 1, 2, ..., m).

The difference between sum $\sum_{i=1}^{n} R_{ij}$ of ranks R_{ij} and constant quantity $\frac{1}{2}n(m+1)$ is calculated for each criterion:

$$\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2} \tag{3}$$

The square of the difference between ranks‘ sum $\sum_{i=1}^{n} R_{ij}$ and constant quantity $\frac{n(m+1)}{2}$ is calculated:

$$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)\right]^2 \tag{4}$$

Upon calculation as per formulas (1) to (4), the next step is to calculate the concordance coefficient W:

$$W = \frac{12S}{n^2(m^3 - m)} \tag{5}$$

Significance of concordance coefficient and compatibility of expert evaluation of factor groups is determined by χ^2:

$$\chi^2 = \frac{12S}{nm(m+1)} \tag{6}$$

Min value of the concordance coefficient W_{min} is calculated from formula (7):

$$W_{min} = \frac{\chi^2_{v,\alpha}}{n(m-1)} \tag{7}$$

where:
$\chi^2_{v,\alpha}$ – Pearson critical statistics, which value is found in the table [12], taking the degree of freedom v = m – 1 and significance level α.

The survey conducted among 13 experts revealed that the most crucial component for ensuring AV traffic is the impact of AV platooning on infrastructure (0.2137). Standard road signs ranked second in importance (0.1581), followed by delineator posts in third place (0.1517), and static and dynamic digital road signs in fourth place (0.1239). The weights of the other infrastructure components are illustrated in Figure 1.

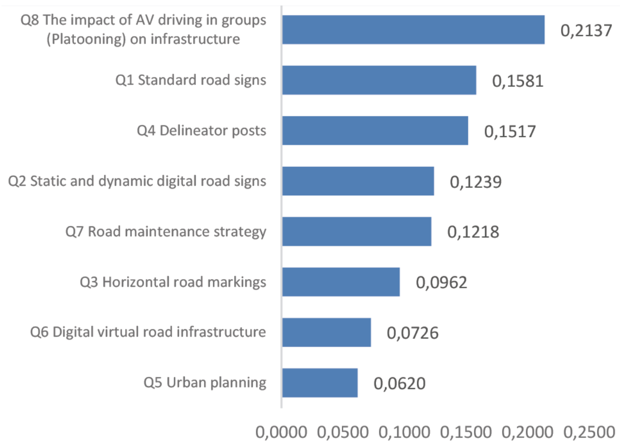

Figure 1 Determined weights for each component

3 Discussion and conclusions

1. The study and overall assessment indicate that a coordinated approach, which includes upgrading the existing road network infrastructure, adapting, and utilizing digital technologies, and planning for future regulatory changes, is necessary for the successful integration of AVs into the real traffic ecosystem.
2. The analysis carried out using Kendall's Method presents a hierarchy of the components selected for the study that influence the participation of AVs in real traffic. This highlights the importance of adapting the infrastructure to AV technology, with special attention to vehicle communication with road systems and the need to maintain physical road elements to meet the requirements of autonomous driving systems.
3. The concept of AV "platooning", with the highest influence on traffic dynamics (0.2137), indicates that group driving can significantly alter traffic patterns and road usage, increasing road capacity. However, it may also demand more extensive infrastructure improvements. The importance of standard road signs (0.1581) signifies their key role in the interaction between human-controlled and AVs, underscoring the need to maintain signage standards and apply AV technologies for accurate interpretation. The relevance of delineator posts (0.1517) shows their critical role in ensuring safe AV traffic, especially during low-visibility conditions. Static and dynamic digital road signs, with a moderately important role (0.1239), suggest that successful AV integration depends on implementing digital technologies, necessitating investments in digital infrastructure to facilitate AVs' participation in traffic and their interaction with road systems. Components with lower values have a lesser effect on AV traffic participation.
4. The study mainly addresses the technical and infrastructural aspects of AV integration, with less focus on human factors, including driver and pedestrian behavior in mixed traffic environments.
5. Future research should include a wider array of factors, such as cybersecurity risks, the impact of weather conditions on AV technology, and the psychological effects of AVs on human drivers and pedestrians.

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