Transportation Research Interdisciplinary Perspectives 24 (2024) 101033

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.sciencedirect.com/journal/transportation-research-interdisciplinary-perspectives

Automated driving regulations – where are we now?

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ARTICLE INFO

Keywords:
Accountability
Automated vehicle
Driver
Safety standards
Self-driving car
Traffic laws

ABSTRACT

Self-driving vehicles are a tool that contributes significantly to sustainable development, both nationally and globally, as their positive effects extend beyond national borders. For their wider use, we need an appropriate regulatory framework as well as certain technical capabilities. It is not only technically sophisticated vehicles that are important, but also the infrastructure that supports automated driving. This paper analyses the legal frameworks of selected states, aside from those frameworks at international and EU level. The research indicates that national regulations often concentrate on the testing phase of automated vehicles. Furthermore, these rules frequently require a certain degree of driver involvement, highlighting that some form of human control remains essential. It seems that regulation does not match the speed of technological development or is sometimes somehow unsynchronized with it.

Introduction

The automotive sector undeniably plays a significant role in the economy, particularly within certain EU member states. This influential industry is frequently subject to lobbying efforts, often intended to preserve existing power dynamics within the realm of the automotive industry.

In this respect, a conflict of private and public interests becomes evident. The main objective of automated vehicles or automated driving systems (ADSs) is to ensure safer driving conditions. Data from the European Commission highlights the urgency of this goal: annually in Europe, human error is responsible for over 90 % of road accidents. Moreover, these accidents result in the tragic loss of more than 40,000 lives and cause injuries to more than 1.5 million individuals (European Commission, 2003).

Beyond potentially ensuring safer driving, ADSs[1] may offer a multitude of other societal benefits. They can aid in alleviating traffic congestion, simplify parking procedures, and help environmentally friendly driving. Additionally, they have the potential to increase the mobility of elderly and disabled individuals, as well as other underserved communities, thereby promoting inclusivity in transportation (Wu et al., 2021).

It must be noted that a higher level of safety due to use of ADSs might be reached only when a certain number of such vehicles are operating among traffic. During the transition period when these vehicles are in a minority, human drivers might still be better at understanding the driving environment and preventing accidents (Bertolini and Riccaboni, 2021).

Despite many benefits, ADSs raises several legal and ethical questions, which need to be regulated on both EU and national levels. For now, new regulations do not seem to follow the trend of fast-developing technology. Although various authors (Gurney, 2013; Surden and Williams, 2016) highlight that new regulation is absolutely necessary, and that existing legal frameworks are only partly useful. In particular, there are certain specific situations introduced by new technologies that are not envisaged by current legislation, or else not regulated adequately. There are various issues to be solved, such as liability in case of accidents, privacy protection, security risks in terms of intrusions into the system etc. We need regulations that keep personal safety as the highest priority, but that do not hinder the future development of automated vehicles. This means we need a consistent certification framework and a standardized set of safety tests for the acceptance of automated vehicles

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[1] For the purposes of this paper, we use the term automated driving system (ADS) or self-driving vehicle, which refers to a vehicle with various sensors (cameras, radars, LIDARs, etc.) with the help of which it detects the environment and enables safe driving with little or no human effort. In the literature, other terms such as “autonomous,” “automated,” and “cooperative” are also used to describe these vehicles. More on this is explained in chapter Driving Automation: features and definitions.

https://doi.org/10.1016/j.trip.2024.101033
Received 13 July 2023; Received in revised form 20 January 2024; Accepted 3 February 2024
Available online 28 February 2024

(Hansson, 2020).

There are also ethical, not just legal, questions; choices that may affect the life or death of humans. Furthermore, there are technical obstacles such as artificial intelligence (hereinafter AI) properly reading occurrences in the environment (behavior of cyclists, pedestrians, other vehicles, animals)[2]; correctly reading signs (e.g. signs that are damaged; hacked with stickers etc.); questionable adequacy of road infrastructure; questionable up-to-dateness of high-definition maps; and detecting the environment correctly.[3] For example, in the case of a regular, human-driven vehicle, the pedestrian and the driver have eye contact, whereby the pedestrian can detect whether or not the driver will stop (Nuñez Velasco et al., 2021; Stange et al., 2022). The driver can also wave the pedestrian to cross the road (Surden and Williams, 2016).[4] The nature of ADSs, on the other hand, is "autistic and narcissistic" (Teffer, 2018). A pedestrian will find it difficult to communicate with a self-driving vehicle on the same "intuitive" level. For example, when crossing the road with a self-driving car approaching, the latter slows down. A pedestrian could understand this to mean that the car that will stop. However, this will not necessarily be the case. Furthermore, drivers are capable of recognizing specific situations such as a visually impaired pedestrian crossing a road. The latter might not be so easy for an ADS.[5] In 2018, an Uber self-driving vehicle killed a pedestrian who crossed a road outside of a crosswalk (National Transportation Safety Board, 2018). There are some possible solutions to these problems. For example, Drive.ai installed LED signs outside the vehicle telling pedestrians what is going on (e.g. "going now, don't cross" and "waiting for you.") (Cahlan, 2018). Another question is the capability of these vehicles to react to unexpected road situations, such as ambulances or fire engines.[6] Human-machine interaction brings several challenges, such as misunderstanding of automation, overreliance on automation, and failed feedback on system states provided by the automation (Sheridan and Parasuraman, 2005). Finally, the automation can have positive and negative effects on human performance. For example, (Parasuraman et al., 2000) analyze the following aspects of human performance: mental workload, situation awareness, complacency, and skill loss.

As mentioned, ADSs have environmental and social influence. The environmental implications of ADSs are complex and largely influenced by user behavior and system adoption. These dynamics are explored in a dedicated section later in this paper. Regarding societal impact, the high initial cost of ADSs may initially limit their diffusion to various levels of society, leading to a disparity in safety access. However, such discrepancies exist in today's society, where expensive vehicles often have more safety features than cheaper ones. In the longer term, car-sharing could diffuse, raising questions about the preferences of driving enthusiasts and about potential shifts away from personal car ownership. Furthermore, ADSs could be transformative for individuals with disabilities and for others without the possibility of driving, granting them increased societal access and improving their quality of life.

On the other hand, another societal effect is the potential job shift of professional drivers (truck drivers; taxi drivers; bus drivers, etc.) While there may be new opportunities in areas like technical support for ADSs, it remains uncertain whether these will compensate for the jobs lost. Equally pressing is the reduction of human driving skills, as already observed in aviation, where over-reliance on autopilot compromised pilots' abilities. This reflects a broader problem of complacency and over-trust in automation. As noted by (Parasuraman et al., 2000), complacency is most pronounced when operators, managing multiple tasks, neglect to monitor the failure of automated systems. An increased focus on complete automation can lead to overestimation of the capability of self-sufficiency, which can fail when faced with scenarios outside of the routine (Bradshaw et al., 2013). Greater machine autonomy doesn't necessarily disprove the need for human capabilities. On the contrary, it changes the dynamics of human–machine interdependent activities, reassessing human skills (Bradshaw et al., 2013). Challenges include maintaining situational awareness and a capacity for quick intervention, especially when automation behaves unexpectedly. Despite these concerns, ADSs are increasingly present in our society and needs an effective regulatory framework.

This paper provides an overview of various issues relating to self-driving vehicles, such as ethical dilemmas and various legal questions that need to be addressed by new regulation, such as liability, cyber security, and personal data protection. Finally, it provides a comparative analysis of the laws of the states that have already enacted this content to certain extent (e.g. United States of America, United Kingdom, Norway, Sweden, Germany, Italy, and Slovenia). We also look at the latest developments at the EU level.

Driving Automation: features and definitions

The authors recommend to refer to the taxonomy given by SAE International (formerly the Society of Automotive Engineers) (SAE International, 2021). According to SAE guidelines, the term "autonomous" is ambiguous because it does not clarify if the system depends on communication and/or cooperation with outside entities for important functionality (such as data acquisition and collection). In fact, in jurisprudence, autonomy refers to the capacity for self-governance, while ADS is generally not "self-governing."

According to (SAE International, 2021), the general term to be used is "**driving automation system**", which refers to the system that performs part or all of the dynamic driving task on a sustained basis. SAE suggests also the more specific definition of an **Automated Driving System (ADS)** as the hardware and software that are collectively capable of performing the entire dynamic driving task on a sustained basis. This term is used by SAE, and also in this paper, specifically to describe a Level 3, 4, or 5 driving automation system according to the definitions below. In this paper, "self-driving vehicle" is used as synonym of ADS, referring to automated motor vehicles moving on land.

The final goal of the manufacturers is a vehicle that drives by itself, without human management. SAE established the six-level scale of driving automation (see Fig. 1), from no automation to full automation:

Level 0: No Driving Automation: The human does the driving. However, some features, such as automatic emergency braking, blind spot warning, and lane departure warning, can provide assistance to the driver.

Level 1: Driver Assistance: Level one has features that provide steering support or brake and acceleration support to the driver (e.g. lane centering or adaptive cruise control).

Level 2: Partial Driving Automation: The vehicle has features that support the driver, such as steering and brake and acceleration support (e.g. the vehicle can at the same time perform lane centering and adaptive cruise control).

Level 3: Conditional Driving Automation: The vehicle has features that can drive the vehicle under certain limited conditions, and will not operate autonomously unless these conditions are fulfilled. The driver still needs to stay alert and take over if needed.

Level 4: High Driving Automation: The system can perform all driving tasks without a driver under specific conditions; automated driving features will not require the driver to take over.

[2] E.g., Volvo discovered that software could recognize caribou, deer and elk, but would not recognize kangaroo (Zhou, 2017).

[3] E.g., Tesla fatal accident in 2016 where the driver nor the self-driving automation system did not see the tractor-trailer due to brightly lit sky and no brakes were applied (Thompson, 2017).

[4] Authors apply the psychologists' theory of the mind, which allows estimation of other people thinking or behavior from our own internal mental states. Theory of mind cognitive mechanisms enable us fast and unconscious decisions about others behavior and as such keep us safe within the driving context.

[5] E.g. Collision of visually impaired pedestrian and a self-driving vehicle in 2021 in Olympic and Paralympic Games in Tokyo (Shivdas and Kelly, 2021).

[6] E. g. In April 2022, Cruise's testing vehicle blocked fire engine on emergency call (Marshall, 2022).

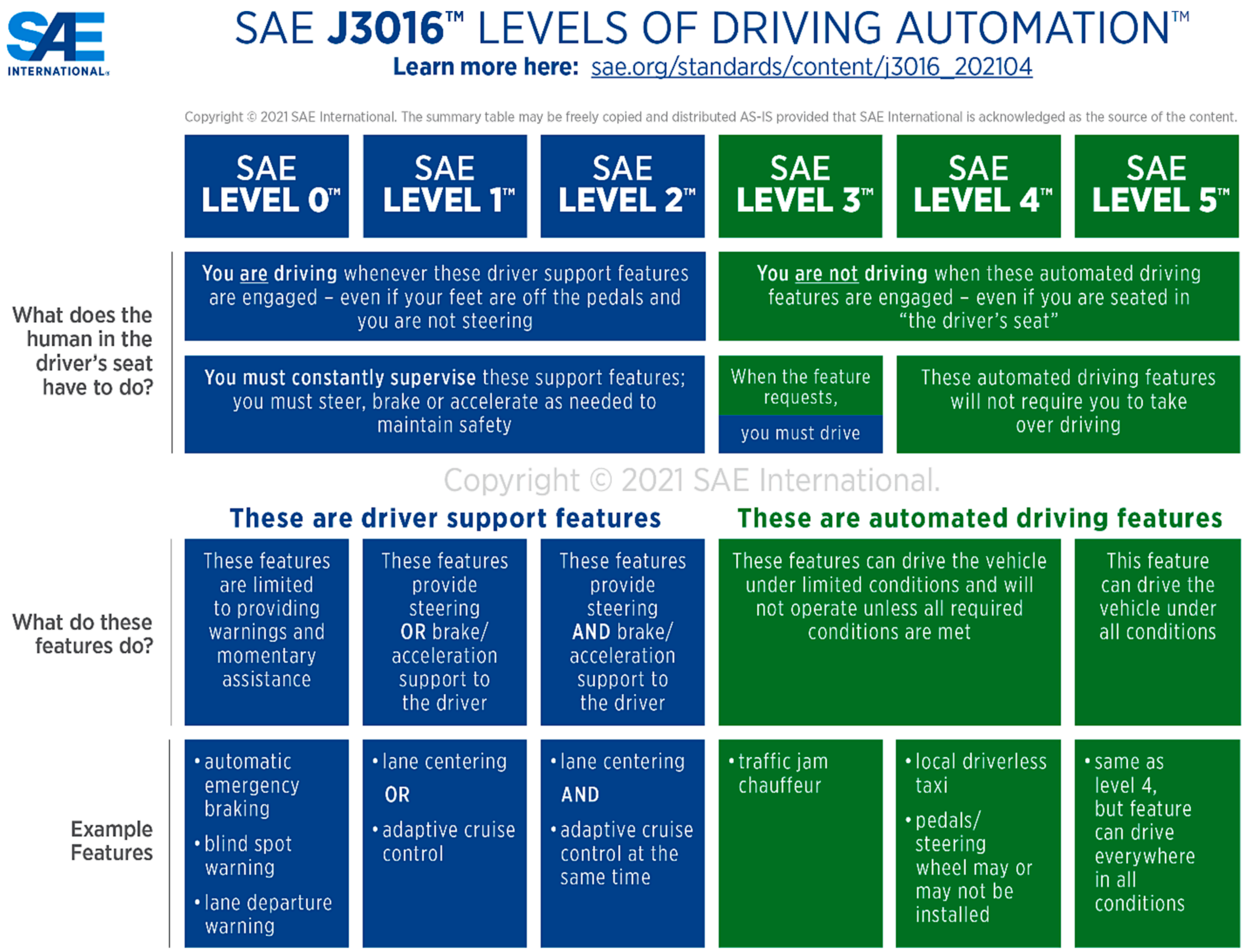

Fig. 1. SAE's six levels of automation.
Source: SAE International, 2021

Level 5: Full Driving Automation: Vehicles performs all driving tasks under any conditions without any human attention or intervention.

All levels can be implemented on a vehicle that has manual controls, so that the user can decide to drive at any time, but only level 4 and 5 can be implemented in vehicles without manual controls.

The most significant leap is from level 2 to level 3, as the driver can legally take his attention off the road and, under certain conditions, the system manufacturer may be liable for any potential accidents.

In 2022, Mercedes' Drive Pilot was the world's first fully certified Level 3 automated driving system.[7] Nevertheless, current models on the market with self-driving capabilities are mainly level two: Tesla's Autopilot with "Full Self-Driving", Audi's Traffic Jam Assist, GM's Super Cruise, BMW's Extended Traffic Jam Assistant, Ford's Blue Cruise, Hyundai's automated driving package, and many more (The State of Level 3 Autonomous Driving in 2023 | AUTOCRYPT, 2023). This means the vehicle still needs a human behind the steering wheel who can take over if needed for safety reasons. Moreover, the use of the automation function is usually recommended only in good weather or other beneficial driving conditions. Level four vehicles already exist and are used in certain predefined routes and under specific circumstances (e.g. shuttle buses at airports, university campuses, etc.) (Altunyaldiz, 2020). At level four, the system can perform all driving tasks without a driver under specific conditions. Level five (full automation) vehicles, which perform all driving tasks in any operating conditions without any human attention or intervention, are still not on the market. Today's driver assistance technologies do not qualify as self-driving since they still need human control. However, for commercial purposes, some car manufacturers misleadingly market their vehicles as "automated" or "self-driving." Such misrepresentation is misleading for consumers (Barry, 2021), who wrongly over-rely on these vehicles, increasing the risk of accidents[8]. Currently, we are still in a transition phase, from active driving to automated driving, which means that until full automation is available, drivers need to remain vigilant for a longer time, potentially compromising safety (Banks et al., 2018).

Two approaches towards full autonomy appear to being pursued: incremental progression through the SAE levels, and the direct-to-level-four approach (see Fig. 1). The incremental approach is typical for original equipment manufacturers (e.g. Tesla, BMW, Mercedes). In

[7] Mercedes' Drive Pilot system, the first legally approved level 3 system, will drive only within geofenced areas on the German highway (up to 60km/h). The driver will be able to take their hands off the wheel and allow the ADS to assume total control of the car's functions. The company will accept legal responsibility for accidents caused directly by mistake of the ADS (technology). If an accident is caused due to driver's failure to exercise due care, the driver will be responsible for the damage (Kotoulas, 2022; MacKenzie, 2022; Wilkinson, 2021).

[8] E.g. recently, there was a campaign against Tesla's Full Self Driving Tech (Brooks, 2023).

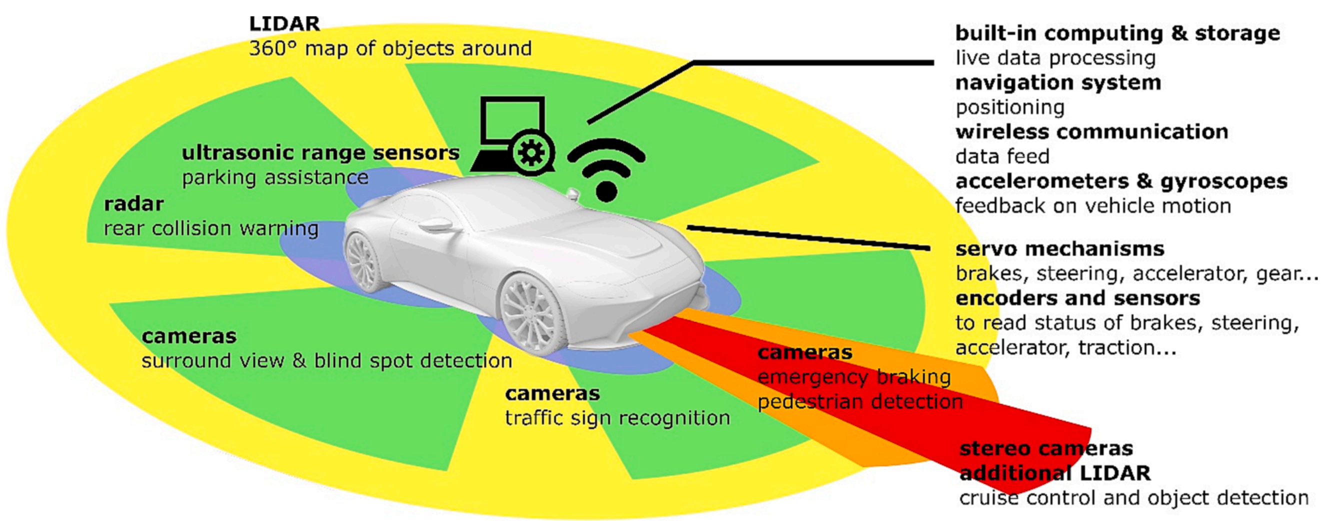

Fig. 2. Technical features of ADS.

contrast, start-ups like Google's Waymo[9] opt for the direct-to-level-four approach, focusing on automated trialing, and aiming to provide mobility as a service (Jeffs, 2022). Despite differences, all these vehicles rely on technical features and data processing integrated into the vehicle. Another approach, however, is to exploit not only the ADS's capabilities, but also the road and infrastructure. An example of this kind of real-life test-track was done by prof. Sahin Albayrak, executive director of the Distributed Artificial Intelligence Lab in Berlin (Altunyaldiz, 2020).

Currently, one of the most common approaches is to reinforce ADS by introducing the supervision of a human operator outside the vehicle. The role of a human operator outside a self-driving vehicle can be encompassed by the concept of "remote assistant," as opposed to "remote driver."

A **remote assistant** provides strategic or tactical guidance to the ADS, providing indirect control. The assistant is not involved in the operational driving functions, but assists in decision making, such as route planning, handling uncertainties (e.g. unfamiliar patterns) and emergency management.

The **remote driver** is responsible for operational driving functions (steering, accelerating, braking …) with hands-on control. Some examples may include taking over for complex maneuvers, or in areas where the vehicle can't operate in an automated manner, or for testing and training.

Sometimes the two definitions might have overlapping areas. A remote operator may perform a fallback, bringing the vehicle to a minimal risk condition, or may assist in areas with inadequate or ambiguous signals. For more details please refer to (Carey and Lienert, 2022; Smith, 2022).

However, having a remote human operator, who can assist drivers or passengers in case of technical issues, can help in building trust in the use of these technologies (Davies, 2017).

From a technical perspective, ADSs need various technical features in order to function, such as sensors, radars, global positioning system, on-board cameras for navigation and detecting environment, servo mechanisms to control brakes, steering, accelerator, gears (if present) and much more (a brief overview is presented in Fig. 2). Data collected by this technology is saved by advanced control systems (Khan et al., 2021), which take relevant decisions about navigation and detected obstacles. The system needs to read traffic signals and navigate safely among other vehicles to bring the vehicle to the desired destination. There are three technologies used: sensors, connectivity, and software or control algorithms. Most of the sensors required for automated driving are already available, integrated into advanced safety solutions like lane-keeping, collision alerts, and blind-spot warnings (Ignatious et al., 2022). Sensors like radar, lidar, ultrasonic functions, and cameras collectively gather the data necessary for the safe operation of the vehicle. Connectivity allows vehicles to get updates about traffic, weather, maps, neighborhood vehicles, road infrastructure, etc. The above data is important for monitoring the environment surrounding the vehicle, and consequently for making the right decisions, such as braking or withdrawal from dangerous conditions. Software or control algorithms are needed to reliably obtain data from sensors and connectivity, and to make decisions about control, braking, acceleration, etc. This decision-making part must faultlessly handle simple and more complicated situations which may arise while driving.

All the information gathered by the aforementioned technologies is processed in order for the vehicle to define location, follow the route, and appropriately respond to the environment (e.g. to road signs, lines, obstacles, other vehicles, pedestrians, cyclists, etc.) This processing is done via built-in computing systems using traditional algorithms or AI. These algorithms have large datasets that accumulate information from the vehicle's driving history as well as from other vehicles within the same system. Based on this information, they constantly improve performance. Looking into levels three and four, where the system has full control of the vehicle (at least for some time), the software takes decisions on life and death (Altunyaldiz, 2020).

Dynamic Driving Task (DDT): According to SAE: "All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints" (SAE International, 2021).

Minimal risk condition (MRC): According to SAE: "A stable, stopped condition to which a user or an ADS may bring a vehicle after performing the dynamic driving task fallback in order to reduce the risk of a crash when a given trip cannot or should not be continued" (SAE International, 2021). In essence, an MRC is a safe state that the vehicle can be put into when it's not feasible or safe to continue the trip. It can mean stopping the vehicle at a parking place beside the road (when it is not dangerous).

At Levels 1 and 2, the human driver is expected to achieve an MRC as needed.

At Level 3, the DDT fallback-ready user is expected to achieve an MRC when necessary, or to otherwise perform the DDT if the vehicle is operable.

[9] Other examples of ADS resulting from start-ups are: Cruise, Baidu, and AutoX.

At Levels 4 and 5, the ADS is capable of automatically achieving an MRC when necessary, such as due to an exit from the Operational Design Domain or a system failure with an effect on the DDT.

Dynamic Driving Task fallback: the actions taken by either the human driver or the ADS to bring the vehicle to a safe state (MRC) when the ADS is unable to continue the DDT, or when a human driver does not respond appropriately to a takeover request (SAE International, 2021; Zhang et al., 2021).

Other definitions

SAE definitions focus on the term "driving automation system" to avoid ambiguity, and clearly distinguishes between different automation levels, limiting ADS to levels 3, 4 and 5. This division into levels is crucial for regulatory and safety considerations, as each level may require different standards and interventions. Moreover, SAE definitions emphasize the capacity of the hardware and software system to perform the entire dynamic driving task (controlling the vehicle's motion, reading the environment, and responding to events) on a sustained basis (SAE International, 2021).

For the aforementioned reasons, we consider SAE definitions to be the most exhaustive. Nevertheless, for the sake of completeness, we will also cover other definitions used by other European institutions.

The **European Parliamentary Research Service (EPRS)** (Pillath, 2016) defines an **automated vehicle** as a motor vehicle - such as a car, bus, or truck - equipped with technology that assists the driver by delegating certain driving functions to a computer system. This means the human operator still retains some control and responsibility. On the other hand, EPRS defines **autonomous vehicle** as a more advanced form of automation, capable of executing all driving tasks independently without any human intervention (Pillath, 2016).

EU regulation 2019/2144 of the European Parliament (EUR-Lex - 32019R2144 - EN - EUR-Lex, 2019) and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users (hereinafter EU Regulation 2019/2144) (EUR-Lex - 4434255 - EN - EUR-Lex Type-approval requirements to ensure the general safety of vehicles and the protection of vulnerable road users, 2019). As defined in points 21 and 22 of Article 3 an "(21) '*automated vehicle*' means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required*; (22) 'fully automated vehicle'* means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision."

The amendment to the Vienna Convention on Road Traffic prepared by United Nations Economic Commission for Europe's Global Forum for Road Traffic Safety (Amendment proposal to the 1968 Convention on Road Traffic, 2020) adds two new definitions in Article 1: "*(ac) "Automated driving system" refers to a vehicle system that uses both hardware and software to exercise dynamic control of a vehicle on a sustained basis." (ac) "Dynamic control" refers to carrying out all the real-time operational and tactical functions required to move the vehicle. This includes controlling the vehicle's lateral and longitudinal motion, monitoring the road, responding to events in the road traffic, and planning and signaling for maneuvers*."[10] The amendments of Article 1 and new Article 34 bis to the Vienna Convention on Road Traffic were accepted by January 2022 and entered into force on 14 July 2022.

As another example, the **Automated and Electric Vehicles Act (2018) of the United Kingdom** (Commission, 2022d), which was one of the first European regulations, refers to automated vehicles as vehicles "*designed or adapted to be capable, in at least some circumstances or situations, of safely driving themselves, and may lawfully be used when driving themselves, in at least some circumstances or situations, on roads or other public places in Great Britain*." Furthermore, the UK Automated and Electric Vehicles Act (2018) states, "*a vehicle is "driving itself" if it is operating in a mode in which it is not being controlled, and does not need to be monitored, by an individual.*"

As already mentioned at the beginning of this chapter, automated and autonomous are not necessarily understood as synonyms, as seems to be the case in Europe according to EU Regulation 2019/2144. Autonomous means self-governing (Antsaklis et al., 1991), automated means to be made automatic. For example, as argued by (Antsaklis et al., 1991), several historical projects connected to vehicle automation have been automated because of heavy reliance on artificial aids in their environment, such as magnetic strips. Automated control means acceptable execution under serious variability in the environment, and the capability to recompense for system non-performance without external intervention (Antsaklis et al., 1991). Furthermore, we can distinguish three dimensions of autonomy. The first one is independence, which relates to system's ability to perform a task on its own (capability independence), and organizational independence, which means that the system achieves tasks within socio-technical structure as a whole (Sartor and Omicini, 2016). The second dimension is cognitive skills, which refers to a system's capacity to perform complex discriminative functions. This relates to information acquisition, analysis, decision adoption, and implementation (Sartor and Omicini, 2016). Finally, the third dimension is cognitive architecture, comprised of a system's direction towards a purpose, adaptiveness, and capacity to have representations of the environment, to have objectives to attain, and to recognize suitable means (Sartor and Omicini, 2016).

Ethical dilemmas and ADS

Automatic systems taking decisions that affect the lives of humans raise ethical concerns of various kinds. Some at more fundamental, philosophical level, and others on a practical level. One popular example is the so-called "trolley problem",[11] where the automatic system needs to make a moral decision about who may live and who may die or be injured. According to utilitarian ethics, the algorithm has to make a decision to protect the maximum number of lives possible, or maximize the benefit for the greatest number of people. However, in practice this approach is too simple to tackle problems as complex as deciding on life and death in possible accidents. Although most people like the utilitarian approach of maximizing the benefit for the greatest number of people, they would not buy such a vehicle, since when they are in the vehicle, they want to be the one that the system primarily protects. Moreover, they do not want regulation to follow this utilitarian approach (Bonnefon et al., 2016).

Another approach is Kantian deontology, which finds utilitarian objectification of the individual unacceptable. The individual should not be sacrificed to achieve a certain goal. This theory proposes to define a universal law that needs to be followed in every situation (there is no weighing up of which decision maximizes the benefit).

[10] Moreover, the Amendment adds new Article 34 bis: "*The requirement that every moving vehicle or combination of vehicles shall have a driver is deemed to be satisfied while the vehicle is using an automated driving system which complies with: (a) domestic technical regulations, and any applicable international legal instrument, concerning wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles, and (b) domestic legislation governing operation.*" (Amendment proposal to the 1968 Convention on Road Traffic, 2020)

[11] A "trolley problem" is a series of thought experiments in ethics and psychology, involving stylized ethical dilemmas of whether to sacrifice one person to save a larger number. The typical example describes a situation where a runaway trolley with five passengers is going to crash, killing all five of them. However, a bystander can intercede and redirect the vehicle to kill just one person on a different track.

The big questions are: Who decides on the ethical approach? And should the same ethical approach be built into all ADSs? (Contissa et al., 2017) propose the approach of an ethical knob which enables the driver to decide which ethical line the ADS should follow. Either the altruist approach, which saves others, the egoist approach, which saves the passengers, or the impartial approach, which gives equal importance to passengers and third parties. The altruistic mode can be seen as based on the utilitarian approach. Interestingly, altruism can be embedded within the egoist mode, protecting not just the passenger, but also the passenger's family or significant other. With the ethical knob, the responsibility to make ethical choices lies within the ADS users and not manufacturers. (Contissa et al., 2017) further argue that the egoistic approach increases the chances of accidents and should therefore have a higher insurance premium for the passengers who choose this mode. Even if the choice of the ethical guidelines of the ADS does not fall in the hands of the users, the idea of tunable ethical settings (even if not tunable by the final user) might be of help for many use cases, like in the use of ADS across areas with different regulations. Sometimes a certain degree of difficulty in achieving a global consensus on ethical guidelines for ADS is unavoidable, given cultural and legal differences.

(Gentzel, 2020) proposes an interesting hypothesis that a government of the future might mandate the use of ADS (level 5) in order to save lives. However, since in western society there is a strong value of equality before the law, the question is: How should the algorithm in the ADS be set up in order not to discriminate? His proposal is a random choice. For example, in case of a choice between hitting a child or an older person, with random choice there would be a 50 % chance of hitting one or the other. Such an approach would respect the value of equality before the law.

Although the ethical debate draws attention from the general public, in practice ADS sensors in their current form have problems distinguishing the personal attributes of people around the vehicle or of the passengers of other vehicles. Furthermore, in the future there should be no trolley problem, since the ADS will be programmed to avoid it and simply stop (Stange et al., 2022). The deterministic approach on which various ethical debates are based does not correspond to real life. Namely, it is not possible to predict at certainty what lives will be lost as a consequence of a certain driving decision. Therefore, the practice of quantifying probabilistic risks should be applied in ADSs decision-making (Contissa et al., 2017; Goodall, 2016).

Ethical considerations should be integrated into the design of the ADS. The manufacturers are the ones who decide the design and ethical framework of automated driving systems. However, since customers want priority to be given to their own safety, manufacturers may be under pressure and the ethical framework will not be optimal from a utilitarian perspective, i.e. to maximize the benefit for the greatest number of people (Altunyaldiz, 2020; Contissa et al., 2017). Therefore, the state should provide effective policy on and regulation over the matter. Such policy and regulation should, of course, be based on an internationally (globally) accepted consensus on the matter. For now, policies and regulation are more-or-less handled at the national levels of some states, providing different rules. In the future, this should change, and at least for the EU space it will be desirable to have a common framework. Important steps in that direction are the UN Regulations (see chapter Existing regulations that can serve as an example); the Vienna Convention on Road Traffic (1968 with amendments), and Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users (EUR-Lex - 32019R2144 - EN - EUR-Lex, 2019).

As argued by (Altunyaldiz, 2020), regulation should aim for full respect for the right of life. An example of such regulation is that currently defined in Germany, which strictly specifies that accident-avoidance system in these vehicles must be outlined in a way to avoid and reduce damage. If an accident is unavoidable, it must give the highest priority to the protection of human life. However, if an injury to human life cannot be avoided, no further weighting based on personal characteristics, such as age, sex, and physical or mental constitution should be done (Gesley, 2021). Moreover, the Parliamentary Assembly of the Council of Europe urges member states of the Council of Europe to regulate the matter in accordance with Council of Europe standards on human rights and rule of law, respecting privacy and the principle of legal certainty as well as the right to life (Altunyaldiz, 2020).

A comprehensive analysis of the ethical principles driving ADSs was made by the "Ethics Commission on Automated and Connected Driving" of the Federal Minister of Transport and Digital Infrastructure in Germany with the "Report of the Ethics Commission on Automated and Connected Driving" (Commission, 2017). The report focuses on safety, personal autonomy, and the balance between technological dependence and societal benefits.

The key ethical principles include:

- Prioritizing safety and mobility opportunities.
- Ensuring the protection of individuals over utilitarian considerations.
- Requiring official licensing and monitoring of ADSs.
- Balancing personal freedom with the safety and freedom of others.
- Designing technology to prevent accidents and avoid dilemma situations.
- Mandating automated collision prevention where it can limit damage.
- Prohibiting decisions based on personal characteristics even in unavoidable accident situations.
- Shifting accountability from individuals to manufacturers, operators, and regulatory bodies.
- Governing liability for damages caused by automated driving systems under product liability principles.
- Emphasizing the importance of data autonomy, informed public engagement, and the ethical concerns of the complete connectivity and central control of vehicles.
- Highlighting the need for clear distinctions in accountability between driverless ADSs and human-operated vehicles, and the importance of the international standardization of handover procedures.
- Allowing self-learning systems if they enhance safety and comply with established rules.
- Advocating for including the use of ADSs in general digital education and driving training.

In the EU, any AI should be developed, applied, or installed in accordance with EU law, and must fully respect human dignity, autonomy, safety, and other fundamental rights set out in the Charter of Fundamental Rights of the European Union (EUR-Lex - 12007P/TXT - EN - EUR-Lex, 2007). The EU and its member states should stimulate research projects which provide solutions based on AI, robotics, and related technologies, and that try to encourage social inclusion, democracy, plurality, solidarity, fairness, equality, and cooperation (Article 5 of the European Parliament resolution of 20 October 2020 with recommendations to the Commission on a framework of ethical aspects of artificial intelligence, robotics and related technologies (European Parliament, 2020)).

Finally, as stated in the Council of Europe's report "Legal aspects of 'automated' vehicles" prepared by the Committee on Legal Affairs and Human Rights (2020) (Altunyaldiz, 2020), the following ethical principles can be derived as the core set of principles based on various documents on the subject that have been accepted by various bodies and on various levels: transparency, justice, and fairness; responsibility; safety and security; and privacy. Transparency requires that AI systems are accessible, explainable, and explicable (individuals should understand how the systems work and provide results). Justice and fairness refer to non-discrimination, impartiality, consistency and respect for heterogeneity, and plurality. The subjects of AI systems' operation need to have the chance to apply remedy and redress. Responsibility refers to the fact that a human being should be responsible for any decision influencing the rights and freedoms of an individual. The accountability and legal liability for these decisions needs to be defined. Safety and security request that AI systems be robust and secure against external interventions. The principle of privacy needs to be respected when personal data are involved. For example, when an AI system is processing personal data. In these cases, GDPR and the Council of Europe's Convention for the Protection of Individuals with regard to Automatic Processing of Personal Data (with amendments) (Council of Europe, 2018) have to be respected by AI systems.

Accountability

Although self-driving vehicles are supposed to enable safer driving, there are still possible situations when accidents will occur. The question is who is to be held liable? The driver? The manufacturer? The algorithm developer? In addition, the current rules concerning insurance may be inadequate.

Various stakeholders can be held liable, depending on the level of automation. At level 0 (by the SAE definition), the manufacturer can be held liable only when providing a defective or non-standard-compliant tool which leads to an accident (e.g. faulty brakes). In other situations, user liability will be considered (Contissa et al., 2018). At levels 1 and 2, a manufacturer can be liable only when providing a defective or non-standard-compliant tool which leads to an accident (e.g. failed brakes; design defect leading to incorrect information, etc.). In other situations, the user's liability will be considered, since most driving tasks are his or her responsibility, and are under his or her control (e.g. failing to monitor the performance of the system, failing to react in time to system notifications, etc. (Contissa et al., 2018) cf. Fig. 3).

At level 3, most dynamic driving tasks fall under the system's control. Therefore, the manufacturer is liable when providing a defective or non-standard-compliant tool which leads to an accident. The manufacturer is also liable when the system fails to perform a task at a level comparable to that which a human paying due care would achieve under the same conditions (Contissa et al., 2018). On the other hand, the user can be held liable for not responding properly to a system request for intervention, or when the operational design domain limits are exceeded ((Contissa et al., 2018), cf. Fig. 3).

Finally, at levels 4 and 5, all dynamic driving tasks fall under the system's control. Therefore, the manufacturer is liable when providing a defective or non-standard-compliant tool which leads to an accident. The manufacturer is also held liable when the system fails to perform a task at a level comparable to that which a human paying due care would achieve under the same conditions. At these two levels of automation, the user is not expected to intervene when the automated driving system is on. Therefore, the user can be held liable only when the operational design domain limits are exceeded, or when the he or she requests the system to disengage the automated driving system. However, if a level 4 or 5 vehicle is designed in such a way that there are no user interfaces, meaning that the user cannot intervene in dynamic driving tasks, the user cannot be held liable (Contissa et al., 2018).

As argued by (Contissa et al., 2018), intermediate levels of automation are prone to higher liability risks, in that task responsibilities are fragmented between the system and the operator, which can sometimes lead to uncertainties. Moreover, an intermediate level of automation contributes to higher complexity in the interaction between human and machine, presenting additional challenges (Contissa et al., 2018, 2013).

Ambiguous responsibility: the vehicle can perform certain driving tasks, but the human must remain engaged and ready to intervene or to take control. This may cause certain situations when it might not always be clear when the human should intervene. **Over-reliance on automation**: the driver might overestimate the capability of the automated system and reduce their attention level. **Complex feedback**: alerts and warnings employed by the automated system for the human driver's attention might overwhelm or confuse him or her.

The complexity of ADSs aggravates to individual or insurer the proof that a technical failure was the reason behind an accident. It can represent unfair burden on the vehicle's user (Altunyaldiz, 2020).

The existing regulations go in the direction that for mistakes performed by the automated system, the company or software developer that obtained the authorization for self-driving would face regulatory sanctions (Commission, 2022d), and that drivers would remain responsible for vehicle insurance, and for checking loads and ensuring that children are wearing seatbelts. However, to prove the existence and nature of technical mistakes within an ADS might be more difficult than proving a simple mechanical failure in a traditional vehicle (Altunyaldiz, 2020). On the other hand, the introduction of comprehensive electronic data recorders (EDRs or "black boxes") helps to identify the causes of failures. Setting out standards that do not give too much discretion to manufacturers with certain standards can help manufacturer's liability defense. Another important way to limit the liability of the manufacturer is to mandate or constrain design options for automated technologies for all manufacturers (Contissa, 2017). These measures do have a downside, however: setting out too rigid standards that reduce the discretion of the manufacturers can stifle innovation and prevent the implementation of new, even safer technologies that would nonetheless not fit existing standards. Regulations should represent a general trade-off among these various requirements. Finally, clear instructions on product use should be provided (e.g. if there are some risks with the product, this should be clearly stated) (Contissa, 2017).

Insurers are important stakeholders in the field of ADSs. They set insurance premiums depending on the risks involved. With semi- and

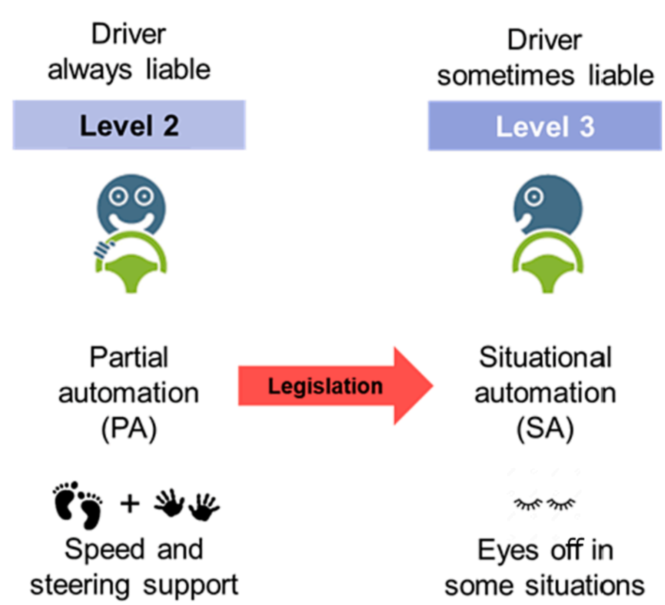

Fig. 3. Illustrative representation of driver liability principles.
Source: Jeffs, 2022

fully-automated-driving vehicles, the risks should be reduced, since this kind of driving should be safer, therefore lowering premiums over time. Of course, for the transition period during which new technologies are introduced, there are some new risks that need to be taken into account (Altunyaldiz, 2020). The proposal for insurers to define premiums is through pay-as-you-drive systems and black boxes. This system would apply telematics systems to calculate premiums, depending on the level of risky driving behavior. It involves high levels of surveillance of drivers, and therefore opens up privacy and security dilemmas (Altunyaldiz, 2020).

Black boxes are recommended, as in aviation, in order to record the whole procedure of events, since the complexity of an ADS makes it difficult to prove what went wrong in the event of accident (Lanzi, 2021).

Another important liability to tackle is product liability (i.e. harm caused by a defect in a product, with causal link between the harm and the defect, (Contissa, 2017)). Manufacturers are held liable only to the extent that their products are deemed defective within the borders of their reasonably expected use. However, clear causality between damage and a defective product is expensive and complex to prove (Bertolini and Riccaboni, 2021). The producer cannot be held liable if the defect could not have been known at the time the product was put into use, depending on the state of technical knowledge at that time (development risk defense) (Altunyaldiz, 2020; Contissa, 2017).

While a legislative framework in the EU regarding the approval ADSs for use on public roads already exists (see chapter European Union), there are various approaches within national legislations as regards liability, favoring various technologies (various levels and types of automation), which leads to market fragmentation in the EU. Therefore, on an EU level a clear policy approach should be provided. This would encourage unification across member states and consequently encourage innovation (Bertolini and Riccaboni, 2021).

Finally, in the following subchapters, two forms of legal responsibility are discussed: civil and criminal liability. Civil liability addresses situations where harm actually takes place. Criminal liability, on the other hand, also addresses intended harm (Lagioia and Sartor, 2020).

Civil liability

In discussions of liability concerning ADSs, it is often presumed that the party who violates road traffic regulations will be held responsible for compensating any damages or injuries caused. Traditionally, if a driver could not have prevented an accident, they would not be held liable (Altunyaldiz, 2020). However, with ADSs, assigning liability becomes more complex. In jurisdictions with traditional tort-based systems, this could potentially absolve the vehicle user from compensating for damages, given that they were not in control of the vehicle at the time of the incident (Altunyaldiz, 2020). The present chapter continues the discussion with regard to traditional tort-based systems.

Adopting an ethical perspective, (Santoni de Sio and Mecacci, 2021) analyze the responsibility gap in order to identify the four interconnected issues of culpability, moral accountability, public accountability, and active responsibility, all arising from technical, organizational, legal, ethical, and societal sources. The paper critically evaluates various approaches to the problem and advocates for 'meaningful human control' that should be aligned with the relevant human reasons and capacities.

The proposal of (Altunyaldiz, 2020; Schubert, 2015) is to establish a strict liability system, which would enable injured parties to be compensated even when there is no evidence of fault. The vehicle owner or driver would be automatically liable for any damage. However, the manufacturer may be requested to contribute partially to the insurance for each vehicle, while their product liability would be restricted. (Lagioia and Sartor, 2020) argue that strict liability may not be a sufficient response to AI crimes, since the benefit gained through the crime exceeds the potential cost of compensating the victims.

A no-fault insurance system would allow affected parties in each vehicle to be compensated directly by the vehicle's insurer. Pedestrians and cyclists would be protected through third-party liability. Under this system, we can see that the damage caused by assisted driving would automatically be compensated by the insurer of the relevant vehicle (Altunyaldiz, 2020). Which option to choose depends on the level of automated driving, and on how much control the human driver still has, or does not have, over vehicle behavior (Altunyaldiz, 2020).[12]

With respect to introducing ADSs with an ethical knob mode, as mentioned in chapter Ethical dilemmas and ADS, there is a question of civil liability in cases where the passenger chooses an extreme egoistic approach. Therefore, regulation should define the limits of user-selected egoism, and define where state-of-necessity defense is still applicable (Contissa et al., 2017). Even though giving the end user direct choice of ethical behavior may hardly be applicable, the idea of software systems with configurable ethical settings might be useful in adapting the settings to the regulatory environment they operate in. The system would be able to adjust to the different regulatory profiles of different countries in a dynamic way (up-to-date with the latest jurisdiction). Ethical guidelines would need to be transparent, documented, traceable, and decided in accordance with important stakeholders (regulators, customers …).

Finally, within the EU there is a proposal to reform product liability via a Directive of the European Parliament and of the Council on liability for defective products COM/2022/495 final (European Commission, 2022a). The proposed revision of the Product Liability Directive aims to ensure that liability rules reflect the nature and risks of products in the digital age. Concerning software systems, the proposal clarifies that they shall be considered as products (meaning that compensation is available when defective software causes damage, without the injured person having to prove the manufacturer's fault), and that software providers and providers of digital services that affect how the product works (such as the navigation service in an automated vehicle) can be held liable. The proposal also ensures that manufacturers can be held liable for changes they make to products they have already placed on the market, including when these changes are triggered by software updates or machine learning. Additionally, the proposal reduces the burden of proof in complex cases, which could include certain cases involving AI systems, and when products fail to comply with safety requirements.

Criminal liability

Current criminal law has a responsibility gap, as it does not envisage any liability of non-human actors, such as those operating semi- or fully-automated vehicles. In particular, the human in the vehicle cannot be held liable for criminal acts if the vehicle was operating in accordance with the manufacturer's design (Altunyaldiz, 2020). Currently in Europe, a driver can mostly still be held liable for negligence even where an assisted driving technology was in use, since drivers are obliged to monitor such systems. However, if there is no negligence, the manufacturer can be held criminally liable. ADSs levels 3 and 4 make it even more difficult to define who is to be held liable, since there are transition phases between automated and manual driving. The distinction between instances where the human driver is liable and instances where they are not should be precisely defined by regulation (Altunyaldiz, 2020). There are emerging legal challenges when level 5 or full driving automation is put into use, like dealing with the "criminal behavior" of non-human entities, such as a software and/or AI. In common law jurisdictions, most crimes require proof both of "mens rea" (from Latin "guilty mind") (a person's awareness of the fact that his or her conduct is criminal) and

[12] See the Automated and Electric Vehicles Act, 2018 of the United Kingdom as an example of the regulation of liability in various situations (Automated and Electric Vehicles Act, 2018).

"actus reus" ("guilty act") before the defendant can be found guilty.

In these cases, there is a possibility to establish a criminal liability for the software and/or AI responsible for driving as "legal person", similarly to the liability of corporations as legal persons that we already know. This will require a reevaluation of how criminal justice is applied (Altunyaldiz, 2020).

In this respect, the European Parliament was, for example, discussing giving robots based on self-learning an "electronic personality." This would allow robots to be individually insured and responsible for damage. For example, a special compulsory insurance scheme could be created, which would be filled up with resources that the robot would accumulate during its existence. It would be a similar arrangement as for corporations that have the recognized status of legal entities. However, certain legal experts and other experts disagree with such a proposal, as they consider granting legal personality to robots inappropriate from both a legal and an ethical point of view (Avila Negri, 2021; Decker et al., 2017). They believe that the current rules of civil law are sufficient, and that such regulation would be premature in view of the actual capabilities of existing technologies. In their view, such regulation would mainly be in favor of manufacturers, who could thus avoid liability for the actions of their machines. Insofar as the EU would accept such a proposal, this would of course also have an impact on member states' national arrangements. Estonia, as one of the leading member states in the field of IT deployment in public administration, proposed introducing the term "robot-agent" in order to determine the status of artificial intelligence in legal disputes. Such entities would have a status that would be between an independent legal entity and an object owned by a person (Ummelas, 2017). Under such an approach, the status of artificial intelligence would be equalized to the same level as the status of natural and legal persons. Of interest is the Estonian arrangement of robots for package delivery (without a driver), which can move in traffic without human assistance at speeds of up to 6 km per hour. The user of such a robot must have compulsory insurance for liability, and the robot must also be equipped with the user's contact information (Ummelas, 2017).

As regards the criminal liability of AI itself, (Lanzi, 2021) argues that one of the grounds for criminal liability is the consciousness (besides the conduct and proper, personal will of the robot) that AI lacks, meaning it cannot be considered a free agent and therefore cannot be held criminally liable. On the other hand, (Lagioia and Sartor, 2020) speculate on the possibility to directly punish AI systems, which would become direct addressees of criminal norms, with the assumption that AI systems have a sufficient level of reason-responsiveness. Furthermore, they argue that the formation of criminal AI systems can be included in broad interpretation of the notion of recklessness ("dolus eventualis"). Persons responsible for deployment are criminally liable for AI crimes when they enable AI crimes to be committed by their systems (Lagioia and Sartor, 2020). Finally, they propose a possibility of a separate criminal offence for the forming and introducing of criminal AI systems.

Another interesting aspect put forward by (Altunyaldiz, 2020) is the fact that some criminal offences will no longer be applicable to automated driving, such as drink driving and "distracted driving" (caused by phone use and other distractions). However, since the transition period with non-autonomous, semi-autonomous and fully autonomous vehicles will be long, regulators have to predict (non) criminal liability for different types of vehicles and their (human) drivers.

Personal data and cybersecurity

With new technologies enabling self-driving, there is a wide possibility of collecting personal data and other information (such as the time, place, and speed of driving; who drove behind the vehicle and who drove in front of the vehicle; voice and video recording, etc.) The main goal of an ADS is safe driving, and in order to achieve this it needs to interconnect with the other vehicles in traffic (V2V) and collect data from them. Moreover, it need to connect to the infrastructure (V2I) and to the environment (V2X). Therefore, when collecting various personal data, the protection of such data needs to be considered (e.g. time limited storage of other vehicles' data; travelled distances; ways of driving; speed, etc.) All of the following have to be defined: where the data is stored (who is competent to keep a register), how long the data can be stored, and who has access to it (especially in case of an accident). Moreover, security against invasion and abuse of the system ("cyber security") is important.

As mentioned above, the data from one ADS is shared with other ADSs, with a central system and, if necessary, with regulatory and law enforcement bodies (Altunyaldiz, 2020). The extent to which data are collected, who has access to these data, and the duration for which are they archived should all be defined by regulation in accordance with the principle of proportionality. Meaning the least invasive measure that achieves the goal should be applied. For now in the EU, General Data Protection Regulation is an act relevant for this field and should be applied to all companies processing data from subjects residing in the EU, no matter where the company's location is (Altunyaldiz, 2020).

The new technologies used in ADSs put cybersecurity in question, since it will be possible to hack the ADS and harm passengers in various ways (causing a crash, kidnapping, terrorism, abusing passengers' personal data, etc.).

Self-driving vehicles have many technical features that enable various cybersecurity breaches, e.g. through wireless networks (keyless entry systems, Bluetooth, cellular, and other connections). Hackers can steal collected (personal) data and sell them, or they can breach security systems and inflict physical harm on passengers and third persons, or cause material damage to the vehicle and environment (Taeihagh and Lim, 2019).

With respect to cybersecurity, the UN has adopted specific regulations related to automated driving (please see chapter Existing regulations that can serve as an example).

An important step in assuring cybersecurity is making ADS users aware of it and knowledgeable about it. Research shows users over-trust automated technologies, which leads to risky cybersecurity behavior (Noy et al., 2018). Moreover, the problem is making an appropriate reaction to a cybersecurity breach, especially initially, when drivers are not used to automated vehicles and may be experiencing a degree of cognitive overload. On the other hand, also cognitive underload can present an equal problem (e.g. drivers losing concentration, vigilance decrement etc. (cf. Ma et al., 2018)). Drivers' abilities to react and reaction times vary. In addition, cybersecurity issues will be more abstract and difficult than real-environment problems (Linkov et al., 2019). (Linkov et al., 2019) suggest that further research on human behavior when dealing with automated vehicles should be done, and that policies on and regulation of automated vehicles should follow these findings.

In the EU, a regulation of the European Parliament and of the Council laying down harmonized rules on artificial intelligence (artificial intelligence act) and amending certain union legislative acts (European Parliament, 2023) (hereinafter EU Artificial Intelligence Act) proposes four different risk levels of specific uses of artificial intelligence: unacceptable risk, high risk, limited risk, and minimal risk.

In its introductory provisions, the EU Artificial Intelligence Act (European Parliament, 2023) requires that high-risk AI systems should perform consistently throughout their lifecycle and fulfill an appropriate level of accuracy, robustness, and cybersecurity in accordance with the generally acknowledged technology. Human supervision is required: according to art. 14, “High-risk AI systems shall be designed and developed in such a way, including with appropriate human–machine interface tools, that they can be effectively overseen by natural persons during the period in which the AI system is in use.” Users should be informed about the level of accuracy and accuracy metrics (see point 49). To ensure a level of cybersecurity appropriate to the risks, suitable measures should be taken by the providers of high-risk AI systems, taking into account the underlying ICT infrastructure. High-risk AI systems must have instructions for their use (e.g. the level of accuracy, robustness, and cybersecurity) (see Article 13). Furthermore Article 15 dictates that high-risk AI systems must be designed to be error-resistant, secure against tampering, and robust against operational inconsistencies. They must include fail-safes and, if they continue learning after deployment, they must include measures to prevent biases. Additionally, they must be safeguarded against cyber threats, including data poisoning and adversarial attacks. The EU Artificial Intelligence Act applies to all systems using artificial intelligence, so some ADSs are directly included.

Environmental impact of ADSs

The potential environmental impact of ADSs covers a wide range of possibilities. Mathematical models (Brown et al., 2013) and empirical surveys (Hardman, 2021; Hardman et al., 2021) illustrate how the outcome strongly depends on the behavior of users and on the level of penetration of ADSs. Assuming that journey lengths remained constant for drivers/passengers, ADSs could potentially reduce the environmental burden of private transport through:

- Optimization of driving style for fuel efficiency (Jungblut et al., 2023).
- Minimization of driving paths.
  - o Optimizations of itineraries for multiple destinations.
  - o Less effort and shorter itineraries for parking (fewer vehicles and less stationary time).
- Higher vehicle occupancy – automated carpooling.
- A lower number of vehicles leads to a reduction in fabrication-related emissions.

Also, benefits of ADSs, such as reduced stress and increased comfort, might alter user behavior:

- Use of ADSs instead of other more emissive means of transport (i.e. plane).
- Use of ADSs instead of low emission alternatives (i.e. public transport) (Bilal and Giglio, 2023).
- Longer journeys due to increased comfort and reduced cost.
- Empty vehicle miles e.g. users will accept longer parking distances by letting the empty ADS reach the parking by itself.
- Demand from new user demographics (people without driving licenses etc.).

Weighting all these factors against others, different models predict a wide variety of outcomes in term of emissions: from significant reductions to potential increases (Brown et al., 2013; Hardman, 2021; Hardman et al., 2021). Legislation, therefore, has the responsibility of guiding positive behaviors and minimizing adverse environmental impact (Schippl et al., 2022). In general, regulations can target the environmental impact of private transportation through mechanisms such as taxation on fuels based on their emissions, circulation limits, etc. For ADSs, specific regulations might include:

(1) Promoting high occupancy of vehicles.
(2) Discouraging or restricting the use of empty or low-occupancy vehicles, especially during peak times.
(3) Discouraging remote parking.
(4) Supporting multi-modal transportation and integration with public transportation systems.
(5) Encouraging eco-friendly routing with the best fuel efficiency.
(6) Encouraging or mandating eco-driving algorithms that optimize driving behavior for fuel conservation.

Existing regulations that can serve as an example[13]

In the realm of road traffic, numerous international agreements compose a legal framework that ratifying countries are obliged to respect. The Geneva Convention on Road Traffic (United Nations, 1949) promotes the development and safety of international road traffic, while the Vienna Convention on Road Traffic (United Nations, 1968) emphasizes road safety among other aspects.

According to Article 8 of the 1968 Vienna Convention, which has been ratified by all EU member states (except Spain), a driver must maintain full control and bear responsibility for the behavior of a vehicle in traffic. In March 2014, the Working Party on Road Traffic Safety approved an amendment to this article, affirming that systems that can influence vehicle operation — but that can be overridden or switched off by a human — are compliant with Article 8 of the Convention.

Furthermore, Article 8 was revised in 2016 to allow the transfer of driving tasks to the vehicle itself, provided the technologies used conform to United Nations vehicle regulations, or can be overridden or switched off by the driver. Despite this amendment, the Vienna Convention still mandates that a vehicle have a driver. However, as evidenced by practices in various countries, the Vienna Convention does not prohibit the testing or use of automated vehicles. The Convention does not specify that a driver must be physically in the vehicle — only that they must retain control over it. However, this control is not defined explicitly. This implies that the driver can be considered to be controlling the vehicle even when they are not physically present in it, provided they choose the destination and route (Ardiyok and Canbeyli, 2020). Therefore, there was another amendment to the Vienna Convention, which was prepared by the United Nations Economic Commission for Europe’s Global Forum for Road Traffic Safety (Amendment proposal to the 1968 Convention on Road Traffic, 2020) and entered into force in July 2022. It defines automated driving systems and determines that presumption of a driver is satisfied while the vehicle is using an automated driving system which complies with national technical regulations and other regulations, as well as relevant international legal instruments.[14]

Furthermore, three UN Regulations related to automated driving were adopted:

UN Regulation No. 155 on Cyber Security and Cyber Security Management Systems (UNECE, 2021a) mandates cybersecurity standards for vehicle approval. It specifies the approval process, required documentation, and conformity checks for ADSs, focusing on managing and mitigating cyber threats. Compliance is marked by a specific approval mark on vehicles.

UN Regulation No. 156 on Software Updates and Software Updates Management Systems (UNECE, 2021b) sets out requirements for the approval of vehicles concerning software updates and Software Update Management Systems (SUMS). It applies to various vehicle categories that allow software updates and outlines the approval process,

[13] Certain subchapters in this part were presented at the 30th NISPAcee Annual Conference, Bucharest, Romania, June 2- June 4, 2022 with the paper: “The regulation of self-driving cars - what is the best approach in accordance with the rule of law?” (Sever, 2022).

[14] This is limited to the territory of the contracting party where the relevant national technical and legal regulations apply.

documentation requirements, and the need for a Certificate of Compliance for SUMS. The regulation ensures that vehicles maintain integrity and safety through controlled software updates, including over-the-air (OTA) methods.

UN Regulation No. 157 on Automated Lane Keeping Systems (UNECE, 2021c) outlines standards for the approval of vehicles with Automated Lane Keeping Systems (ALKS). The regulation includes requirements for system safety, fail-safe responses, human–machine interface, and the ability to perform a minimum risk maneuver if the driver does not take back control when requested. It also addresses data storage for automated driving, cybersecurity, and software updates.

European Union

The EU holds a significant stake in the production of several new technology products. Consequently, in terms of economic development, this is a significant moment and a valuable opportunity for Europe. It is a chance to establish its own regulatory framework and become an equal contender on the global stage, particularly in competition with major players such as the USA, China, Japan, and the Republic of Korea. This effort is not only about securing a market share, but also about asserting influence over the future direction of automotive technologies.

Historically, Europe has accentuated consumer protection, with stringent product requirements before market entry and clearly assigned responsibility for safety compliance. When these conditions are breached, penalties are mandated (Freeman Engstrom et al., 2020). As already mentioned, this philosophy extends to self-driving vehicles, demanding robust regulation.

There are various approaches to this regulatory task. Legal provisions, quality standards for products, and 'soft law' mechanisms, including resolutions and other non-binding instruments, all play a significant role. These measures together create an appropriate regulatory framework for automated vehicles.

From a competitiveness perspective, it would be desirable for Europe to establish certain guidelines at the EU level, followed by national laws within member states. An exemplar of this kind of pan-European coordination is the Declaration of Amsterdam on Cooperation in the field of connected and automated driving, signed in 2016 by the ministries of EU Member States (Declaration of Amsterdam, 2016). This acts as a model for collective action and mutual alignment, fortifying Europe's position in the global automated vehicle sector. On the same perspective of European collaboration, strategies on ADSs were set in 2018: the European Parliament's report on automated driving in European transport (Legislative Observatory, E.P., 2018) and Commission Communication On the Road to Automated Mobility: An EU strategy for mobility of the future (European Commission, 2018).

In 2019, EU level Regulation (EUR-Lex - 32019R2144 - EN - EUR-Lex, 2019) of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users was accepted and has been applied from 6 July 2022 onwards. This regulation uses the terms "automated vehicle" and "highly automated vehicle" (see chapter Driving Automation: features and definitions on details of definition). In June 2022, Commission Delegated Regulation (EU) 2022/2236 of 20 June 2022 amending Annexes I, II, IV and V to Regulation (EU) 2018/858 of the European Parliament and of the Council as regards the technical requirements for vehicles produced in unlimited series, vehicles produced in small series, fully automated vehicles produced in small series and special purpose vehicles, and as regards software update was adopted and entered into force in December 2022.

In August 2022, the European Union adopted Commission Implementing Regulation (EU) 2022/1426 (European Commission, 2022b), which was established on August 5, 2022. This regulation sets forth uniform procedures and technical specifications for the type-approval of ADSs in accordance with Regulation (EU) 2019/2144, issued by the European Parliament and the Council. This regulation came into effect in September 2022.

The legislative framework, extended the existing type-approval addressing many ADSs use cases, including passenger vehicles and cargo that operate a) in a defined area b) hub-to-hub along a predefined route c) automated valet parking. The approach chosen, type-assessment, requires manufacturers to demonstrate that their vehicles meet certain safety standards before they can be sold in the EU, and requires them to establish a safety management system. The legislation on ADSs is divided into two primary sections: the performance requirements for ADSs and the compliance assessment procedures for ADSs. The former delineates the essential functionalities that an autonomous vehicle must demonstrate in order to obtain type-approval within EU jurisdictions, the latter outlines the evaluation, auditing, and testing protocols for the ADS before the type-approval.

Among the obligations required:

- Documentation: necessary documents for type-approval, including an EU type-approval certificate.
- Monitoring: in-service monitoring and reporting obligations for manufacturers.
- Remote Operation: roles and tasks for on-board and remote operators of ADSs.
- Software Identification: a unique identifier for type-approval relevant ADSs software.
- Vehicle Modes: dual-mode vehicles, switching between manual and automated driving at standstill.

Furthermore, the EU actively addresses ethical and cybersecurity concerns related to artificial intelligence through the EU Artificial Intelligence Act (European Parliament, 2023). These aspects are further explored in the chapter on Personal data and cybersecurity, illustrating the multi-dimensional nature of AI regulation.

In the following subchapters, we analyze current existing regulations in selected EU member states: Germany, Italy, Slovenia, and Sweden. Subsequently, Norway, the United States of America, and the United Kingdom are presented.

Germany

In 2015, Germany adopted a Strategy for Automated and Connected Driving (BMDV, 2020). Two years later, its Ethics Commission prepared a report on automated and connected driving and, in addition, Road Traffic Act was amended – "Achtes Gesetz zur Änderungen des Straßenverkehrsgesetzes" (BMDV, 2018). It enabled the implementation of highly and fully automated driving functions in motor vehicles, and determined requirements for doing so. With this legislation, SAE levels 3 (conditional driving automation)[15] and 4 (high driving automation)[16] were allowed. Highly or fully automated vehicles had to obey traffic regulations and recognize, within a reasonable time, when the driver had to take over the control. Finally, the driver had to have the possibility at any time to switch off or manually cancel the automated driving mode (Ardiyok and Canbeyli, 2020).

In 2021, the Act amending the Road Traffic Act and the Compulsory Insurance Act – Autonomous Driving Act (Bundesanzeiger Verlag, 2021) (hereinafter Autonomous Driving Act) came into force. At the end of 2023, the Federal Ministry of Transport and Digital Infrastructure

[15] The human driver responds in adequate time if needed.

[16] The automated driving mode does not need to be supervised by the human driver.

(hereinafter Federal Ministry) will conduct its evaluation. The Autonomous Driving Act allows the introduction of vehicles which can perform automated driving tasks without a driver in specific areas on public roads (SAE level 4). The Federal Ministry also prepared the "Autonomous Vehicle Approval and Operation Ordinance (AFGBV)" (hereinafter the Ordinance). It was promulgated in the Federal Law Gazette in June 2022. The content of the Ordinance sets rules on: granting operating permits for motor vehicles with automated driving modes, access to road traffic, and the acceptance of defined operating areas. The Ordinance sets rules on verification and demands for owners, manufacturers, and technical supervision, and rules on data storage and on the testing of automated driving functions (Steininger, 2021).

A vehicle equipped with automated driving capabilities is subject to a set of stringent technical requirements as stipulated by the Autonomous Driving Act. These requirements include the ability to independently adhere to traffic regulations and, in situations where compliance with traffic rules cannot be maintained, the capability to automatically transition the vehicle into a minimal risk state. Additionally, such vehicles must feature an accident prevention system and be able to promptly alert a technical supervisor in the event of any malfunction. A key requirement is that the vehicle must be capable of being deactivated by the technical supervisor at any time (Gesley, 2021).

Whether or not a vehicle fulfils the technical requirements is checked by The Federal Transport Authority. The producer has to guarantee cybersecurity and present a certification validating that the vehicle is in accordance with technical demands (Gesley, 2021).

A state authority needs to approve that certain public road spaces are intended for vehicles with automated driving modes. A technical supervisor, who can deactivate or enable the driving operations of a vehicle from the outside, is obligatory. The owner of a vehicle must have liability insurance for the technical supervisor (Gesley, 2021). The technical supervisor is a natural person registered as the keeper of the vehicle, but can pass the role onto another person.

The accident prevention system must be defined in a way to avoid or decrease damage. In case a vehicle cannot avoid an accident, the highest priority must be given to the protection of human life. No further weighting based on personal characteristics, such as sex, age, and physical or mental constitution, should be considered in case an injury to a human life cannot be avoided (Gesley, 2021).

The law mandates that certain responsibilities, such as wearing a seat belt, still apply to passengers in automated vehicles. The technical supervisor bears the responsibility of ensuring that all passengers comply with these legal requirements.

In case of accidents, the registered keeper has to store and save certain information: identification number of the vehicle; data on geographical position; the number of times, and at what times, the automated driving function was used, activated, and deactivated; the number of times, and at what times, alternative driving maneuvers were authorized; system monitoring data, including software status data; conditions of weather and environment; transmission latency and available bandwidth; name of the activated and deactivated passive and active security systems, data on the status of these security systems, and the instance that triggered the security system; vehicle acceleration in the longitudinal and transverse directions; speed; lighting equipment status; motor vehicle power supply; and commands and information sent to the vehicle from outside (Gesley, 2021).

Italy

In Italy, in 2017, Statutory Act n. 205/2017 (LEGGE, 2017) granted 2 million euros for the digital transformation of public roads to allow testing of ADSs prototypes. This law required the introduction of a decree of the Minister of Infrastructure and Transport to execute methods and operational tools for testing. Therefore, in 2018 "Smart Road Decree" 28/2/2018 of the Ministry of Infrastructure and Transport (hereinafter the Ministry) ("DECRETO 28 febbraio 2018 Modalita' attuative e strumenti operativi della sperimentazione su strada delle soluzioni di Smart Road e di guida connessa e automatica. (18A02619)," 2018) was accepted, allowing the testing of self-driving vehicles, as well as regulating the application of digital technologies on public roads. However, consumers are not allowed to use levels 3–5 on public roads in Italy.

The Smart Road Decree allows testing only for levels 3–4, under the condition that the driver or supervisor is at any time able to take over control of the vehicle. This means that a qualified supervisor has to always be in the vehicle and be able to switch from auto to manual driving and vice versa. He or she is liable for the vehicle in both modes (automated and manual) (Lanzi, 2021).

Testing is allowed only after receiving a permit issued by the Ministry. The Smart Road Decree specifies who can request a permit: manufacturers of ADS, and/or universities or public and private research institutes which perform tests with such vehicles. Prior to request, at least 3,000 km on simulator or track-road testing are required. The vehicle's manual version should be fully approved for road driving (Lanzi, 2021).

The permit allows driving only on certain public roads and is valid for 1 year, with the possibility to renew. One of the conditions to get the testing approved is to have an insurance contract for civil liability. The maximum coverage of this insurance needs to be equivalent to four times the maximum coverage demanded by law for the same category of vehicle without the automated driving function. Finally, the insurance contract has to explicitly define that the insurer is aware of the methods the vehicle uses and aware that the vehicle will be utilized in automatic operating mode on public roads (De Feo, 2020).

As regards liability, the general liability rules apply, meaning that the vehicle owner and the driver are liable for damages arising out of construction defects or vehicle maintenance defects. The owner can be exempted from liability if he or she proves that the vehicle was driven against his or her will. The manufacturer can be held liable for damages arising from vehicle defects (De Feo, 2020).

Slovenia

In 2021, Slovenia introduced the Road Traffic Rules Act (Official Journal, 156/21, 161/21, hereafter RTRA) (Popravek Uradnega prečiščenega besedila Zakona o pravilih cestnega prometa (ZPrCP-UPB7), 2021; Zakon o pravilih cestnega prometa (uradno prečiščeno besedilo) (ZPrCP-UPB7), 2021), which defines an automated vehicle as "a motor vehicle fitted with systems of first, second, or third level according to the SAE J3016 international standard, which is capable of autonomous operation in road traffic without driver intervention, and which meets all the conditions for participation in road traffic as laid down by the law governing motor vehicles." However, this definition in RTRA is contradictory to what levels 1 and 2 according to SAE actually mean, since levels 1 and 2 expect driver intervention (see chapter Driving Automation: features and definitions). We recommend to correct this in the future in compliance with SAE definitions. The vehicles need to be first tested on surfaces intended for road traffic. These vehicles have special "CAV" plates, made of light-reflecting and weather-resistant materials. The driver has to be on a standby at all times so that control over the automated vehicle can be taken over at any time. The driver of an automated vehicle shall be considered the driver of a motor vehicle as defined in the Drivers Act, needs to be qualified to test such vehicles, and should not be a beginner driver.

The driver's behavior during the testing needs to be monitored and recorded by the electronic systems installed in the vehicle. In case of an accident, an authorized official must have the data for a period of 30 s before and 30 s after traffic offence or the accident.[17]

For the duration of testing, the producer shall have a contract of insurance against liability for damage caused to third parties by the use of the automated vehicle in compliance with the compulsory insurance regulation for road transport. The driver (paragraph 8 of Article 27 a RTRA) shall carry the insurance policy, or other evidence of insurance, when driving the automated vehicle.

A statement by the producer of the automated driving system or automated vehicle constitutes evidence that a vehicle was pretested on road traffic surfaces, and evidence of the competence of the driver. The driver shall carry the statement with them during testing.

The producer of the automated driving system or automated vehicle shall inform the traffic information center and the police of the planned testing. The notification should include details of the producer, the accountable person of the producer, details of the drivers who will test the vehicle, details of the vehicle including the plate number, details of the equipment to be tested, and the time of the test and planned road section (paragraph 10 of Article 27 a of RTRA).

Sweden

In its effort to promote innovative technologies for sustainable transport, the Swedish Government enacted the Ordinance on Trial Operation with Self-driving Vehicles (effective from July 1, 2017, Landsbygds- och infrastrukturdepartementet RSIB TM, 2017). This directive allows the Swedish Transport Agency to grant permits for tests of automated vehicles on public roads. During these trials, the presence of a human driver, either inside or outside the vehicle, is mandatory. In 2021, the Swedish Transport Agency's regulations and general advice on authorization to conduct experiments with automated vehicles was accepted (Transportstyrelsens föreskrifter och allmänna råd om tillstånd att bedriva försök med automatiserade fordon, 2021), and contains provisions on permission to conduct trials with automated vehicles according to the regulation (Landsbygds- och infrastrukturdepartementet RSIB TM, 2017) on trials with automated vehicles.[18]

Under this scheme, the driver must remain in the vehicle, ready to intervene as necessary. While human operators are permitted to take their hands off the steering wheel, advanced driving systems may only be utilized if the ADS manufacturer can guarantee that these automated systems do not interfere with basic driving functions. This ensures that the driver can always take over control.

The responsibility for compliance with the permit issued for trial operations falls on the individual or entity conducting the testing. This means that the tester, whether a natural or legal person, is charged with ensuring that all activities align with the terms of the permit.

Norway

While Norway is not a member state of the European Union, its affiliation with the European Economic Area establishes a strong link to the EU. In 2022, the Norwegian legal environment became more "equivalent" to EU law by implementing EU Regulations 2018/858 and 2019/2144.

However, as regards automated vehicles, in 2017, the Norwegian Parliament already passed the Testing of Automated Vehicles Act (Ministry of Transport (Samferdselsdepartementet), 2017)[19] authorizing the experimental use of self-driving vehicles on public roads.[20] Furthermore, regulations on the testing of self-driving motor vehicles were put into force in 2018.

Unlike its Swedish counterpart, Norwegian law does not require a driver's physical presence inside or outside the vehicle. However, any applicant for testing must demonstrate that he maintains supervision over the vehicle at all times. This supervision, though, does not require the applicant to sit behind the steering wheel, provided the vehicle's technology can independently handle all driving situations (Hansson, 2020).

The National Public Road Administration is accepting applications to start a pilot trial of autonomous pilot driving. When applying it is important to show risk assessments of the pilot area, risk assessments of the vehicle, type definitions of the vehicle and documentation of the vehicle, assessments of GDPR, and how the pilot is to be documented (Connected automated driving.eu, 2021). The application and permit for testing must define a physical person responsible for ensuring compliance with existing regulations. This individual has to ensure that safety measures are implemented when the test involves an automated vehicle without a responsible driver. Additionally, vehicles used for testing are presumed to be insured according to existing laws, with the person conducting the tests expected to arrange suitable insurance coverage for the relevant vehicles (Valevatn, 2018).

United states of America

In the USA, Nevada was the first state to introduce laws authorizing the use of ADSs on public roads in 2011 (Nevada Assembly Bill No. 511, 2011). Today, most US states regulate some level of automated vehicles, either by law or by executive orders (Ilkova and Ilka, 2017) cf. Table 1.[21] At the federal level, the National Highway Traffic Safety Administration has prepared several guidelines for automated driving systems (e.g. Federal Automated Vehicles Policy, 2016; A Vision for Safety 2.0, 2017; Preparing for the Future of Transportation: Automated Vehicles 3.0, 2018; Ensuring American Leadership in Automated Vehicle Technologies, Automated Vehicles 4.0, 2020 and Automated Vehicles Comprehensive Plan, 2021 (US Department of Transportation, 2021) including guidance regarding automated driving systems for industry and for states. Furthermore, new passenger safety regulations were adopted in 2022, replacing outdated terminology that presumed a vehicle would invariably feature a human driver and manual controls. Nevertheless, automated vehicles must provide the same levels of occupant protection as human-driven vehicles (NHTSA, 2022). Regulations state that children should not be in the traditional "driver's seating" position, since the latter is not designed to protect children in a crash. However, if a child is in such a seat, the car will not immediately be required to stop moving (Shepardson, 2022).

Finally, we can say that the United States of America has, since the beginning, been one of the most progressive states in allowing the testing and use of ADSs (California Public Utilities Commission, 2023). Cruise and Waymo were granted full approval for providing taxi rides in San Francisco in August 2023. Both companies have been granted approval to operate driverless vehicles for commercial passenger services in San Francisco, allowing them to charge fares for rides at any time of the day (California Public Utilities Commission, 2023). However, following October 2023 crash, Cruise had to suspend their service due to

[17] The data may be processed by the producer of the automated vehicle or automated driving system for a maximum period of one year. The competent supervisory authority can process data to the extent and for the duration needed for the supervision or proceedings on a misdemeanor or criminal proceedings, but no longer than three years from their acquisition. After the expiry of these time limits, the data shall be deleted (see paragraph 7 of Article 27 a of RTRA).

[18] It was amended in 2021:9 and 2022:82.

[19] Entered into force in January 2018.

[20] It allows the testing of automated vehicles (SAE Level 5 and below, without steering wheels and pedals) in regular traffic, on snow, freezing rain, dark roads, wet roads, dry roads, and all types of road conditions.

[21] See also the National Conference of State Legislatures (2020), available at (National Conference of State Legislatures, 2020).

Table 1
USA State laws on automated vehicles – from (Institute, 2023).

		Does the driving automation law/provision…		
State	What type of driving automation on public roads does the law/provision permit?	Require an operator to be licensed?	Require an operator to be in the vehicle?	Require liability insurance?
Alabama	deployment — commercial motor vehicles only	not addressed	no	yes; $2,000,000
Arizona	deployment	depends on level of vehicle automation[1]	depends on level of vehicle automation[2]	yes
Arkansas	deployment — commercial purposes only	yes	depends on level of vehicle automation[3]	yes[4]
California	deployment	separate permits for testing under driver supervision and driverless testing and deployment[5]	no	yes; $5,000,000
Colorado	deployment	no	not addressed	no
Connecticut	testing	yes	yes	yes; $5,000,000
District of Columbia	testing	yes[6]	no	yes; $5,000,000
Florida	deployment	depends on level of vehicle automation[7]	depends on level of vehicle automation[2]	yes
Georgia	deployment	depends on level of vehicle automation[7]	depends on level of vehicle automation[2]	yes[8]
Hawaii	testing	not addressed	yes	not addressed
Illinois	testing	yes	yes	yes
Iowa	deployment	yes	depends on level of vehicle automation[2]	yes
Kansas	deployment	depends on level of vehicle automation[1]	no[9]	yes
Louisiana	deployment — commercial motor vehicles only	depends on vehicle[10]	no	yes; $2,000,000
Maine	testing	not addressed	no	yes; $5,000,000
Massachusetts	testing	yes	yes	yes[11]
Michigan	depends on vehicle[12]	yes	no	yes
Mississippi	deployment	not addressed[13]	no	yes[14]
Nebraska	deployment	depends on level of vehicle automation[1]	depends on level of vehicle automation[2]	yes
Nevada	deployment	depends on level of vehicle automation[7]	depends on level of vehicle automation[2]	yes[15]
New Hampshire	deployment	depends on vehicle[16]	depends on level of vehicle automation[2]	yes[17]
New Mexico	testing	depends on vehicle[18]	depends on level of vehicle automation[2]	yes; $5,000,000
New York	testing	yes	yes	yes; $5,000,000
North Carolina	deployment	depends on level of vehicle automation[7]	no	yes
North Dakota	deployment	depends on level of vehicle automation[7]	depends on level of vehicle automation[2]	yes
Ohio	testing	yes	no	yes
Oklahoma	deployment	not addressed[13]	no	yes; $1,000,000
Pennsylvania	deployment	yes	no	yes; $1,000,000
Tennessee	deployment	no	no	yes; $5,000,000
Texas	deployment	no	no	yes
Utah	deployment	depends on level of vehicle automation[7]	no	yes
Vermont	testing	yes	yes	yes; $5,000,000
Virginia	testing	not addressed	not addressed	no
Washington	testing	depends on whether operator present in vehicle	no	yes; $5,000,000
West Virginia	deployment	depends on level of vehicle automation[7]	no	yes[19]

Source: Insurance Institute for Highway Safety, Highway Loss Data Institute, updated July 2023 (Insurance Institute for Highway Safety, 2023).

[1] "A vehicle that requires a human to take over driving (Level 3 of the SAE Levels of Driving Automation) requires a licensed human driver.

[2] A vehicle that does not require a human to take over driving (Level 4 or Level 5 of the SAE Levels of Driving Automation) does not require a human to be in the vehicle.

[3] Arkansas does not require a steering wheel in a "fully automated vehicle," which must be "capable of achieving a minimal risk condition" in the event of a failure.

[4] Arkansas requires an "automated vehicle program" to comply with "the minimum liability insurance coverage requirements" under 49C.F.R. § 387.9 as that section existed on January 1, 2021."

[5] As of November 1, 2023, California has issued Autonomous Vehicle Testing Permits with a driver to a limited number of entities. 6 entities are allowed to perform driverless testing on defined areas, in certain weather and visibility conditions, time of the day and with specific speed limitations. As of January 11, 2024, California has authorized the deployment of autonomous vehicles to 3 different entities on defined areas, in certain weather and visibility conditions, time of the day and with specific speed limitations (California, 2024).

[6] "The District requires a "test operator" or "remote operator," who must successfully complete a training program.

[7] A vehicle that does not require a human to take over driving (Level 4 or Level 5 of the SAE Levels of Driving Automation) does not require a licensed human driver.

[8] Georgia requires a "fully automated vehicle" operating "without a human driver" to have liability insurance equivalent to the minimum required under existing insurance law.

[9] Although Kansas requires a driver to be physically present in a "driverless-capable vehicle" for the first 12 consecutive months it is in service, this provision does not apply if the vehicle is not intended to carry human occupants or if the vehicle lacks manual controls for driver operation.

[10] If a vehicle uses a remote driver, that driver must be licensed.

[11] Massachusetts requires applicants who seek to test to maintain a variety of insurance coverages, including commercial general liability, automobile, and workers compensation insurance.

[12] Michigan authorizes testing of any "automated motor vehicle" and deployment of "on-demand automated motor vehicle networks."

[13] The "automated driving system" is considered to be licensed to operate the vehicle.

[14] Mississippi requires "fully automated vehicles" operating without a "human driver" to have liability insurance equivalent to the minimum required under existing insurance law.
[15] Nevada requires a company or person seeking to test to have $5,000,000 of liability insurance and requires an "automated vehicle network company" to have $1,500,000.
[16] If a vehicle uses a test driver, that driver must be licensed.
[17] New Hampshire requires "driverless capable vehicles" operating without a "conventional human driver" to have liability insurance equivalent to the minimum required under existing insurance law.
[18] Testing or operating a vehicle with a driver requires that the driver be trained.
[19] West Virginia requires a "fully automated motor vehicle" operating without a "human driver" to have liability insurance or self-insurance that satisfies existing insurance law."

unreasonable risk to public safety (California DMV, 2023; Curtis, 2023). Similarly, Waymo has been providing taxi rides by automated vehicles in Phoenix, Arizona since 2018, with a human driver sitting at the steering wheel, ready to take over if needed. In 2020, these human drivers were withdrawn, and since then the service has been fully driverless.

United Kingdom

Although the United Kingdom is no longer a member state of the EU, its early engagement (2017, 2018) with automated vehicle regulation presents an interesting case study (UK Department for Transport, 2015; UK Government Actuary's department, 2017). In 2018, the Automated and Electric Vehicles Act was adopted, and in 2022, the Road Vehicles (Construction and Use) (Automated Vehicles) Order. Furthermore, Code of Practice: automated vehicle trialing is to be used by organizations or individuals planning to trial or pilot automated vehicle technologies and services (updated in 2022).

UK regulation has advanced further still, introducing Automated Lane Keeping Systems (ALKS) that allow drivers to safely delegate control to the vehicle. ALKS regulation was adopted in 2020 (Maclean, 2022). Organizations conducting trials in the UK are not required to secure permits or provide surety bonds. However, to adhere to legal requirements, they must have: 1. a designated driver or operator, either inside or outside the vehicle, who is prepared, capable, and willing to take control of the vehicle; 2. A vehicle that meets roadworthiness standards; and 3. appropriate insurance coverage in effect (Department for Transport, 2022). Although the Code is only non-binding guidance, not adhering to it could have implications for legal accountability in any legal proceedings.

Under existing regulations (Automated and Electric Vehicles Act, 2018; UK - House of Commons, 2021), if an accident occurs while the automated vehicle is operating itself and results in personal injury, the insurer is liable for the damage, given that the vehicle is insured at the time of the accident. Automated driving of the vehicle can take place on roads[22] or other public places[23] in Great Britain without explicitly requiring a driver behind the steering wheel. If the vehicle is not insured at the time of the accident, liability falls on the vehicle's owner. The insurer's liability can be negated if the insured individual has made unauthorized alterations to the vehicle's operating system, or has failed to install a required software or software update.

[22] Way, where travelers can move from point A to point B, and public have access (Law Commission of England and Wales, 2022).
[23] A place used by the general public, with no objection by the landowner or occupier (Law Commission of England and Wales, 2022).

Discussion[24]

From the analyzed sources and selected regulations we can conclude that, despite the fact that most accidents are a consequence of a human factor, many of the current rules (guidelines) expect every vehicle to have a driver, or at least a supervisor (e.g. Italy) (see Table 2). There is a whole range of human control requirements, from requiring a driver behind the steering wheel to less strict rules, such as Germany allowing a supervisor outside of the vehicle. An obligatory driving takeover by a human (e.g. 7 s before the accident![25]), though, is contradictory to the primary goal, i.e. safe driving without a human factor. The fact is that most errors that lead to accidents are made by humans. The argument that, in the case of self-driving system, a human will react quicker and better than a system and thus better prevent an accident is not convincing. Human reaction time is much slower than what an automated system can achieve, especially if the driver is distracted by the other activities (phone, movie, etc.) allowed in highly automated ADSs (Gerber et al., 2023). However, humans have the compensatory advantage in their better judgment when navigating through anomalous situations which automated systems may not comprehend. Legislation should consider and hinder scenarios where the vehicle could hand back control to the human driver at last moment before an accident, in order to pass responsibility and liability for the accident to the driver. Moreover, it is an acknowledged certainty in the field of software engineering that software bugs are inevitable, given the current state of technology. Recognizing this, automated driving systems must be designed with multiple layers of risk mitigation strategies. While achieving a safe stop on the side of the road in the event of a failure is an ideal solution (Krook et al., 2019), it is not always feasible. Consequently, developers and regulators are exploring a variety of ways to reach minimal risk condition (MRC) (see chapter Driving Automation: features and definitions) when traditional backup plans are not an option, through DDT fallback or Minimal risk maneuvers (Karakaya and Bengler, 2023).

Clear liability rules should be set for various situations. As we can see from the analyzed regulations, the driver is still responsible for things such as putting on seatbelts, taking care of insurance, etc.

Most of all, regulation requires states to establish registers of ADSs. The selected and analyzed acts regarding self-driving vehicles do not include rules on protection of personal data, ethics, etc. (except in Germany). However, this does not mean that these areas are not protected in these states. Typically, the approach is to apply the existing laws regulating these specific questions to the new aspects of technology (see also the chapter on Personal data and cybersecurity).

[24] The arguments, and part of the Table 2, in this chapter were presented at the 30th NISPAcee Annual Conference, Bucharest, Romania, June 2- June 4, 2022 with the paper: "The regulation of self-driving cars - what is the best approach in accordance with the rule of law?" (Sever, 2022).
[25] The 2016 case of a fatal accident involving a Tesla car was an example of this. It turned out that the system had warned the driver to take over seven seconds before the accident occurred, but that the driver had not responded to the warning (Shepardson, 2017).

Table 2
Overview of national legislation on ADSs [1].

Country	Regulation	Where vehicles can drive?	Driver in control?	Liability	Ethical notions?
Germany	Autonomous Driving Act (2021) (federal level); Autonomous Vehicle Approval and Operation Ordinance (2022)	Specific operating areas on public road space.	Allows level 4 vehicles. External technical supervisor obligatory.	Manufacturer or driver (depends who was in charge and failed).	Yes. Highest priority to the protection of human life; no discrimination is allowed.
Slovenia	Road Traffic Rules Act (2021)	Specific areas on public roads for the purpose of testing.	Allows testing of levels 1–3. Driver on standby at all times and can take over at any time.	Manufacturer.	No.
Italy	Statutory Act n. 205/2017 (2017) and Decree 28/2/2018 of the Ministry of Infrastructure and Transport (2018)	Only certain public roads – for testing.	Yes, driver or supervisor always needs to be able to take over control.	General liability regime applies.	No.
Sweden	Road Traffic Ordinance (2017) [2]; Swedish Transport Agency's regulations and general advice on authorization to conduct experiments with automated vehicles (TSFS 2021:4, amended TSFS 2021:9 and TSFS 2022:82) [3]	Public roads – for testing.	Yes, manufacturer needs to assure that driver can take control at any time.	Person carrying out the testing.	No.
Norway	Testing of Automated Vehicles Act (2017, into force 2018)[4] and Regulations on the testing of self-driving motor vehicles (2018)[5]	Public roads - for testing.	No.	Person carrying out the testing.	No.
United Kingdom	Automated and Electric Vehicles Act (2018); Road Vehicles (Construction and Use) (Automated Vehicles) Order (2022).	Roads and other public places in Britain.	Not necessarily.	Insurance company.	No.

Source: legal sources of selected states as defined in the first line of the Table.
[1] Because of diversity among the states in the USA, the latter is not added in this Table. For the USA, see Table 1.
[2] Landsbygds- och infrastrukturdepartementet RSIB TM (2017).
[3] Transportstyrelsens föreskrifter och allmänna råd om tillstånd att bedriva försök med automatiserade fordon (Transportstyrelsens föreskrifter och allmänna råd om tillstånd att bedriva försök med automatiserade fordon, 2021).
[4] Lov om utprøving av selvkjørende kjøretøy (Samferdselsdepartementet, 2018a).
[5] Forskrift om utprøving av selvkjørende motorvogn (Samferdselsdepartementet, 2018b).

Moreover, in case of high or full automation (levels 4 and 5) there are still the questions of the procedure required to acquire a driving license, and of what kind of training for "vehicle users" (drivers) will be sufficient. Especially given that higher levels of automation and less driving by driver lead to a reduction in driving competences. Similar cases occurred in aviation, where pilots were so reliant on autopilot systems that they were unable to perform certain tasks by themselves when needed. The consequences in such cases were disastrous.

Also, based on the analyzed regulation of selected states, we can see that most states took the approach of first regulating only the testing of automated vehicles in specific areas. The second step will then be to regulate the use of such vehicles by the general public (Shladover and Nowakowski, 2019).

The trend seems to be that countries where automotive industry is of great economic importance strive to regulate the matter sooner so as to enable testing of automated vehicles in their territory (e.g. US, UK, Germany, Italy and Sweden). In addition, flexible legal frameworks can attract foreign investors and producers to come and test their products, which can be seen as an incentive for states that do not have a strong automotive industry to prepare such legal frameworks within reasonable time (Hansson, 2020, p. 6).

As argued by (Hansson, 2020), the shaping of new regulation goes through various phases. First, we have existing regulation, which does not fit to automated vehicles, but is still taken as a basis to prepare new regulation. This is the so-called transition phase, where existing regulation needs to change due to the evolution of technology. (Hansson, 2020) argues that during this phase there co-exist three types of regulation mode: existing regulatory standards, self-regulation, and elements of open method coordination. The existing regulatory standards influence the forming of new regulation and are valid until new regulation is formed. On the other hand, private sector (industry) forms its own standards (e.g. SAE) (Hansson, 2020). International regulatory standards and conventions also have important influence on national regulation, representing open method coordination, in addition to benchmarks and learning experiences from other countries. Finally, there is a consolidation phase, during which new regulation is adopted (Hansson, 2020). Ultimately, as argued by (Altunyaldiz, 2020), the regulation of ADSs and the software that drives it should focus on full respect towards human life and impose positive obligations on states.

Forging the Path: The future of ADS regulation

As automated vehicle technology progresses, regulatory bodies must address various concerns while at the same time nurturing innovation and international collaboration. The future of ADS regulation will be centered on finding the right balance and forging strong partnerships between policymakers and industry stakeholders.

As already mentioned, coexistence between human-driven scenarios and driverless vehicles is inevitable for a long time yet (Sipetas et al., 2023; Tabone et al., 2021), given the limitations in computational capabilities and connectivity. For now, self-driving systems have restricted computing capability so as to keep costs and computational time down. Furthermore, they cannot rely on cloud computing, since constant connectivity cannot be guaranteed for moving systems.

Artificial intelligence is rapidly entering in many aspects of citizens' daily lives and ADSs will make no exception. AI will enhance perception with sensor data and improve decision making through adaptive learning. It will help traffic management and optimization and it will strongly influence human–machine interaction, making it more intuitive and responsive. On a more technical side, it may increase automation in varying conditions, where current systems are struggling and it may recommend predictive maintenance of the vehicles. In view of increasing ADS safety, it will be impossible for legislators to ignore the possibilities given by AI, but there will be new challenges to ensure the compliance to ethical guidelines and safety standards and design appropriate testing and certifications on AI-based systems.

Emerging technologies promise to reduce the cost of computing capacity, and new data transfer technologies, like 5G, will significantly improve connectivity (Attaran, 2021), allowing ADS manufacturers access to more data from the vehicles circulating on roads. The amount of data, and its diversity, will be crucial in training more successful machine learning algorithms, such as those employed by Tesla (Van Laer, 2022). Data diversity will stem from different types of sensors responding to different types of driving scenarios. The non-deterministic outcome of each decision in machine learning will pose challenges when ensuring a solid ethical base for algorithm certification. Collaboration between academia and industry stakeholders will be necessary.

As self-driving technology becomes increasingly accurate, regulatory bodies will likely establish higher standards and requirements for safety (reducing risk to passengers and others), security (data protection, access control, etc.), and reliability. New testing and validation processes will emerge, introducing new criteria for evaluating the performance of ADSs (Deichmann et al., 2023; Griffor, 2023).

In the long term, there might be a need for regulatory bodies dedicated to infrastructure updates, such as Vehicle-to-Infrastructure (V2I) communication systems (Kanthavel et al., 2021), traffic management systems capable of coordinating with automated vehicles (Li et al., 2023; Rubin et al., 2019), but at the same time capable of managing mixed human-ADSs scenarios with the goals of maximizing passenger convenience and minimizing accidents and fuel consumption (Diakaki et al., 2015; Roncoli et al., 2015; Zhao et al., 2018).

Historically, regulatory harmonization has been a common trend in fields such as the pharmaceutical industry (ICH, 2024) and, through the World Health Organization, food safety. A similar trajectory can be expected for ADS regulations, with a gradual convergence of national rules and adoption of international standards in order to facilitate cross-border travel and global market expansion.

In conclusion, as ADS technology rapidly evolves, regulations must remain adaptable and flexible in order to accommodate new advancements. The challenge will be to respond to technological changes without hindering innovation. Regulation will play a fundamental role in shaping public perception and building trust in ADSs, by fostering safety, promoting transparency, and facilitating consumer education.

Conclusions

Automated vehicle technology, as a rapidly evolving field, requires a dynamic and collaborative approach between technology experts and legislators. At the same time, the safe deployment of these vehicles requires a robust legal framework. Even though initial steps have been made at both EU and national levels, future regulations must dig deeper into unresolved issues.

This paper presents ethical dilemmas and legal liability linked to self-driving vehicles, and outlines existing regulations. Currently, different states have adopted different approaches: in its guidelines, the EU generally underlines the importance of data privacy, human oversight, and safety. However, there are many differences in approach among EU member states. The USA has, since the beginning, been very progressive in allowing testing and use. In this case, there has been a more hands-off regulatory approach, with individual states developing their own rules for automated vehicle testing and deployment.

Despite the fact that it is positive progress to see the first regulations at the national level, this also opens up the problem of different rules in different states. Therefore, the international and supranational regulation of this field is of great importance, in order that unified use of ADSs be enabled and that legal certainty for ADS users be provided. As argued by (Bertolini and Riccaboni, 2021), different legal frameworks for the testing of self-driving vehicles is not a problem. On the contrary, it encourages competitiveness. However, different liability regulation gravely influences the development and distribution of connected and automated driving solutions, and so influences which technology will be adopted and which automation approach will win (Bertolini and Riccaboni, 2021). Different approaches in member states influence technology use, leading to different technological solutions, and consequently to fragmentation of the EU market. Finally, the parceling of regulation by individual member states leads to lower competitiveness for the EU as a whole.

In general, the establishment of comprehensive policy and effective regulation centers on clarifying foundational terminology. A harmonized definition and classification of ADS features, along with unified safety standards, liability norms, data security protocols, and requirements for human oversight, are highly desirable. Given the cross-border implications of this phenomenon, it is essential that uniform terminology, vehicle categorization, and regulations are established, ideally at an EU-wide or even global scale.

Funding resources

The research was funded by University of Ljubljana, Faculty of Public Administration.

Credit authorship contribution statement

Tina Sever: Writing – review & editing, Writing – original draft, Methodology, Investigation. **Giuseppe Contissa:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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