Periodica Polytechnica Transportation Engineering, 50(4), pp. 426–434, 2022

Road Safety Analysis of Autonomous Vehicles

An Overview

Herman Szűcs[1,2*], Jozefin Hézer[3]

[1] Department of Whole Vehicle Engineering, Audi Hungaria Faculty of Automotive Engineering, Széchenyi István University, Egyetem tér 1, 9026 Győr, Hungary
[2] Audi Hungaria Zrt., Audi Hungária út 1, 9027 Győr, Hungary
[3] EDAG Hungary Kft., Zrínyi Miklós utca 11, 9024 Győr, Hungary
[*] Corresponding author, e-mail: szucsherman@outlook.hu

Received: 27 November 2021, Accepted: 15 June 2022, Published online: 22 June 2022

Abstract

For the widespread use of Autonomous Vehicles (AVs), a huge number of challenges must be solved by vehicle manufacturers, in contrast they do have significant potential to increase road safety in both passenger and freight transport. In addition to reducing road traffic accidents and traffic jams, AVs also offer a major opportunity to reduce pollutant emissions and CO_2 emissions from environmental point of view. In order to implement accident-free traffic, also called Vision Zero, it is essential to examine the safety and reliability of AVs. This article analyzes road traffic accident data and the potential safety benefits of AVs. Furthermore, the paper also sets the safety of the conventional vehicles against AVs and examines the type, location, causes, and dynamics of the accidents. The article also provides an overview over the current development trends and challenges, such as the risk of cyber-attacks, the necessary improvements in sensing technologies, and the not insignificant moral issue of AVs.

Keywords

autonomous vehicle, road accident, road traffic safety, safety analysis

1 Introduction

Autonomous vehicles (AVs) will play an important role in road traffic safety and accident reduction, as well as in solving critical social and environmental issues. Autonomous vehicles are defined by Sarkar and Mohan (2019) as vehicles that are able to reach their destination without human intervention. This requires the installation of different technologies in vehicles, such as cameras, radar, or lidar. Due to the increasing demand for autonomous technology, many companies have already been developing AVs, including Apple, Audi, BMW, General Motors, Google, Mercedes, Nissan, Tesla, Toyota, and Volvo. Current challenges in the development of AVs include accurate detection of the vehicle environment, the development of reliable GPS and communication systems, the avoidance of objects and obstacles, lane-keeping, and adequate protection against cyber-attacks (Petrović et al., 2020; Sarkar and Mohan, 2019; Tettamanti et al., 2016; Törő et al., 2016; Wang et al., 2020).

Autonomous vehicles and autonomous transportation could have an impact on our lives in three major areas: economy, society, and environment. From economic point of view, it should be pointed out that autonomous vehicles can significantly reduce the number of road accidents – by up to 90% according to Sarkar and Mohan (2019) – by eliminating the impact of the human factor. As a result, the economic damage is significantly decreased. AVs' social impact can be found in the fact that AVs can be used to eliminate accidents that occur due to a person's wrong decision, poor judgment, or human negligence (e.g., drunk driving). They also have a significant impact from environmental point of view, as they can reduce fuel consumption and thus carbon dioxide (CO_2) emission as well as pollutant emission. In this way, AVs also contribute to the achievement of future climate goals. Petrović et al. (2020) and Wang et al. (2020) highlighted the important role of autonomous vehicles in increasing mobility among people who are not able to drive (e.g., young people, blind, disabled), thereby improving their independence. Autonomous transport will also have a significant impact on taxis and other shared passenger services (i.e., Uber). In addition, Volvo and Mercedes are developing self-driving trucks,

Cite this article as: Szűcs, H., Hézer, J. (2022) "Road Safety Analysis of Autonomous Vehicles: An Overview", Periodica Polytechnica Transportation Engineering, 50(4), pp. 426–434. https://doi.org/10.3311/PPtr.19605

which will radically transform the logistics. The disadvantages of AVs also need to be pointed out. The cost of the vehicle (AV) will increase significantly, drivers will lose their jobs and become unemployed, and the responsibility of vehicle manufacturers will increase (Cao and Zöldy, 2020; Petrović et al., 2020; Sarkar and Mohan, 2019; Tettamanti et al., 2016; Wang et al., 2020).

All in all, the combined reduction of accidents, traffic jams, and emissions can be considered as important goals of AVs. According to Wang et al. (2020), despite significant improvements, fully autonomous vehicles are still not ready for widespread use, which has primarily safety concerns. Therefore, it is crucial to study the safety and accidents of AVs (Cao and Zöldy, 2020; Petrović et al., 2020; Sarkar and Mohan, 2019; Wang et al., 2020).

2 Potential safety benefits of autonomous vehicles

One of the current trends in the automotive industry is "Vision Zero", which aims to achieve accident-free traffic. The vision of accident-free transportation is currently a hot topic especially for vehicle manufacturers, such as BMW, Daimler, and the Volkswagen Group. According to Wang et al. (2020), 94% of accidents are caused by human error, so "Vision Zero" could be implemented with fully automated vehicles, but the risk of expected technical failures must also be taken into account (Wang et al., 2020; Winkle, 2016).

In Germany, there were a total of 198,175 road accidents involving personal injuries in 2010; the distribution of these types of accidents is shown in Fig. 1. 29.6% (58725) of road accidents occurred at intersections, 22.6% (44812) during parallel traffic, 17% (33649) during turning, 15.5% (30737) were a single-vehicle (dynamic) accident, 5.2% (10,353) were in stationary traffic and 3.1% (6,148) were pedestrian accidents. It can be clearly seen from Figs. 1 and 2 that out of all accidents, intersections accidents, parallel traffic, and accidents during turning are considered to be relatively common. With the increasing automation, the number of road accidents could be reduced by 50% by 2050 and completely eliminated by 2070 (Winkle, 2016).

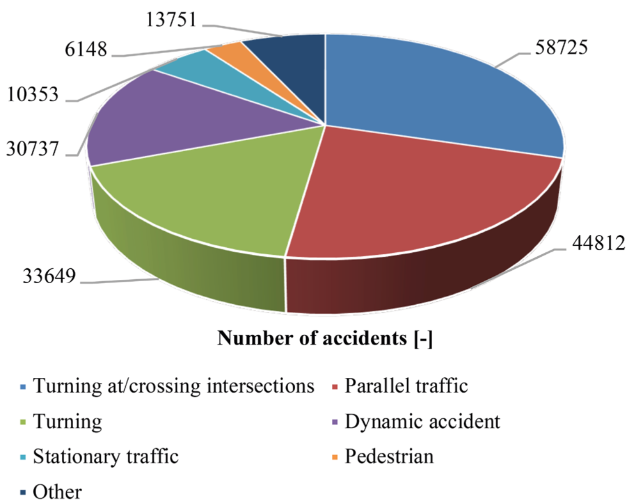

Fig. 1 Types of road accidents in Germany, 2010, created by H. Szűcs based on Winkle (2016)

Fig. 2 shows the statistical distribution of the causes of road accidents in Germany in 2010 (GIDAS accident database) as well as the expected future distribution for AVs. According to the data, 93.5% of accidents are caused by human error. In the case of fully autonomous driving, human error is completely omitted, so it is assumed that in the future the category of technical failure will increase proportionately due to new technical risks (Winkle, 2016).

3 Road traffic safety of autonomous vehicles

AV safety is determined by the combination of AV architecture, software, and hardware. The accidents of AVs are strongly connected to the mistakes and errors made by AVs, so it is also important to investigate them. These errors can be grouped according to architecture as follows (Wang et al., 2020):

- Detection error: occurs during the detection of the environment (sensor error)
- Decision error: wrong or erroneous decision made based on the processed data from perception
- Intervention error: failure of actuators.

The management and the solution of these errors differ significantly, so special attention should be paid to them during the technical development of AVs.

In the analysis of AV's road traffic accidents, the researchers (Favarò et al., 2017; Petrović et al., 2020; Wang et al., 2020) primarily used the California Department of Motor

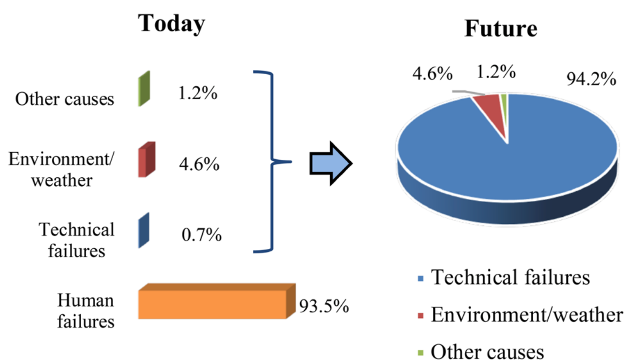

Fig. 2 The causes and the distribution of accidents of AVs now and in the future (expected), created by H. Szűcs based on Winkle (2016)

Vehicles database, where the data are publicly available. The research of Favarò et al. (2017) analyzed the data from the California database between 2014 and 2017 on accidents involving autonomous vehicles. Wang et al. (2020) in a similar study examined actual AV accidents between 2014 and 2018, for which the California database was also used. During this period, a total of 128 accidents occurred with AVs. Petrović et al. (2020) compared the safety of autonomous vehicles with conventional vehicles, in which the specifics of traffic accidents were examined. In this research, accidents were studied that occurred in the state of California between 2015 and 2017. It analyzed a total of 300 accidents over the three years, of which 53 occurred with AVs and 247 with conventional vehicles. It is important to highlight that there was no fatal accident with AVs, nor an accident between two AVs, which is encouraging data for the safety of AVs (Favarò et al., 2017; Petrović et al., 2020; Wang et al., 2020).

3.1 AV accidents by manufacturers

During the studied period (2014–2017), a total of 30 different AV manufacturers had road testing licenses, of which only 5 manufacturers reported road traffic accidents (Fig. 3). Fig. 3 shows that Google vehicles are responsible for 84% of AV accidents, but it is important to note that the tested vehicle fleet is significantly larger than that of other manufacturers: Google tested 60, GM Cruise 25, Nissan 5, and Delphi 2 vehicles (Favarò et al., 2017). Wang et al. (2020) also examined AV accident reports by manufacturers in the period of 2014–2018 (Fig. 4). Statistically analyzing the 128 accidents, most accidents were caused by GM Cruise (46%) vehicles, followed by Waymo (22%), Google (17%), and Zoox (5%). It can be seen that in just one year, accident statistics have been significantly rearranged, and many manufacturers have started testing AVs (Favarò et al., 2017; Wang et al., 2020).

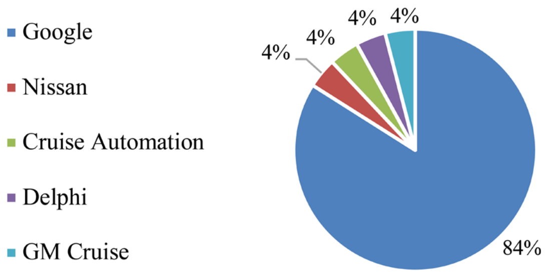

Fig. 3 Distribution of accidents involving autonomous vehicles by manufacturers between 2014 and 2017, created by H. Szűcs based on Favarò et al. (2017)

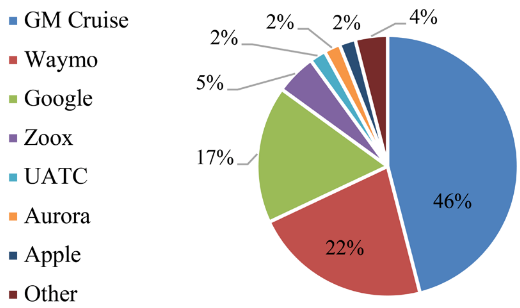

Fig. 4 Distribution of accidents involving autonomous vehicles by manufacturers between 2014 and 2018, created by H. Szűcs based on Wang et al. (2020)

3.2 Types of AV accidents

Several previous studies show that road traffic accidents with AVs are more common than with conventional vehicles, but AVs are still strongly in the development phase, so these comparisons are not practical or justified. In contrast, Petrović et al. (2020) did not examine the frequency of accidents, but the type of accidents (Fig. 5), the maneuvers, and the errors that caused the accidents. The researchers did not find significant differences between the maneuvers that occurred during the accidents, so in the following, this paper will not introduce these in detail. In terms of the type of collisions (Fig. 5), rear-end accidents are the most common in the case of both conventional vehicles (CV) and AVs, but they are exceptionally high in the case of AVs (64.2%), which will be covered later in the article. The incidence of broadside collisions is much lower for AVs (5.7%) than for conventional vehicles (25.8%). Pedestrian accidents caused by an AV did not occur at all.

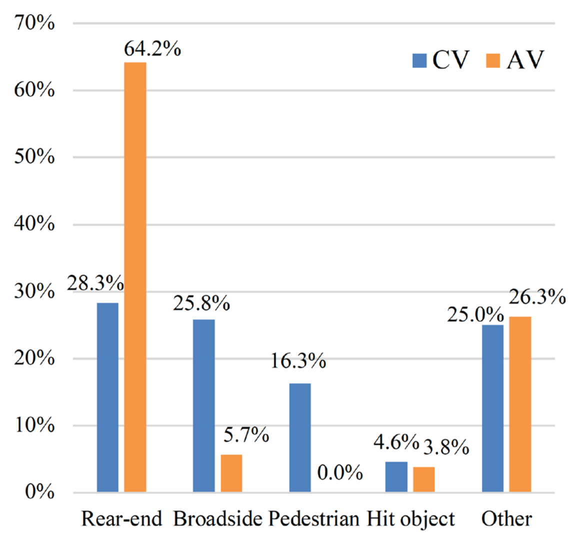

Fig. 5 Distribution of traffic accidents by type of collision, created by H. Szűcs based on Petrović et al. (2020)

The frequency of collisions with an object is slightly lower in the case of AVs (3.8%) than that of conventional vehicles (4.6%) (Petrović et al., 2020).

3.3 Dynamics of AV accidents

Favarò et al. (2017) also examined the dynamics of AV accidents by visually reconstructing the involved accidents by indicating the position of the vehicles (Fig. 6). Visual reconstruction greatly contributes to the research and understanding of the causes of the accident. Favarò et al. (2017) made a similar finding as Petrović et al. (2020) that the majority of accidents are collisions, and found that in collisions, another vehicle typically collides with the AV from the rear (Fig. 6). A rear-end accident in reverse conditions, when a conventional vehicle brakes and the AV behind it collides with it, is practically impossible due to automatic braking. Favarò et al. (2017) highlight that no frontal collision occurred. The results suggest that AV technology can effectively prevent all other accident typologies except rear-end accidents. This is an important finding that manufacturers must address in the future and provide a solution to this problem in vehicle development (Favarò et al., 2017; Petrović et al., 2020).

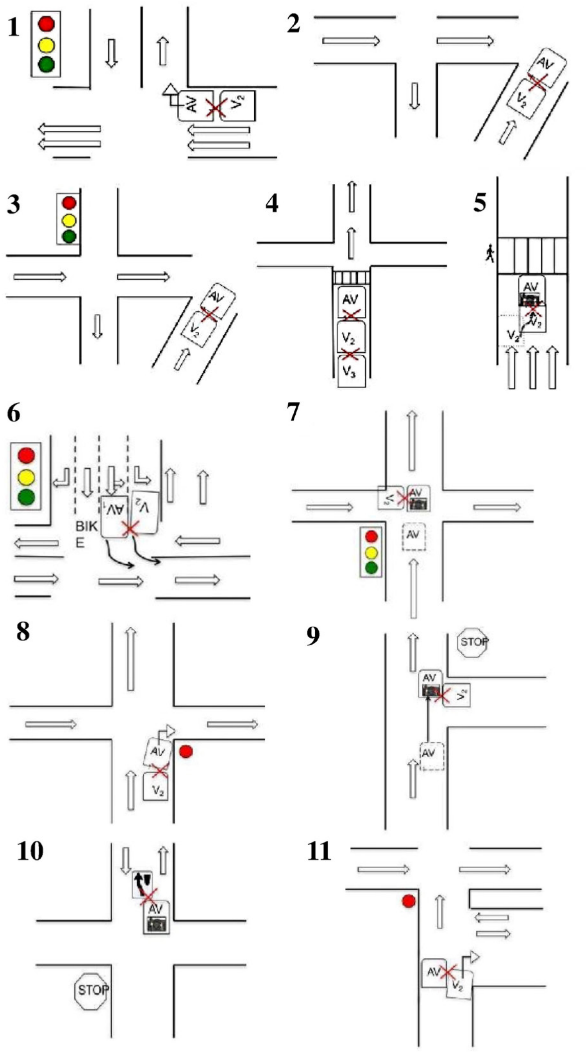

Fig. 6 Reconstruction of the dynamics of some AV accidents, created by H. Szűcs based on Favarò et al. (2017)

Fig. 6 shows a representation of some real accidents to illustrate the accidents of AVs. The AV was in manual mode in accidents Nos. 5, 7, 9, and 10. In accident No. 1, the AV waits at an intersection with a traffic light while a vehicle collides with the AV from the rear. According to the author, the different dynamic behavior (acceleration) of the vehicles could have caused the accident. Similarly, in accidents Nos. 2 and 3, a conventional vehicle collides with the AV. These accidents may also have been caused by different driving styles and dynamic behaviors. In accidents Nos. 4 and 5, the AV gave priority to the pedestrian, which presumably the driver of the conventional vehicle did not expect. According to the authors, these accidents occurred because the drivers of the conventional vehicle did not want to give priority to the pedestrian or did not notice the pedestrian and therefore did not slow down. Accident No. 6 shows a side swipe between a conventional vehicle and an AV. During the accident, the vehicles turned side by side at an intersection with a traffic light. In accident No. 7, we can see an accident at an intersection with a traffic light. The AV was going straight as a vehicle collided with it from the side (broadside accident). Since the lamp indication is not known for accidents Nos. 6 and 7, it cannot be clearly stated that the driver of the AV or conventional vehicle caused the accident. In the case of accident No. 8, an intersection with a traffic light can be seen, where the traffic light is red. During the accident, another vehicle collides with the AV from the rear. In this case, the driver of the conventional vehicle made a mistake and is responsible for the accident. In accident No. 9, the AV travels straight while a vehicle collides with its side. In this case, the driver of a conventional vehicle would have had to wait at the STOP sign until the AV passes. Here, too, the driver of the conventional vehicle can be responsible. In the case of accident No. 10, the AV drove up to a traffic island. Other vehicles were not involved in the accident. It is important to note that the vehicle was switched to manual mode at the time of the accident, hence, the inattention of the vehicle driver could have caused the accident. In accident No. 11, the AV was going straight while another vehicle was turning right.

For the majority of accidents, it can be seen that the cause of the accident is the driving style of the driver of a conventional vehicle. For this reason, artificial intelligence is particularly important for AVs to be able to learn and incorporate this driving style and dynamics into their decision-making. In addition, in the case of the accidents, it can be clearly seen that the accidents typically occurred at or near intersections. This fact shows that the dynamic behavior of AVs still needs to be improved strongly.

3.4 Damages of AVs

When analyzing accidents, it is also worth examining the location of damages caused during the accident. Fig. 7 illustrates the statistical distribution of the location of damages in autonomous vehicles. AVs mostly (62%) suffer from rear damage in accidents. Side damages are rare (23%), while the front of vehicles is very rarely damaged (15%). These data also support the frequency of rear-end collisions (Favarò et al., 2017).

3.5 Location of AV accidents

Favarò et al. (2017) also examined 66 accidents by location (Fig. 8). In 35% of the cases, the accident occurred at an intersection. In addition, accidents at traffic lights are common (21%), as well as during turning (15%) and turning lane accidents (14%). Accidents at STOP signs and lane changes were rare (6%) with AVs (Favarò et al., 2017).

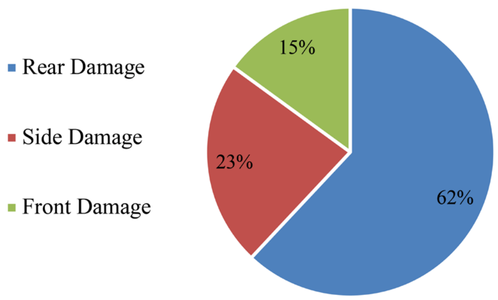

Fig. 7 Location of damages caused by road accidents in AVs, created by H. Szűcs based on Favarò et al. (2017)

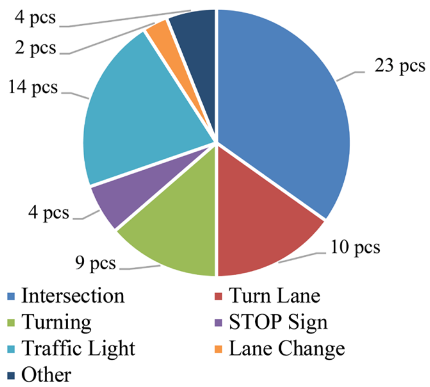

Fig. 8 Location of road accidents in autonomous vehicles, created by H. Szűcs based on Favarò et al. (2017)

Based on Fig. 8, it can be stated that the majority of the accidents can be related to an intersection as the turning lane, the STOP signs, and the traffic light also occur at intersections. This is an important observation, as examining the data in this way, 91% of AV accidents can be attributed to intersections. These intersections and their immediate surroundings can therefore be considered extremely critical for AV accidents.

3.6 Causes of AV accidents

Analyzing the errors and causes of the accidents (Fig. 9), it can be stated that the unsafe speed (43.5%) and the too close following distance (26.1%) were outstandingly high compared to the conventional vehicles. The reason for this can be found in the fact that the driving styles of AVs and conventional vehicles are significantly different. AVs accelerate and decelerate gently, while drivers of conventional vehicles have a more aggressive driving style and are not accustomed to the different dynamic behavior of AVs. This different dynamic behavior has been illustrated earlier (Fig. 6) in real-life examples and accidents. Petrović et al. (2020) suggest that a sign on the back of the vehicle could indicate that the vehicle is AV. This sign could draw the attention of drivers to be more careful. In this way, the number of accidents between AVs and conventional vehicles could be reduced. With the widespread use of AVs and their appearance on public roads, drivers of conventional vehicles are expected to become accustomed to different dynamics and more cautious about AVs (Petrović et al., 2020).

Examining the data in Fig. 9, an interesting finding is that there were more AV accidents (15.2%) due to traffic signals or sign violations than in the case of conventional vehicles (12.6%). This fact shows well that machine perception still needs serious development. AVs caused accidents with unsafe lane changes less frequently (6.5%) than conventional vehicles (8.8%). It is noteworthy that AVs did not cause any accidents at all due to a violation of pedestrians or the right of way.

According to Wang et al. (2020), 36.7% of the accidents occurred in conventional manual operation and 63.3% in autonomous operation. This is a particularly important finding, as it would be useful to examine accidents in the future based on which accident typologies occur in autonomous and manual operation. Only 6.3% of the accidents

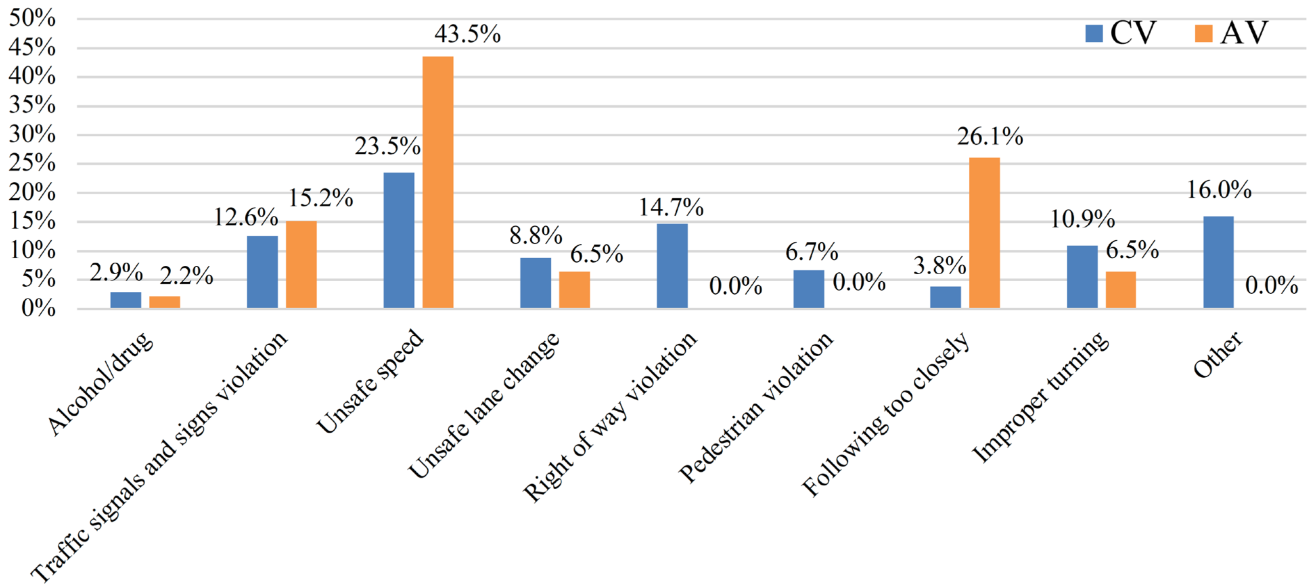

Fig. 9 Distribution of traffic accidents according to drivers' errors, created by H. Szűcs based on Petrović et al. (2020)

were caused by AV itself, while 93.7% were caused by other parties, including pedestrians, cyclists, and conventional vehicles. These accidents are considered as passive accidents in literature. According to Wang et al. (2020), the avoidance of passive accidents is a critical issue for the road safety of AVs, which could drastically reduce the number of AV accidents in the future. Wang et al. (2020) emphasized that the majority of AV-related accidents are not caused by the AV, but by another vehicle, cyclist, or pedestrian. Therefore, it is essential for AVs to be able to effectively recognize the dangers caused by others, predict dangerous behavior, and intervene effectively to prevent an accident. Without these, the number of AV accidents will not be sufficiently reduced (Wang et al., 2020).

4 Development challenges and opportunities

There are still a large number of problems and challenges in the development of autonomous vehicles that still need to be addressed by manufacturers. These include optimizing the dynamic behavior of the vehicle, the risk of cyber attacks, or computer vision and detection. For these improvements, tests under real driving conditions are essential, in which data on the vehicle, accidents, traffic, and weather can also be collected. Through this data, the behavior and reaction of the vehicle can be optimized. One of the biggest opportunities for AVs is fuel consumption, CO_2 emissions, and pollutant emission reductions, which can help to meet future climate targets. This potential direction of development is expected to receive serious attention due to increasingly stringent emission standards (Cao and Zöldy, 2020; Khadka et al., 2021; Olofsson and Nielsen, 2021; Winkle, 2016).

Vehicles use a variety of sensors to gather information, primarily radars, lidars, infrared and ultrasonic sensors, and various cameras. Fig. 10 shows the measurement principles of each sensor in a simplified and color-coded way and compares it with human perception under poor visibility conditions. At the top of Fig. 10, the radar detection was marked with a blue star and the lidar with a yellow rectangle. In the middle of Fig. 10, the camera detection is marked in green and red. At the bottom of Fig. 10, human perception is also illustrated along with the signals from the sensors, thus illustrating well the boundaries of human and machine perception and their differences. An interesting detection error can also be seen in Fig. 10. Detection of the left radar is considered as a false detection because it is a reflection of light from the wet path. This phenomenon is easily perceptible to the human eye, but it is still difficult for computer vision. The example demonstrates well that developers still face a large number of technical challenges in developing AV detection and computer vision. Nevertheless, there is great potential in the development of computer detection, as the AVs can detect much more in poor visibility conditions than the driver of a conventional vehicle (Winkle, 2016).

Researchers are developing different models to optimize the dynamic behavior of autonomous vehicles to study critical situations, e.g., lane departure. The combined goal

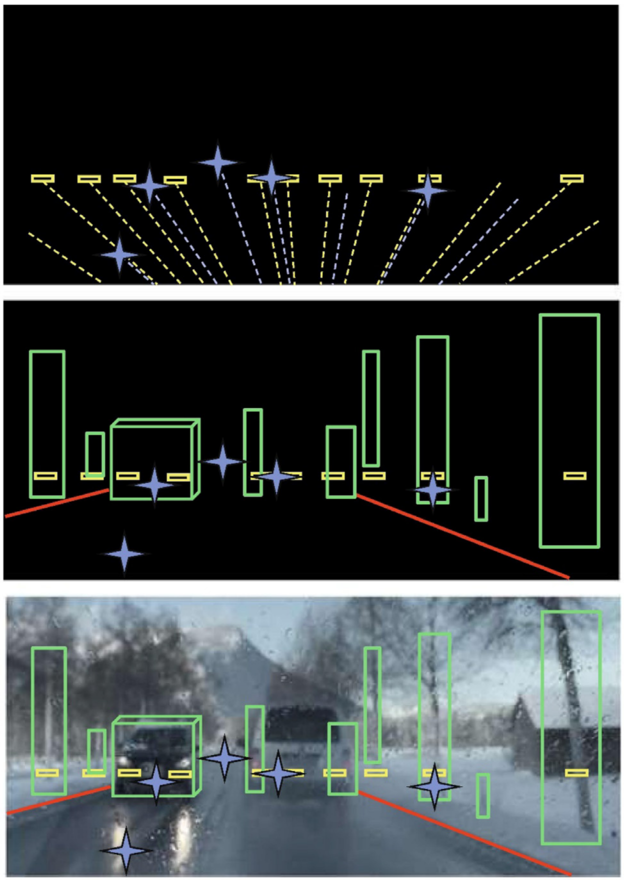

Fig. 10 Comparison of the machine and human perception and boundaries (© Winkle, 2016:Fig. 17.8)

of these models is to effectively prevent accidents. The use of past accident data in algorithms is particularly important for numerical optimization of vehicle behavior. These methods help to avoid accidents (i.e., by using lane-keeping) or to mitigate the damage caused by accidents (e.g., by reducing speed). For this reason, building and maintaining an accident database for autonomous vehicles play a particularly important role in optimizing their dynamic behavior (Olofsson and Nielsen, 2021).

Cybersecurity is essential for both the security and reliability of connected and autonomous vehicles. This is because hackers mean a high-security risk to AVs. Both computer vision and networks are essential for the efficient operation of autonomous vehicles, thereby making AVs vulnerable to cyber-attacks. For this reason, it is especially important to address computer security issues and identify vulnerabilities. Such vulnerabilities include GPS, image recognition, and light detection. By hacking the GPS system, hackers can set the wrong direction for vehicles or control or influence the route of a vehicle. The vehicle system can be misled when detecting traffic signs or graffiti (pattern attack). Currently, even autonomous vehicles are vulnerable to cyberattacks and hackers, which manufacturers will have to deal with in the future. Due to the detailed problems, the security risk needs to be minimized for AVs to be traffic safe and reliable (Khadka et al., 2021).

Cao and Zöldy (2020) investigated the possibilities of reducing fuel consumption and pollutant emissions of autonomous vehicles. Driving style and conditions as well as vehicle type are important factors in optimizing energy consumption. The different driving style of the AV reduces fuel consumption by up to 10–20%. AVs can reduce their energy consumption and emissions by avoiding unnecessary stops, driving at a constant speed, shifting the transmission into optimal gear, and applying optimum braking and acceleration. These optimal driving conditions cannot be solved by the driver of a conventional vehicle, as such optimization requires fast calculations. The type of the vehicle, especially its weight, has a significant effect on consumption and emissions, the heavier the vehicle, the more energy, and emissions are needed to move it. This is the reason why vehicle manufacturers have begun to engage in the application and development of lightweight aluminum bodies (Cao and Zöldy, 2020).

5 Moral aspects of AVs

The ethics and moral issues of AVs have received a great deal of attention recently, which remains an open and sensitive issue. The moral theory of how vehicles should behave in certain accident situations plays an important role in AV development. Accident situations, that result in human injury or even death, are really critical. In such situations, moral judgment would be the task of an algorithm that was pre-programmed based on some principles. Such unavoidable accident situations are called the moral dilemma of AVs when the algorithm has to make an ethical decision (Evans et al., 2020; Rhim et al., 2021). It is important to note that personal morality also differs between cultures, e.g., Eastern and Western cultures have different views on certain situations (Rhim et al., 2021). The trolley dilemma has also been frequently mentioned in moral problems related to AVs. When defining good and bad in AV decision-making, it is questionable whether it should be based on a set of rules or outcomes (Rhim et al., 2021). However, discrimination between potential victims in AV accidents is condemned by the majority (Evans et al., 2020).

It is also important that the passenger is distinguished from other vulnerable road users by the vehicle (Herzog and Hoffmann, 2020). According to a survey, people prefer AVs that save more lives but would not buy them because the vehicle could sacrifice them as well (Rhim et al., 2021). Another interesting question is whether AVs could violate traffic rules in order to alleviate dangerous situations (Herzog and Hoffmann, 2020). Penmetsa et al. (2021) examined the perception of people before and after two fatal AV accidents through the use of social media (Twitter data). After the incidents, the number of negative tweets related to self-driving technology increased. Generally, public fear of AVs can greatly delay or even prevent the adoption of AVs.

6 Summary and outlook

Autonomous vehicles will have a significant impact on our lives in many areas and will completely transform transport, passenger, and freight transport. The implementation of autonomous vehicle safety and accident-free traffic ("Vision Zero") is an active research area nowadays, which is also addressed by many companies (e.g., Google, Apple, BMW, Volvo). Currently, AV technology still needs to be developed in many areas (i.e., improving computer vision and detection or cybersecurity), but it has significant potential to reduce road accidents by eliminating the possibility of human error. In addition, AV technology can also reduce CO_2 and emissions.

In the case of AVs, the most common accident is rear-end accident, in which a conventional vehicle collides with the AV from the rear. The primary cause of these accidents can be found in the different dynamic behavior of the vehicle. Drivers of conventional vehicles need to get used to the different driving styles of the AV. An indication/sign that the vehicle is an AV can be of great help in avoiding accidents, thus alerting the driver of a conventional vehicle to different dynamic behavior. It is noteworthy that there was no pedestrian accident caused by an AV and no accident between two AVs. Intersections and their immediate surroundings are particularly critical for the location of AV accidents. Since most AV accidents are not caused by the AV but by another party, it is also important to address the avoidance of passive accidents in the future. The AV must recognize dangerous situations and respond correctly.

AVs still require a huge number of improvements to minimize accidents. Among other things, the numerical optimization of the dynamic behavior of the vehicle, in which data from accident databases are used, can contribute to accident prevention. The moral and ethical issues of AVs will also need to be addressed in the future, which is still an open and sensitive topic. Autonomous vehicles also represent a great opportunity in terms of fuel consumption, CO_2 emissions, and pollutant emission reductions, which is expected to lead to even more attention in the development of AVs in the future.

Acknowledgment

We would like to thank Professor Dr. Csaba Koren for his advice and guidance.

References

Cao, H., Zöldy, M. (2020) "An Investigation of Autonomous Vehicle Roundabout Situation", Periodica Polytechnica Transportation Engineering, 48(3), pp. 236–241. https://doi.org/10.3311/PPtr.13762

Evans, K., de Moura, N., Chauvier, S., Chatila, R., Dogan, E. (2020) "Ethical Decision Making in Autonomous Vehicles: The AV Ethics Project", Science and Engineering Ethics, 26(6), pp. 3285–3312. https://doi.org/10.1007/s11948-020-00272-8

Favarò, F. M., Nader, N., Eurich, S. O., Tripp, M., Varadaraju, N. (2017) "Examining accident reports involving autonomous vehicles in California", PLoS ONE 12(9), e0184952. https://doi.org/10.1371/journal.pone.0184952

Herzog, C., Hoffmann, N. (2020) "Automating Morals – On the Morality of Automation Technology, Ironies of Automation and Responsible Research and Innovation", IFAC-PapersOnLine, 53(2), pp. 17457–17462. https://doi.org/10.1016/j.ifacol.2020.12.2120

Khadka, A., Karypidis, P., Lytos, A., Efstathopoulos, G. (2021) "A benchmarking framework for cyber-attacks on autonomous vehicles", Transportation Research Procedia, 52, pp. 323–330. https://doi.org/10.1016/j.trpro.2021.01.038

Olofsson, B., Nielsen, L. (2021) "Using Crash Databases to Predict Effectiveness of New Autonomous Vehicle Maneuvers for Lane-Departure Injury Reduction", IEEE Transactions on Intelligent Transportation Systems, 22(6), pp. 3479–3490. https://doi.org/10.1109/TITS.2020.2983553

Penmetsa, P., Sheinidashtegol, P., Musaev, A., Adanu, E. K., Hudnall, M. (2021) "Effects of the autonomous vehicle crashes on public perception of the technology", IATSS Research, 45(4), pp. 485–492. https://doi.org/10.1016/j.iatssr.2021.04.003

Petrović, D., Mijailović, R., Pešić, D. (2020) "Traffic Accidents with Autonomous Vehicles: Type of Collisions, Manoeuvres and Errors of Conventional Vehicles' Drivers", Transportation Research Procedia, 45, pp. 161–168. https://doi.org/10.1016/j.trpro.2020.03.003

Rhim, J., Lee, J-H., Chen, M., Lim, A. (2021) "A Deeper Look at Autonomous Vehicle Ethics: An Integrative Ethical Decision-Making Framework to Explain Moral Pluralism", Frontiers in Robotics and AI, 8, 632394.
https://doi.org/10.3389/frobt.2021.632394

Sarkar, S. B., Mohan, B. C. (2019) "Review on Autonomous Vehicle Challenges", In: Bapi, R., Rao, K., Prasad, M. (eds.) First International Conference on Artificial Intelligence and Cognitive Computing, Springer, pp. 593–603. ISBN 978-981-13-1579-4
https://doi.org/10.1007/978-981-13-1580-0_57

Tettamanti, T., Varga, I., Szalay, Z. (2016) "Impacts of Autonomous Cars from a Traffic Engineering Perspective", Periodica Polytechnica Transportation Engineering, 44(4), pp. 244–250.
https://doi.org/10.3311/PPtr.9464

Törő, O., Bécsi, T., Aradi, S. (2016) "Design of Lane Keeping Algorithm of Autonomous Vehicle", Periodica Polytechnica Transportation Engineering, 44(1), pp. 60–68.
https://doi.org/10.3311/PPtr.8177

Wang, J., Zhang, L., Huang, Y., Zhao, J. (2020) "Safety of Autonomous Vehicles", Journal of Advanced Transportation, 2020, 8867757.
https://doi.org/10.1155/2020/8867757

Winkle, T. (2016) "Safety Benefits of Automated Vehicles: Extended Findings from Accident Research for Development, Validation and Testing", In: Maurer, M., Gerdes, J., Lenz, B., Winner, H. (eds.) Autonomous Driving, Springer, pp. 335–364. ISBN 978-3-662-48845-4
https://doi.org/10.1007/978-3-662-48847-8_17