12th International Conference

ENVIRONMENTAL ENGINEERING

April 27–28, 2023, Vilnius, LITHUANIA

eISSN 2029-7092
eISBN 978-609-476-342-7
Article ID: enviro.2023.913
https://doi.org/10.3846/enviro.2023.913

II. SMART CITIES, ROADS AND RAILWAYS *http://vilniustech.lt/enviro*

AN ASSESSMENT OF SELF-DRIVING VEHICLES: ROAD MAINTENANCE AND INFRASTRUCTURE NEEDS

Vladislav KONDRATOVIČ*, Donatas ČYGAS, Vytautas PALEVIČIUS

Department of Roads Faculty of Environmental Engineering, Vilniaus Gediminas Technical University, Vilnius, Lithuania

Received 16 January 2023; accepted 20 February 2023

Abstract. In the coming years, on the roads of the European Union countries, we will increasingly see self-driving vehicles (SDV), which will face considerable challenges on the roads. At first, SDVs will aim to adapt to the existing road infrastructure, but their increasing use on roads will make tangible influence on the progress of the components of the road infrastructure ecosystem. The following main trends in global car transport can be distinguished: artificial intelligence in SDV, various SDV digital and communication systems, SDV sharing platforms and other components of the SDV ecosystem. Although the benefits of using new autonomous technologies for transport have been widely explored, research on requirements for the physical infrastructure for the SDV traffic is still at an early stage. In this context, the emergence of new technologies calls for immediate action to adapt the existing transport infrastructure system to the evolving SDV industry. This paper examines the impact of SDVs on the physical road infrastructure in order to identify road infrastructure elements that influence the SDV traffic.

Keywords: road infrastructure, self-driving vehicles, transport infrastructure system, Kendall method, road maintenance.

JEL Classification: L91: Transportation: General.

Introduction

The Internet connection is considered to be one of the most important elements enabling self-driving vehicles to drive on roads and communicate with other vehicles and with individual infrastructure elements. British researchers have prepared a scientific publication and conducted a comprehensive review of the latest technological advances in methods of determining the position between the ego vehicle and the transport network infrastructure. The possibilities of location accuracy, complexity and adaptability, taking into account the requirements of self-communicating autonomous vehicles and intelligent transport systems have been also analysed. We can conclude that in order to realize smart transport networks and self-driving vehicles, it is necessary that self-driving vehicles communicating with each other can estimate their position with centimetre accuracy (Adegoke et al., 2019).

Canadian researchers propose to first carry out interdisciplinary work in order to understand the self-driving vehicles known as a whole and prepare it in everyday life even having a good internet connection, but not ensuring the safe movement of self-driving vehicles on the roads. They argue that all technological improvements brought about by this evolution will have a direct impact on society. These self-driving vehicles challenge to doubt about the paradigm of individual mobility in various aspects: economic, social, legal and other aspects. The models on which these vehicles will be based will continue to differ from those currently known. As interest in self-driving vehicles technology grows, the social and economic implications of this technology will affect various stakeholders (Chehri & Mouftah, 2019). For example, British researchers studied the attitudes of 211 blind people towards self-driving vehicles and found that the development of self-driving vehicles up to level 5 is the "hope" of blind people to travel freely and independently (Bennett et al., 2020).

Having a good Internet connection and having done interdisciplinary work, after evaluating the economic, social and legal aspect, the question arises about the self-driving vehicles communication with external elements, i.e., with road infrastructure elements. It is important to mention that each self-driving vehicles manufacturer uses different technologies, so their perception of the environment is very different. Therefore, many researchers

* Corresponding author. E-mail: *vlakon1972@gmail.com*

in this field have begin to conduct various scientific studies to analyze the difficulties that self-driving vehicles will face in traffic. Thus, two British researchers pointed out in their scientific publication that they are very interested in exploring how self-driving vehicles in urbanized areas will cooperate with different road users, such as pedestrians and cyclists, in the future. To conduct the research, they have chosen the England's city Carlise. The researchers' findings showed it is necessary to fundamentally change the infrastructure elements of city streets in order to adapt the safe movement of self-driving vehicles and other road users together. Changes have to be done by installing new or reconstructing old street infrastructure objects: bicycle lanes, bicycle traffic lights, installing safer and quieter traffic adaptation streets (Latham & Nattrass, 2019). Other researchers have developed a theoretical framework to understand the diffusion of self-driving vehicles in cities based on three interrelated factors: social attitudes, technological innovation, and urban policies. In addition, an in-depth survey (1,233 respondents) was conducted in Dublin to provide empirical evidence on public interest in self-driving vehicles and intentions to use them once they become available, individual fears and concerns about how people intend to use this new breed. The results showed that in Dublin the public (about 71%) is not yet sure about the use of self-driving vehicles in public traffic and the majority remains neutral (Cugurullo et al., 2021).

The works done by researchers who have researched isolating each individual element of road or street infrastructure that is vital for self-driving vehicles to communicate with external elements will be reviewed below. Thus, the Hungarian researchers prepared a scientific article which purpose was to shed light on the trends of self-driving vehicles and automated transport systems and to show future challenges in the field of transport engineering. They found that intelligent cooperation between self-driving vehicles and infrastructure elements will be a part of everyday life in the future, and it is likely that most of the traditional traffic lights will completely disappear over time, giving way to virtual traffic lights adapted inside self-driving vehicles (Tettamanti et al., 2016).

French and German researchers claim that the majority of future self-driving vehicles will likely be electric, so in their opinion it is important to understand how the dislocation of self-driving vehicles and charging infrastructure will affect the overall performance of self-driving electric vehicle services in the city. Research results have shown that the efficiency of self-driving vehicles is strongly related to the charging infrastructure. It is important that the faster the charging infrastructure and the denser arrangement of charging points based on the minimum distances between demand nodes and charging stations ensures higher performance (Vosooghi et al., 2020). For example, Indian scientists have proposed how it would be possible to detect missing road surfaces faster or choose another better route due to a bad road in the future. They state that due to poor road maintenance in India self-driving vehicles have to have a system that can detect and recognize cracked pavement on poor road quality. Cracks and their types can be detected using a technique called surface crack detection (Bhat et al., 2020).

Hungarian and Polish researchers conducted research to find out how self-driving vehicles should behave before entering unregulated intersections. To carry out the analysis, they analyzed the visibility requirements for conventional vehicles and those that will be required for self-driving vehicles in the future. Three criteria have been chosen to determine the visibility requirements: distance, viewing angle, and the abilities of self-driving vehicles and human drivers. These criteria were calculated separately for self-driving vehicles and human drivers at various speeds on the main road and intersections with 90° and 60° lean angles. The researchers concluded that the sight distances required for self-driving vehicles are between 10 and 40 meters shorter than conventional ones (Magyari et al., 2021). German researchers analyzed intersections controlled by traffic lights by developing a mixed-integer linear programming model to describe the interaction between traffic lights and discrete traffic flow (Le et al., 2022).

The current road infrastructure is designed assessing the human factor in mind. Drivers make various mistakes due to distraction, fatigue, inexperience and other factors. For example, roadways and curbs are much wider than the width of the vehicle to act as a buffer zone that reduces the probability of head-on collisions or run-off accidents. In addition, traffic safety measures such as dividing lines, guardrails, transverse bars, prohibition and warning signs are used to reduce the probability of driving errors. High-contrast and high-reflective pavement markings improve the determination of traffic lane gauges, both for drivers and self-driving vehicles (SDV) (Pike et al., 2019).

The need for some infrastructure is likely to vary in different areas of the city. For example, the city's current parking schemes may change due to the expected reduction in the number of car parking spaces in the city centre and the increased demand for passenger pick-up and drop-off areas. As it was pointed out by Duarte and Ratti (2018), cities are likely to free up a lot of land occupied by large car parks, especially in the city centre.

From a vehicle performance perspective, SDV will not have a significant impact on design standards, as the basic laws of physics governing vehicle performance will remain the same. In general, driving behaviour is a key factor influencing design elements (Khoury et al., 2019). For example, driver reaction time, eye height, and other human-related behaviours are key factors influencing the design of highway geometric elements. A study has shown that geometrical design elements will change when the entire vehicle fleet is composed of SDV

(Othman, 2021). However, two main phenomena, acceleration and deceleration of SDV, can affect the geometric design of the road in certain areas (Washburn & Washburn, 2022). The SDV will be used by people, so the acceleration and deceleration criteria cannot be changed drastically, which may make the ride uncomfortable for the passengers of the SDV. In other words, human needs and tolerance levels are expected to continue to dictate the geometric parameters of the road and are therefore not expected to lead to major changes in road design. Washburn and Washburn (2022) also noted that SDV can respond to an obstacle in the road by breaking much faster, which can increase the design speed of roads if all other factors remaining the same.

A group of researchers from the USA, Great Britain and China identify three stages in response to the research question "How should road infrastructure be designed to accommodate SDV traffic". The first phase mainly includes maintenance works, the second phase includes the construction of the infrastructure necessary to separate the SDV from traffic, and the third phase is related to the creation of a simplified road infrastructure construction standard. Although the 3-phase plan has significant limitations related to the immaturity of the SDV market and the lack of collected data, it should be considered as a starting point that can be used to stimulate further research in the area of road infrastructure upgrades during the integration of SDV into mixed traffic. Future research can develop specific plans based on appropriate city sizes, population, and even energy distribution constraints (Liu et al., 2019). No matter how fast the SDV develops, it is better to upgrade the infrastructure while maintaining it rather than fundamentally changing it at an early stage (Magyari et al., 2021). This will meet not only the needs of SDV development (Johnson et al., 2017), but also the safety requirements of conventional vehicles (Lawson, 2018).

Maintenance work may include the following:

- to create improved standards and shorten communication tool maintenance intervals;
- to increase the frequency of pavement maintenance (e.g grading, sealing and patching) (Chen et al., 2016);
- it is also worth considering a wider range of maintenance of the drainage system.

According to Hungarian researchers, the current width of traffic lanes is determined by the ability of the driver to keep the car in the lane, the width of the vehicle and the speed. SDV and all other vehicles equipped with a lane keeping assist system can drive much more accurately, so vehicle characteristics are expected to be the most important factor in determining lane width in the future (Barsos et al., 2020). However, the lane width cannot be reduced as long as regular vehicles and SDV are involved in the traffic. The possible reduction in road surface width is questionable (Snyder, 2018) due to the expected growth in the demand for movement (young and elderly people, disabled, etc.).

Fully automated SDV will be able to run without passengers. In the case of private SDV, such driving can be beneficial as it avoids the cost of parking at their intersection. SDV owners can arrange for their vehicle to take them to their destination and then drive elsewhere to park. In particular, when zones have asymmetric parking infrastructure costs, optimized parking fees can encourage the parking of SDV in cheaper locations, thereby reducing the area used for parking in high land value zones (Levin et al., 2020).

As Lu (2018) emphasized at the beginning of the transition period (it can be considered that it has already started and continues until the roads are free of conventional vehicles), reliable recognition and comprehension of road markings and traffic signs are required for SDV operation. The system of signs has to be unambiguous, homogeneous and adapted to AV. These principles are also declared in 1968. Vienna Convention on Road Signs and Signals (United Nations [UN], 1968) and EU Directive 2019/1936 (European Parliament, 2019).

Self-driving vehicles will prioritize the safety of pedestrians and other vulnerable road users (Botello et al., 2019).

1. Determination of the weight criteria by Kendall method

The list of criteria was drawn up before conducting the expert survey. In order to compile the list of criteria, a review of the existing scientific literature was carried out. It was determined that the main elements of the road infrastructure ecosystem that influence the integration of SDV into traffic are not only road design components and good Internet connection, but also proper road maintenance (Chen et al., 2016). It has also been noted that SDV operation requires a reliable understanding of road markings and traffic signs (Lu, 2018). Human needs and tolerance levels are expected to continue to condition the geometric parameters of the road (Washburn & Washburn, 2022). However, vehicle characteristics are expected to be the most important factor in determining lane width in the future (Barsos et al., 2020).

Below is a list of criteria, which was compiled with the help of 11 experts, and who selected five main criteria (Table 1), which will be weighted later. The experts were selected on the basis of work experience and possession of a scientific degree in the field of examination. The expert group consisted of experts working in Lithuania: innovation, ITS and C-ITS, electronic communications, autonomous car legislation and policy-making areas.

Individual surveys to these experts, hereinafter referred to as E1-E11, gave the results about the importance of criteria that can be observed in the Table 2.

Table 1. Criteria list and description

Item No.	Road infrastructure technical parameter	Description
Q1	Intersections	Intersection is a place where roads cross, join or branch at a level, including open areas formed by road crossings, junctions or branches. Intersections are not considered places where you leave the road to the areas next to it or enter the road from the areas next to it.
Q2	Shopping center parking lots	Parking lots are areas designed for temporary or permanent storage of cars, marked with appropriate road signs or markings. There is intense pedestrian and car traffic in the parking lots of shopping centers, which has a significant impact on the movement of SDV. It is planned that the loading and parking of SDV parcels will be organized in the parking lots of shopping centers.
Q3	Pedestrian crossings	Pedestrian crossing is the place of crossing over the carriageway, marked with road signs "Pedestrian crossing" and marking lines or only road signs "Pedestrian crossing". The boundaries of the pedestrian crossing are marked by marking lines, and if there are none, by imaginary lines running perpendicularly from the road signs across the road.
Q4	Type of road surface	Road surface is the upper, usually multi-layered, structure of the carriageway, laid on the ground bed. The road surface is also called according to the material of the upper layer: asphalt concrete, concrete, pavement, gravel. The type of pavement depends on how SDV will determine the road boundaries.
Q5	Road maintenance strategy and road works	The conductivity of vehicles on the streets is reduced in winter weather, slippery road surfaces, in the event of a traffic accident.

Table 2. Criteria ranks awarded by each expert

	Criteria (K1)	Criteria (K2)	Criteria (K3)	Criteria (K4)	Criteria (K5)
Expert (E1)	2	3	1	5	4
Expert (E2)	3	4	1	5	2
Expert (E3)	2	4	1	3	5
Expert (E4)	1	5	2	3	4
Expert (E5)	1	3	2	4	5
Expert (E6)	4	2	1	5	3
Expert (E7)	1	5	2	4	3
Expert (E8)	2	3	4	1	5
Expert (E9)	2	5	1	4	3
Expert (E10)	1	5	2	3	4
Expert (E11)	2	5	3	1	4

One of the simplest methods applicable is Kendall method (Kendall, 1970). Ranking is done pursuant to the criteria list, i.e., when the highest rank is given by an expert to the most important criterion, i.e., place or score equal to one. The second most important criterion is given a rank equal to two, the third one – three and etc. The last rank receives the lowest value of ranking. This method is logical and easily applicable in practical calculations (Jakimavicius et al., 2016).

Kendall concordance coefficient (Kendall, 1970) is linked with the sum of rank of each factor R_j and with regard to respondents or experts = 1, 2, ..., m).

$$R_j = \sum_{i=1}^{n} R_{ij}. \tag{1}$$

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)–(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:

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

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

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

where: $\chi^2_{\nu,\alpha}$ – Pearson critical statistics, which value is found in the table (Montgomery, 2009), taking the degree of freedom $\nu = m - 1$ and significance level α.

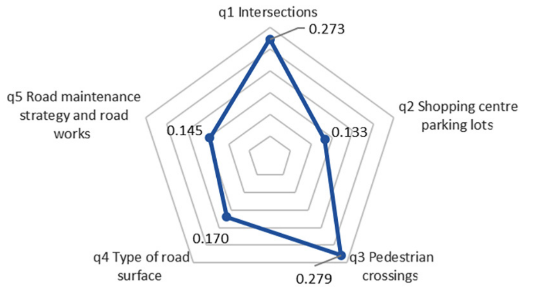

Figure 1. Determined criteria weights

The outcome from 11 expert surveys was that the structure gauge should be firstly pedestrian crossings and bicycle crossings (0.279), second place is One-level intersections. (0.273), third place is Road surface and SDV arrangement on the road. (0.170), fourth place is Road maintenance strategy and road works. (0.145), fifth place is Shopping center vehicle parking lots (0.133). The results about determined criteria weights can be observed in the Figure 1.

Conclusions

1. After a detailed analysis, we can conclude that the evaluation model for adapting road infrastructure to SDV traffic, in the initial stages of development, would allow SDV to be integrated into the general transportation system without allocating much investment and adapting the existing infrastructure. In the later stages, after all existing opportunities have been used and a significant increase in SDV traffic, there would be a need for investments to separate the flows of SDV and conventional vehicles, as well as to install interactive intelligent transport systems, without which smooth and efficient SDV traffic is not possible.
2. It was found that the criteria of pedestrian crossings and bicycle crossings have the highest significance (0.279) considering the results of the expert assessment obtained in the article and the obtained significances of the efficiency criteria. Regarding the opinion of experts, this efficiency criterion is the most important because the majority of traffic accidents are cases of running into pedestrians, and not anywhere, but at pedestrian crossings. This is the most dangerous place on the street where a traffic accident involving SDV and pedestrians can occur.
3. Another efficiency criteria with similar significance are one-level intersections (0.273). This performance criteria are important in that it describes the most important obstacles that have a significant impact on SDV traffic. Intersections are intersections of vehicular flows that need to evaluate many dynamic variables to overcome SDV, which can cause significant disruptions to smooth traffic. It is very important to assess the types of intersections on the route and the priority of traffic participants when organizing SDV traffic.
4. Less significant is the efficiency criterion of road surface and SDV placement on the road (0.170). The importance of this efficiency criterion has only to increase in the future by reducing the road width and expanding of urban areas where SDV will be used.
5. Although road maintenance strategy and road works (0.145) are the fourth most important efficiency criterion, its influence on smooth traffic is significant. The condition and legibility of road signs can be affected by various environmental influences. In addition to the harmonization of road signs, it is necessary to create standards and set the limit values of the criteria, so that during their maintenance, it is possible to determine whether the fading and interference of pavement markings and road signs do not prevent SDV systems from recognizing them. The poor condition of road lane markings and signs may hinder the organization of SDV traffic in the affected areas.
6. The fifth is the criterion of the efficiency of parking lots of shopping malls (0.133). There is mixed traffic in the parking lots, in which pedestrians also participate together with cars. Organizing of SDV traffic in parking lots can become a big challenge knowing that SDV systems are adjusted to maximally protect pedestrians from possible running over them and will immediately stop driving at the slightest threat.

References

Adegoke, E. I., Zidane, J., Kampert, E., Ford, C. R., Birrell, S. A., & Higgins, M. D. (2019). Infrastructure Wi-Fi for connected autonomous vehicle positioning: A review of the state-of-the-art. *Vehicular Communications*, *20*, 100185. https://doi.org/10.1016/j.vehcom.2019.100185

Barsos, A., Koren, C., Mako, E., Miletics, D., & Nagy, R. (2020). *Selected aspects of the road infrastructure in relation to vehicle automation*. https://mmaws.bme.hu/2020/pages/program/papers/IFFK_2020_Paper_24_Borsos_Koren_Mako_Miletics_Nagy-Selected_aspects_of_the_road.pdf

Bennett, R., Vijaygopal, R., & Kottasz, R. (2020). Willingness of people who are blind to accept autonomous vehicles: An empirical investigation. *Transportation Research Part F: Traffic Psychology and Behaviour*, *69*, 13–27. https://doi.org/10.1016/j.trf.2019.12.012

Bhat, S., Naik, S., Gaonkar, M., Sawant, P., Aswale, S., & Shetgaonkar, P. (2020, February). A survey on road crack detection techniques. In *2020 International Conference on Emerging Trends in Information Technology and Engineering* (ic-ETITE) (pp. 1–6). Vellore, India. IEEE. https://doi.org/10.1109/ic-ETITE47903.2020.67

Botello, B., Buehler, R., Hankey, S., Mondschein, A., & Jiang, Z. (2019). Planning for walking and cycling in an autonomous-vehicle future. *Transportation Research Interdisciplinary Perspectives*, *1*, 100012 https://doi.org/10.1016/j.trip.2019.100012

Chehri, A., & Mouftah, H. T. (2019). Autonomous vehicles in the sustainable cities, the beginning of a green adventure. *Sustainable Cities and Society*, *51*, 101751. https://doi.org/10.1016/j.scs.2019.101751

Chen, F., Baileu, R., & Kringos, N. (2016). Potential influences on long-term service performance of road infrastructure by Automated Vehicles. *Transportation Research Board*, *2550*(1), 72–79. https://journals.sagepub.com/doi/abs/10.3141/2550-10

Cugurullo, F., Acheampong, R. A., Gueriau, M., & Dusparic, I. (2021). The transition to autonomous cars, the redesign of cities and the future of urban sustainability. *Urban Geography*, *42*(6), 833–859. https://doi.org/10.1080/02723638.2020.1746096

Duarte, F., & Ratti, C. (2018). The impact of autonomous vehicles on cities: A review. *Journal of Urban Technology*, *25*(4), 3–18. https://doi.org/10.1080/10630732.2018.1493883

European Parliament. (2019). Directive (EU) 2019/1936 of the European Parliament and of the Council of 23 October 2019 amending Directive 2008/96/EC on road infrastructure safety management. *Official Journal of the European Union L 305/1*. https://www.cnu.org/publicsquare/2018/03/12/streetdesign-implications-autonomous-vehicles

Jakimavičius, M., Burinskienė, M., Gusarovienė, M., & Podviezko, A. (2016). Assessing multiple criteria for rapid bus routes in the public transport system in Vilnius. *Public Transport*, *8*(3), 365–385. https://doi.org/10.1007/s12469-016-0146-7

Johnson, C. (2017). *Readiness of the road network for connected and autonomous vehicle*. RAC Foundation. https://www.racfoundation.org/wp-content/uploads/2017/11/CAS_Readiness_of_the_road_network_April_2017.pdf

Kendall, J. M. (1970). The turbulent boundary layer over a wall with progressive surface waves. *Journal of Fluid Mechanics*, *41*(2), 259–281. https://doi.org/10.1017/S0022112070000617

Khoury, J., Amine, K., & Saad, R. A. (2019). An initial investigation of the effects of a fully automated vehicle fleet on geometric design. *Journal of Advanced Transportation*, *2019*, 6126408. https://doi.org/10.1155/2019/6126408

Latham, A., & Nattrass, M. (2019). Autonomous vehicles, car-dominated environments, and cycling: Using an ethnography of infrastructure to reflect on the prospects of a new transportation technology. *Journal of Transport Geography*, *81*, 102539. https://doi.org/10.1016/j.jtrangeo.2019.102539

Lawson, S. (2018). *Roads that cars can read: Report III – Tackling the transition to automated vehicles*. EuroRAP. https://eurorap.org/wp-content/uploads/2020/01/B2.-2018-06-13-EuroRAP-GA-Roads-that-Cars-Can-Read-S-Lawson.pdf

Le, D. D., Merkert, M., Sorgatz, S., Hahn, M., & Sager, S. (2022). Autonomous traffic at intersections: An optimization-based analysis of possible time, energy, and CO_2 savings. *Networks*, 79(3), 338–363. https://doi.org/10.1002/net.22078

Levin, M. W., Wong, E., Nault-Maurer, B., & Khani, A. (2020). Parking infrastructure design for repositioning autonomous vehicles. *Transportation Research Part C: Emerging Technologies*, *120*, 102838. https://doi.org/10.1016/j.trc.2020.102838

Liu, Y., Tight, M., Sun, Q., & Kang, R. (2019, April). A systematic review: Road infrastructure requirement for Connected and Autonomous Vehicles (CAVs). *Journal of Physics: Conference Series*, *1187*(4), 042073. https://iopscience.iop.org/article/10.1088/1742-6596/1187/4/042073/pdf

Lu, X. (2018). *Infrastructure requirements for automated driving* [Master Thesis at Delft University of Technology]. https://repository.tudelft.nl/islandora/object/uuid:0540e0c5-3ee1-43a0-ad75-89ba928ea272?collection=education

Magyari, Z., Koren, C., Kieć, M., & Borsos, A. (2021). Sight distances at unsignalized intersections: A comparison of guidelines and requirements for human drivers and autonomous vehicles. *Archives of Transport*, *59*(3), 7–19. https://doi.org/10.5604/01.3001.0014.9553

Montgomery, D. C. (2009). *Introduction to statistical quality control* (6th ed.). John Wiley & Sons. https://www.uaar.edu.pk/fs/books/12.pdf

Othman, K. (2021). Impact of autonomous vehicles on the physical infrastructure: Changes and challenges. *Designs*, *5*(3), 40. https://doi.org/10.3390/designs5030040

Pike, A. M., Whitney, J., Hedblom, T., & Clear, S. (2019). How might wet retroreflective pavement markings enable more robust machine vision? *Transportation Research Record*, *2673*(11), 361–366. https://doi.org/10.1177/0361198119847620

Snyder, R. (2018, March). Street design implications of autonomous vehicles. *Public Square: a CNU Journal.*

Tettamanti, T., Varga, I., & Szalay, Z. (2016). Impacts of autonomous cars from a traffic engineering perspective. *Periodica Polytechnica Transportation Engineering*, *44*(4), 244–250. https://doi.org/10.3311/PPtr.9464

United Nations. (1968). *Vienna convention on road signs and signals*. United Nations Publication.

Vosooghi, R., Puchinger, J., Bischoff, J., Jankovic, M., & Vouillon, A. (2020). Shared autonomous electric vehicle service performance: Assessing the impact of charging infrastructure. *Transportation Research Part D: Transport and Environment*, *81*, 102283. https://doi.org/10.1016/j.trd.2020.102283

Washburn, S. S., & Washburn, L. D. (2022). *Future highways – Automated vehicles*. https://s3.amazonaws.com/suncam/docs/208.pdf?1536490909