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Legal and Safety Aspects of the Application of Automated and Autonomous Vehicles in the Republic of Croatia

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Abstract: In its draft proposal for the Road Transport Act, the Croatian government referred to European Union Directive 2022/738, which concerns the use of hired vehicles for goods transport, rather than the pertinent European Union regulations on automated and autonomous vehicles, specifically Regulation 2019/2144 and Implementing Regulation 2022/1426. This oversight highlights Croatia's lack of preparedness to integrate highly automated and autonomous vehicles, which are crucial for safety and environmental performance as per European Union standards. This paper aims to clarify the safety and legal recommendations for the trafficking of these vehicles in Croatia. Level 2 and Level 3 automated vehicles, present in smaller numbers in road traffic in Croatia, were compared from the perspective of the lack of driving tasks and its impact on driver safety. The stages of road liability for traffic accidents were also investigated, with recommendations of strict (default) liability of manufacturers for fully autonomous vehicles as well as presumed liability of all road traffic participants for highly automated vehicles. The safety and traffic benefits of possible infrastructure upgrades for highly automated and fully autonomous vehicles were discussed, mostly in the segment of dedicated lines.

Keywords: automated vehicles; fully autonomous vehicles; legal recommendations; road traffic safety; road liability recommendations

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1. Introduction

In the current Croatian legal system, there is no practical possibility for driving highly automated and/or fully autonomous vehicles on the roads of the Republic of Croatia (further: Croatia), not only due to the lack of and/or undefined legal acts in the Road Transport Act (Official Gazette NN 114/22) [1] and in the Act on Road Traffic Safety (NN 133/23 [2]) but also due to the unadjusted and/or insufficient road infrastructure that is highly necessary for fully autonomous vehicles to be able to drive safely on Croatian roads. This paper will also address the recommendations to amend the Law on Obligations of the Republic of Croatia NN 155/23, 156/23 [3] concerning the liability of the owner/operator/manufacturer or service provider of higher levels of automated and fully autonomous vehicles in the event of a road traffic accident, concerning the level of the automation. However, certain other member states (further: MSs), such as France, Germany, the Netherlands and Sweden, have amended their respective Laws on Obligations within their national legislations, acknowledging the need to establish liability conditions in the event of accidents involving automated vehicles (SAE1-SAE4 as defined by the Society of Automotive Engineers) but not for fully autonomous vehicles (SAE5). On the one hand, the Croatian Road Transport Act, mentioned above and currently in force, does not in any context mention automated/fully autonomous vehicles, and the proposal of the Act on Amendments to the Road Transport Act [4] (the Proposal), which at the time of writing this paper was under e-consultation, mentions it only by definition (automated or autonomous vehicles). Although the legislator has the will to introduce the possibility of driving autonomous vehicles in Croatia, the two main legal acts in Croatia in the field do not sufficiently regulate the mentioned categories. The legislator, in this case the Ministry of Sea, Transport and Infrastructure, was eager to pass the Proposal of the Act so it could enable a specific company to place its automated vehicles on the market and eventually bring its fully autonomous vehicles to Croatian roads. Furthermore, there are currently several obstacles to introducing automated/fully autonomous vehicles on the roads in Croatia, and one of the biggest is the proposal to use German laws and regulations for the use of automated and fully autonomous vehicles. Namely, Germany is a country with a new legal act of 2021 concerning the regulation of the liability of autonomous vehicles [5]. It enabled the imposition of liability on car owners, except in cases of technical malfunctions of such vehicles, which must be substantiated by mandatory confirmation from the manufacturer. According to German law, the owner's responsibility is bound by stringent civil liability under prevailing general rules, tempered by *force majeure* and contributory negligence. Disputes may arise regarding the allocation of responsibilities between the owner, relevant manufacturer, and system provider. An amendment to the German Road Traffic Act of 2017 [6] has increased the maximum amount of strict liability for highly and fully automated driving functions to EUR 10 million. Furthermore, civil and criminal liability for negligence are applicable under standard regulations. Also, one of the key questions that will permeate the paper is the following: How is it possible for artificial intelligence (AI) to render a decision that results in an accident, and why would the vehicle owner be held liable in such an instance? This paper will try to explain the legal regulations for the introduction of highly automated and fully autonomous vehicles in the EU and, consequently, in Croatia, and it also deals with issues that explain how safe automated vehicles are from the end-users' perspective, i.e., the vehicle owner or the operator who drives the vehicle, and whether there is a possibility of placing vehicles of higher levels of automation into circulation on the roads in Croatia.

2. Legal Aspects of Automated and Autonomous Vehicles in Croatia

The legal framework for autonomous vehicles in Croatia is still under development. However, the country is taking some steps to adapt its legislation to accommodate today's emerging technologies. To bring automated and fully autonomous vehicles onto Croatian roads, several factors need to be considered:

- Legislation: The Ministry of the Sea, Transport, and Infrastructure in Croatia has started working on drafting regulations to address the use of autonomous vehicles. The regulations should define technical requirements, safety standards, liability concerns, and operational guidelines for automated and fully autonomous vehicles in the country.
- EU Regulations: Croatia, as a member of the European Union, must also comply with EU regulations (mentioned earlier in this paper) related to automated vehicles. The European Commission has also issued guidelines and regulatory frameworks for autonomous driving that MSs must align with.
- Vehicle Certification: Automakers and technology companies developing autonomous vehicles need to obtain the necessary certifications to ensure their vehicles meet safety standards and comply with regulations. This involves testing and demonstrating the safety and reliability of autonomous technology, which will be explained in more detail in Section 5.

- Infrastructure: The existing road infrastructure in Croatia needs to be modified or updated to support highly automated and fully automated vehicles. Road infrastructure will have to be significantly improved in the context of needs suitable for autonomous vehicles, such as traffic signalization, road signs, etc. Also, it may include the installation of smart infrastructure, such as CCTV/video surveillance, communication systems, sensor networks, and dedicated lanes, limited to the piloting of highly automated (SAE4) and fully autonomous (SAE5) vehicles only.
- Liability (owner, operator, service provider, hardware/software manufacturer): For SAE5 vehicles, insurance companies will need to know who is liable/responsible in the event of a malfunction or accident so they take this possibility into account when insuring such vehicles because the current legal framework, i.e., the previously mentioned Law on Obligations, does not define the issue of liability in the event of damage committed by such an automated/fully autonomous vehicle.
- Public acceptance and trust in autonomous vehicles play a vital role in their deployment. Educating the public about the benefits and safety of autonomous vehicles is crucial to gaining public support for delivering fully autonomous vehicles commercially to Croatian roads, as well as the roads of the remaining 26 MSs.

As for Croatian laws, the proposed law [4] amends Article 1, Paragraph 3, stating that it does not apply to domestic and international cargo transport with vehicles under specific weight limits, transport for personal use, or passenger transport in M1 vehicles with up to seven seats. It references Regulation 1072/2009 [7] and Directive 2006/1/EC [8], which govern road transport but do not address automated or fully autonomous vehicles, as its legal basis. The proposed law [4] amends Article 1, Paragraph 3, excluding certain categories of transport from its scope. However, these acts do not address automated or autonomous vehicles, making the amendment insufficient to regulate such technologies.

The proposed law references Regulation 1072/2009 and Directive 2006/1/EC, which regulate access to the international road haulage market and the use of hired vehicles for goods transport. However, neither addresses automated or fully autonomous vehicles. The Draft Act also incorporates provisions from Directive 2022/738 [9], which updates Directive 2006/1/EC [8] but still excludes regulations on fully autonomous vehicles. Notably, the proposal omits any reference to Regulation (EU) 2019/2144 [10], which explicitly covers type-approval requirements for motor vehicles, including automated and autonomous systems, and addresses safety and protection for occupants and vulnerable road users.

Amendments to both mentioned acts are as follows: In the Road Traffic Safety Act—amendments and additions adopted on 15th of November 2023—Art. 2 para. 107 defines an automated vehicle as a vehicle that utilizes hardware and software for continuous complete dynamic vehicle control (fully automated vehicle without a steering wheel), and Art. 197 states that the driver must be seated in the driver's seat and in control of the vehicle while driving, except in the case of a fully automated vehicle. The proposed Act of amendments and additions to the Road Transport Act entered into procedure on the 23rd of November 2023—the voting date in the Croatian Parliament was the 26th of January 2024—and at the 21st session, on 26th of January 2024, it was concluded that the proposed law is accepted.

All comments, proposals and opinions were to be sent to the proposer for the preparation of the final proposal of the law (79 votes "for", 14 "against", 34 "abstentions") [4]. Therefore, in Article 4, paragraph 1, after point 1, a new point 2 was added, which reads as follows: "2. automated road passenger transport is a public passenger transport service performed by an automated vehicle in a predefined operating area if one passenger or a related group of passengers boards at one or more locations and disembarks at one or more locations, and such transport is carried out based on a single order executed by an electronic application and with a single payment of the total fee for the completed transport determined by an electronic application, from which the passenger can see in advance the maximum price and the planned travel route according to pre-known conditions." In Article 5, a new paragraph 4 was added, which reads "(4) Safety drivers and safety operators or persons supervising and/or monitoring automated vehicles for the performance of automated road passenger transport must obtain initial qualification according to a special program". After Article 20, a heading above the articles and Article 20a was added, which reads "Professional qualification of responsible persons in the activity of automated road passenger transport—Article 20a—The carrier performing the activity of automated road passenger transport must employ a professionally qualified transport manager under Article 20 of this Act and a safety operator". These are the only amendments and additions related to automation and fully autonomous vehicles expected to hit Croatia's roads as early as the first quarter of 2025 [11]. Neither of the two laws provides detailed regulations on how and on which designated lanes such vehicles should operate, considering that road infrastructure requires adaptation for automated and fully autonomous vehicle operation and the establishment of a detailed regulation on their traffic, which the current law does not foresee. Furthermore, it can be hazardous to pass such amendments and additions to the law that are not thoroughly elaborated to protect the safety and security of citizens, consumers, and road users, especially since either of these two Croatian acts do not prescribe the liability of such vehicles, especially for SAE4 or SAE5.

SAE [12] has established a unified taxonomy and definitions for six levels (SEA0-SAE5) of driving automation, ranging from SAE0, where the vehicle provides warnings or instant assistance and the driver performs all tasks related to vehicle control. The first three (3) levels of automation, SAE1 to SAE3, can be described as forms of driver assistance. Table 1 shows recommendations for liability depending on the SAE level of automatization, for which the Croatian legal system has not made any recommendation. Therefore, insurance companies will not be able to offer insurance policies for vehicles with level SAE5.

Table 1. Liability recommendations depending on SAE level of automation.

SAE Level	Description	Longitudinal and Lateral Control	Monitoring of Driver Environment	Fall-Back When Automation Fails	Operational Design Domain	Recommendations for Road Liability in Croatia *
0	No automation	Human	Human	Human	Limited	The owner is liable for material liability, and the driver is liable for criminal liability
1	Driver assistance	Human/ System	Human	Human	Limited	
2	Partial automation	System	Human	Human	Limited	
3	Conditional autonomy	System	System	Human	Limited	
4	High automation	System	System	System	Limited	Presumed liability of owner/operator/service provider/manufacturer
5	Full automation	System	System	System	Unlimited	Strict liability (default liability) of software/hardware manufacturer

Source: Taken from SAE [12] and amended with liability recommendations * by authors.

However, if SAE4 and SAE5 vehicles could participate in road traffic in Croatia, it is necessary to define road liability at the mentioned SAE levels.

Therefore, the authors recommend the solutions for road liability shown in last column of Table 1 for all SAE levels.

Our recommendation is modeled after the Montreal Convention [13] in air transport, suggesting the introduction of a compensation framework for the carrier's liability. For SAE 4, "Presumed liability of owner/operator/service provider/manufacturer" means that the responsibility for damages is presumed to lie with the owner, operator, service provider or manufacturer, unless proven otherwise. For SAE5, "Strict liability of software/hardware manufacturer" means that the software or hardware manufacturer is always held fully responsible for any damages caused by their products, regardless of fault or negligence.

According to the above, as follows for SAE4, the authors propose *Presumed Liability of owner/operator/service provider/manufacturer* (in air transport, this refers to the liability assumed by the owner, operator, service provider or manufacturer in the event of an accident or damage).

Liability is "presumed", meaning that they are considered responsible for the damage unless they can prove otherwise (e.g., that an accident was caused by external circumstances).

This is modeled after the system under the Montreal Convention, where air carriers are liable for damage to passengers and their property, with the possibility of proving they took all reasonable precautions.

For SAE5, the authors propose *Strict Liability of hardware/software manufacturer*. This refers to the strict liability of manufacturers of software or hardware components used in aircraft (e.g., flight control systems, avionics, etc.).

In this road context, manufacturers should also be liable, for SAE5 liability is assumed by default, for any damage caused by their products, regardless of whether they were negligent or not. Even if the product was used correctly, if it causes damage due to a design or manufacturing defect, the manufacturer is responsible for compensation.

This is an example of strict liability, which is commonly applied in many industries, including air transport, to ensure greater safety and protection for users. This model allows for quicker compensation as users do not need to prove the fault of the manufacturer or operator, with responsibility being transferred to them according to predefined rules.

In the context of air transport, liability can be equally shared among all stakeholders (owners, operators, manufacturers and service providers). This means that, while each stakeholder may be responsible for different aspects of operations (e.g., technical issues, human errors or regulatory violations), all of them can be held liable for damages in the event of an accident.

This approach is similar to a system of joint liability, where multiple parties can be responsible for the damage caused, rather than just one party. In practice, this means that owners and operators may be liable for accidents arising from vehicle maintenance or poor operational management, manufacturers may be liable for design or production flaws that caused the accident and service providers (e.g., pilots and air traffic controllers) may be liable if they are proven to have made errors in their duties.

This system of shared liability ensures that affected parties (e.g., passengers) have access to compensation, while also ensuring that responsibility is distributed among all relevant stakeholders based on their roles and obligations in the process.

We have linked this aspect of liability to air transport precisely because air transport has the highest level of safety among all modes of transportation, and the system has been functioning effectively since 1999 in terms of liability and compensation for damages.

This long-established framework ensures that passengers and users are protected and can receive compensation more efficiently, and it serves as a model for other industries.

The high safety standards and well-defined liability systems in air transport provide a clear precedent for handling similar issues in other sectors, ensuring that responsibility is allocated appropriately and in a way that protects those affected by accidents or damages.

3. Introduction of the EU Legal Framework Regarding Automated and Fully Autonomous Vehicles into the Legal System of the Republic of Croatia

Regulation (EU) 2019/2144 of the European Parliament and of the Council [10] on type-approval requirements for motor vehicles and their trailers, 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, states the following in its preamble: Preamble (1) Regulation (EU) 2018/858 of the European Parliament and of the Council (3) [14] lays down administrative provisions and technical requirements for the type-approval of all new vehicles, systems, components and separate technical units, with a view to ensuring the proper functioning of the internal market and in order to offer a high level of safety and environmental performance (10). Advanced emergency braking systems, intelligent speed assistance, emergency lane-keeping systems, driver drowsiness and attention warnings, advanced driver distraction warnings and reversing detection are safety systems that have a high potential to considerably reduce casualty numbers. In addition, some of those safety systems form the basis of technologies which will also be used for the deployment of automated vehicles. Any such safety systems should function without the use of any kind of biometric information of drivers or passengers, including facial recognition, which is permitted by the proposal of the EU AI Act [15]. Also, the ban on the use of real-time biometric data is prohibited in the Recital (21) of an unofficial version of the final AI Act [16] that states that every deployment of a "real-time" remote biometric identification system in publicly accessible areas for law enforcement purposes must undergo explicit and specific approval either by a judicial body or an independent administrative authority whose decision holds legal weight within a member state. Generally, such authorization should be obtained prior to usage, except in cases where the system is deployed to identify individuals. Exceptions to this principle should only be made in duly justified urgent situations, where the necessity of immediate system usage renders obtaining prior authorization effectively and objectively impossible. In such urgent scenarios, system usage must be limited to the absolute minimum required and be accompanied by appropriate safeguards and conditions, as stipulated by national law and specified for each individual urgent use case by the law enforcement agency itself. Moreover, in such urgent situations, the law enforcement agency should promptly seek authorization, providing reasons for the delay, and must carry this out within 24 h at the latest. If the authorization is denied, the use of real-time biometric identification systems associated with that authorization must cease immediately, and all data pertaining to such usage must be discarded and deleted. As a result, standardized regulations and testing methods for approving both vehicles with integrated systems and those systems as standalone units need to be set at the Union level.

Ongoing advancements in technology must consistently inform assessments of current legislation to ensure its relevance for the future, all while upholding strict principles of privacy and data protection. Moreover, the objective should be to minimize accidents and injuries in road transportation. Additionally, it is vital to guarantee the safe usability of these systems throughout a vehicle's lifespan. The mentioned regulation refers to an (21) "automated vehicle", which 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, and (22) a "fully automated vehicle", which means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision; neither single Croatian act mentions such definitions of automated or/and fully autonomous vehicles. It only provides partial definitions without further elaboration and the possibility of allowing autonomous vehicles to drive on Croatian roads. Automated vehicles have the potential to make a huge contribution to reducing road fatalities, given this and according to the Collaborative Science Centre for Road Safety's Report from December 2020 [17].

As automated vehicles increasingly assume the responsibilities of human drivers, standardized regulations and technical standards for automated vehicle systems (ADSs), including those concerning verifiable safety assurance for the decision-making processes of automated vehicles, ought to be implemented at the European Union level. This should be performed while adhering to the principle of technological neutrality and advocating for these standards internationally through the UNECE's World Forum for Harmonization of Vehicle Regulations (WP.29) [18]. Article 11 of Regulation (EU) 2018/858 outlines specific requirements pertaining to automated vehicles and fully automated vehicles. These vehicles must adhere to technical specifications detailed in implementing acts for various systems, including those for replacing driver control, providing real-time vehicle and surrounding information, monitoring driver availability, event data recording, data exchange formats for multi-brand vehicle platooning and safety information dissemination to other road users. However, technical specifications related to driver availability monitoring systems do not apply to fully automated vehicles. The Commission is tasked with adopting uniform procedures and technical specifications through implementing acts for the systems listed in paragraph 1. These acts also cover the type-approval process for automated and fully automated vehicles concerning these systems to ensure safe operation on public roads.

The adoption of these implementing acts follows the examination procedure outlined in Article 13 (2). Autonomous vehicle regulations vary among different MSs, including in Germany, where significant liability matters have been largely addressed through national laws. According to German legislation, the owner of the vehicle bears the primary responsibility. Liability insurance owned by the vehicle owner covers personal injury and property damage for both traditional and automated vehicles (SAE4). Additionally, there is a requirement for the operator/technical supervisor/safety driver to have liability insurance. In the event of a traffic violation or accident, the cause and fault are determined on a case-by-case basis.

The law was passed in 2021 and is the key legal framework governing the use of vehicles (SAE4) on public roads in Germany. This law has taken a significant step in regulating liability, safety standards and operating conditions for autonomous vehicles. In the event of an accident, liability is divided between several key entities: According to the German Compulsory Insurance Act (Pflichtversicherungsgesetz [19]), the vehicle owner is obliged to insure the autonomous vehicle. In the event of an accident, the vehicle owner's insurance is liable for the damage, similar to with traditional cars.

If the accident is the result of a technical failure of the automated driving system, the manufacturer may be liable under the Product Liability Act (Produkthaftungsgesetz [20]).

If the technical supervisor fails to intervene in the event of a critical situation, they may be liable for the consequences of the accident. If a software error is found to have contributed to the accident, the software supplier may be liable under the Product Liability Act.

In 2019, France enacted the Mobility Orientation Law (Loi d'Orientation des Mobilités—LOM—[21]), which establishes the legal framework for regulating autonomous vehicles, including Level 4 automation vehicles as defined by SAE standards.

Under the LOM Law, liability for vehicles with a high level of automation (SAE4) primarily rests with the operator of the automated driving system. The operator refers to a legal or natural person responsible for managing an autonomous mobility service and ensuring the safety and proper functioning of the vehicle during automated driving operations. Article 31 of the LOM Law defines the conditions under which autonomous vehicles may operate in traffic, including the responsibilities of operators and insurance requirements. This article also provides for adjustments to existing laws to account for the specific characteristics of autonomous vehicles, ensuring legal clarity regarding liability in the event of accidents or incidents. For SAE5, there are still no defined regulations. Hence, the authors propose solutions and compare legal practices within the EU for SAE4 and SAE5 levels, as shown in Table 2.

Table 2. Liability and recommendations for SAE Levels 4 and 5 across selected countries.

SAE Level of Automation	Recommendations	Road Liability According to the Regulations	
	Croatia	Germany	France
SAE4	Presumed liability of owner/operator/service provider/manufacturer	Owner/operator/vehicle manufacturer/software supplier	Primarily on the system operator
SAE5	Strict liability of software/hardware manufacturer	Still not defined	Still not defined

Source: Taken from [19–21].

In countries like Sweden or the Netherlands, the Netherlands has conducted several pilot projects with SAE4 vehicles, adhering to strict safety protocols and approval requirements. The regulation is based on existing road traffic laws, with adjustments made for autonomous vehicles. Currently, there is no specific regulation for Level 5 vehicles (SAE5). However, the Netherlands actively participates in European initiatives aimed at developing common standards and regulations.

Sweden also allows the testing of SAE4 vehicles on public roads under special permits and safety measures. The regulatory framework is being adapted to support innovation in the field of autonomous driving. Similar to other countries, Sweden monitors technological advancements and actively participates in international discussions on the regulation of fully autonomous vehicles (SAE5).

At the European level, there are currently no legally binding regulations regarding liability issues in fully autonomous vehicles. If a safety driver is present, they assume responsibility for accidents and traffic violations, while the manufacturer is held liable for technical malfunctions and system failures in the vehicle [22].

Commission Implementing Regulation (EU) 2022/1426 of 5 August 2022 [23] lays down rules for the application of Regulation (EU) 2019/2144 [10] of the European Parliament and of the Council regarding uniform procedures and technical specifications for the type-approval of the ADSs of fully autonomous vehicles. For the whole vehicle type-approval of fully autonomous vehicles, the type-approval of their ADSs under this regulation should be complemented with the requirements set out in Annex II, Part I, Appendix 1 of Regulation (EU) 2018/858 of the European Parliament and of the Council (3) [14].

Furthermore, IUS INFO lists various unresolved legal, ethical and safety issues regarding vehicles with autonomous driving systems [24]. How can a natural person, as the owner of the vehicle, be held liable for decisions made by the AI in a fully autonomous vehicle, particularly in the event of a traffic accident? What are the moral, ethical and legal norms, and how are the rights of end-users protected, specifically in the case of the driver of a fully autonomous vehicle?

Furthermore, whose fault would it be and who is responsible if the software is programmed and able to decide by itself, like in SAE5?

Also, some examples where PII (personally identifiable information) may be collected by IoT devices include the driver of the autonomous vehicle or fleet vehicle that is being tracked, e.g., where the vehicle or, therefore, the driver has traveled, and those data are not allowed under Article 9 of the General Data Protection Regulation on confidentiality of personal data due to the fact they are a special type of personal data [25].

Therefore, what we propose is the following amendment to the Law on Obligations: Articles 1068 and 1069 should be amended to include the terms "automated vehicle" and "fully autonomous vehicle", and the articles should be supplemented in accordance with Table 2 of this paper.

4. Relations Between Road Traffic Safety and Level of Automatization from the Point of Human Factors

SAE5 includes fully autonomous vehicles, characterized by complete automation where an advanced artificial intelligence system takes full control of the vehicle under all conditions, rendering the driver a passive observer or passenger [12]. This depends on the level of automation shown in Table 1. In chapter two, vehicles are equipped with various Advanced Driver Assistance Systems (ADASs) [26]. Numerous ADASs are currently in use on the commercial market, with additional concepts described in the scientific and professional literature, including real-time monitoring of driver conditions, adaptive cruise control, lane departure warning systems, forward collision warning systems, traffic signal recognition systems, tire pressure monitoring systems, night vision, pedestrian detection (recognition of pedestrians and other vehicles as obstacles to be avoided), parking assistance systems, automatic emergency brake systems, driver behavior monitoring and the regulation of vehicle speed based on speed limits, blind spot detection, alcohol interlock systems, and similar.

Presently, SAE2 and SAE3 automated vehicles are the highest SAE levels which operate on the roads in Croatia. A critical question arises concerning liability in the event of a traffic accident when the automated system is engaged—whether the driver, the vehicle manufacturer or a third party bears responsibility. The difference in sensor equipment between SAE2 and SAE3 automation is minimal, yet the role of the driver is fundamentally distinct. The key difference between SAE2 and SAE3 is as follows: in SAE2 (partially automated driving), the responsibility still lies with the driver at all times. For example, when the BMW Highway Assistant is in use, drivers must monitor what is happening on the road and be able to resume the driving task at any time. This is continuously monitored by an intelligent surveillance camera. SAE2, or partial automation, involves a vehicle with a combination of automated functions such as longitudinal and lateral control. The interesting aspect of SAE2 automation is that, in some implementations, existing technologies such as radar and machine vision can be employed to ensure robust automation [27]. An example of an SAE2 automated vehicle is the Tesla Model S [28].

Moving to SAE3 automation, or conditional automation, vehicles can perform all driving tasks in specific circumstances. The driver is still required to take control when the system cannot operate and it is not necessary to monitor the traffic environment while the system is engaged. However, the driver is expected to be ready to resume control at any moment with prior notice. The Audi A8, debuting in 2017, was the first commercially available vehicle equipped with SAE3 automation [29], but was canceled soon after due to inconsistencies in the legal regulations of individual countries. Vehicles at the SAE3 level can use technologies like radar and machine vision or an entirely different set of technologies. SAE3 automation allows the driver to relinquish both supervisory and control roles under specific conditions, with the expectation that the driver will be ready to resume control when prompted by the system.

SAE3 vehicles can drive themselves, although the driver must be present and ready to take control at basically any time. In this case, if an accident occurs the driver is responsible. In late 2023, the company Mercedes certified the first SAE3 production vehicle, but only for the American market [30]. Currently, it is not clear how this success is significant, as most of the other manufacturers plan to take the step from SAE2 straight to SAE4.

Also, representatives of levels SAE4 and SAE5 can be described as fully autonomous cars. These vehicles can participate in driving without a person sitting in the driver's seat. Consequently, if an accident happens, the manufacturer should be responsible.

SAE4 automated vehicles do not need to be able to navigate all roads and all-weather conditions. On the contrary, an SAE5 automated vehicle must be able to drive anywhere humans can. Apparently, in the long term, considering vehicles at level SAE2 and SAE3, when there are sufficient number of these vehicles on the roads they will cause a decrease in the number of traffic accidents related to the cause of the wrong reaction of the driver; this is because, according to [31], 90% of traffic accidents are caused by driver errors, and according to [32] this is even more, 94%. However, in a situation where the vehicle still requests the driver's intervention, e.g., SAE3, the driver's successful performance is questionable and related to the following factors: the level of automation, loss of fundamental driving skills, excess free time to engage in secondary distraction tasks and, as proven in the literature, increases in the time drivers look away from the road [33].

Research in aviation has revealed that pilots, if they do not practice procedural tasks (pre-flight checklists, emergency procedures and standard operating procedures for take-off, landing and other critical flight phases) and compensatory tracking tasks (maintaining control or alignment with a desired trajectory), gradually lose fundamental flying skills [34].

According to [35], drivers of vehicles with various levels of automation will be responsible not only for driving but also for monitoring the traffic environment to respond promptly to unexpected situations. Therefore, a driver monitoring system is crucial to ensure that the driver remains in a suitable condition during the journey. Criteria for determining driver concentration levels will differ for various levels of vehicle automation and the time required for driver supervision. Vehicles at SAE1 and SAE2 levels of automation should detect undesirable driver states such as fatigue, drowsiness, distraction and inattention in real time. At the SAE3 level, the lack of monitoring and driving tasks allows drivers to actively engage in secondary distraction tasks while the system monitors the traffic environment. This differentiates it from SAE2, where the driver is responsible for the monitoring of the environment. Generally, from a driver safety perspective, an examination of the short-term implications within the current traffic scenario reveals that the SAE3 level exhibits a lower risk to the driver compared to the SAE2 level. This discrepancy arises from the synergistic enhancement of the driver's capabilities in conjunction with the advanced features embedded in SAE3, surpassing the combined capabilities of the driver and the SAE2 level of automation. The SAE3 level emerges as a higher risk factor for the driver when juxtaposed with the SAE2 level due to the expected loss of basic driving skills. This assertion finds support in several empirically substantiated scientific principles, interwoven and corroborated in the existing literature.

Firstly, the alleviation of the critical task of monitoring the traffic environment liberates the driver from pivotal cognitive engagement, rendering them physically detached from the primary responsibility of vehicle control [36]. Secondly, an observed escalation in the duration during which the driver diverts their gaze from the road correlates with an abundance of discretionary time that may be directed towards secondary distractions [33]. This includes activities of non-driving-related tasks (NDRTs) such as mobile phone usage [37]. Noteworthy is the fact that this surplus of free time stems directly from the reduction in the number of tasks imposed on the driver, as delineated in Table 3 [12]. A study from 2014 [38] also confirms that, as the level of automation increases, drivers are more inclined to engage in NDRTs during conditional automated driving. In essence, the intricate interplay between driver capabilities and the nuanced features of automation underscores the nuanced and context-dependent nature of the safety implications associated with varying levels of automation. For this reason, Regulation (EU) 2019/2144 [10] is of vital importance as it underscores the significance of implementing advanced driver assistance systems in motor vehicles of categories M (four-wheeled vehicles for passenger transport) and N (four-wheeled goods transport vehicles), such as drowsiness and attention warning systems; when designed to be user-friendly and efficiently integrated, these contribute to reducing fatalities, decreasing the number of road accidents, and mitigating injuries and damages. The authors believe that such systems should be a legal obligation for all vehicles including the SAE2 and SAE3 levels of automation.

Table 3. Comparison of vehicle control activity executors between SAE2 and SAE3 automation.

Vehicle Driving Activities	Who Performs Them?	
	SAE2	SAE3
Accelerator/brake pedal activation	System	System
Turning the steering wheel	System	System
Monitoring of the traffic environment	Human	System
System activation/deactivation	Human	Human
Taking control of the vehicle after the termination of automation	Human	Human

Source: Prepared by the authors using publicly available materials from SAE [12].

Consequently, it is essential to enable partial driver supervision just before issuing system deactivation warnings due to limitations, ensuring timely checks of the driver's concentration and ability to respond appropriately. A similar situation occurs in SAE4 automation, where the vehicle is able to perform all control functions, but there are spatial limitations where such a system cannot function. SAE5 vehicles will no longer have a driver, possibly providing passengers with greater comfort, necessitating monitoring of passenger seat positions to enable safety systems to react appropriately in unavoidable collisions.

5. The Possible Impact of Higher Levels of Fully Autonomous and Connected Automated Vehicles on Drivers' Behavior and Performance

Why do the authors of this paper anticipate issues in real-life scenarios regarding the performance of drivers of SAE3 and SAE4 vehicles, particularly SAE4, when drivers are required to respond to the requests of these vehicles? It is widely acknowledged that driver performance and workload have a non-linear relationship. Additionally, driver performance varies depending on the level of automation, with safer performance observed in manual driving compared to partially and highly automated driving. Conversely, workload decreases with higher levels of automation (SAE3-SAE4), as drivers experience a higher workload in manual driving conditions compared to highly and partially automated driving conditions [39]. Furthermore, it is understood that both underloading and overloading negatively affect a driver's performance and that each driver has an individual optimal level of workload for successful performance. According to [40], individual differences in workload levels can significantly impact driving performance. The study revealed that experienced and male drivers tend to demonstrate lower driving speed and lane deviation compared to non-professional and female drivers under similar workload conditions. This suggests that individual characteristics, such as driving experience and gender, influence how drivers manage workload demands and maintain driving performance.

Furthermore, the three main groups of driver workload factors are listed in order according to the intensity of the negative effect on a driver's performance: time pressure (i.e., short time for response), multiple simultaneous tasks and the complexity of an individual task. Therefore, during a significant portion of the driving period, there are no simultaneous tasks in vehicles with SAE3 and SAE4 levels of automation, and there are almost no tasks, especially not complex ones. However, the driver is expected to always be ready to respond to the vehicle's request in a very short time, particularly in exceptional circumstances, for all those tasks that automation cannot handle without a driver. It is expected that very complex and urgent traffic situations may arise if automation is unable to resolve them.

The authors anticipate that in such emergency situations (responding to the vehicle's request), the driver may perform optimally, neither quickly nor accurately, among other factors, due to a delayed regaining of awareness of the situation. Both excessively short and lengthy lead times for takeover requests (ToRs) are suboptimal for regaining situation awareness, highlighting the importance of striking a balance in determining the optimal lead time for effective transition in conditionally automated driving scenarios. According to the findings of one of the publicly available studies from 2022 [41], ToRs show a positive correlation with driver situation awareness (SA) during the process of resuming manual control to exit from freeways in conditionally automated driving scenarios. The study suggests that ToRs ranging between 16 and 18 s are considered most suitable for ensuring adequate SA levels and facilitating successful takeover maneuvers. Additionally, the research indicates that drivers (not all) tend to delay their takeover actions until the last possible moment, when provided with extended lead times.

A much older study from 2012 [42] found that drivers could take control of the vehicle within 4-8 s, depending on the complexity of the takeover situation. A recent study from 2022 [43] reported that six seconds is the balance between shorter driver reaction times and higher quality of the takeover.

Namely, more studies indicate a gradual loss of a pilot's fundamental flying competencies, i.e., skills due to the excessive use of autopilot during the flight period, compared to the percentage of the time in which the pilot manages the flight manually. One of the older aviation studies cited above confirmed this scientific fact [34]. Some companies are trying to solve this problem with different measures; among other things, some of the big companies that offer long-distance transoceanic flights have prescribed a minimum percentage of the flight time during which the pilot has to manage the flight manually.

On the other hand, the classic devices for detecting and/or preventing fatigue that such vehicles are already equipped with, will to some extent help to keep the driver awake in circumstances of the appearance of fatigue due to the monotony at night on roads with high speeds and monotonous environments, such as highways, may not completely solve the problem with the lack of fundamental driver competence.

In addition, conditionally automated driving also permits engagement in various non-driving tasks, which may result in reduced situational awareness for the driver. According to [44], this challenge can be addressed by introducing a visual stimulus, such as an LED bar positioned along the bottom of the windscreen, to communicate the automation system's confidence level and to prompt manual takeover when required. This visual stimulus encompasses multiple configurations, each denoting different automation systems' confidence levels and prompts for manual takeover requests when required through diverse frequencies and colors.

The next significant challenge is that private owners of individual autonomous vehicles will probably seek to generate income or reduce the costs of using them through car-sharing services.

When there is a significant percentage of CAVs on the roads which give car-sharing services, which operators will be liable for unblocking such vehicles when they stop or collide? Certain studies show substantial possible traffic, logistical and safety advantages of networked vehicles at the highest levels of automation (SAE4-SAE5). The point of the study in [45] is to propose and validate an image-like representation of spatial vehicle-based speed distribution using heat maps on a motorway model. The study demonstrates that this representation can be utilized for learning the categorization of traffic safety, as validated by high prediction accuracy and lower loss produced by a proposed convolutional neural network model. Additionally, the study explores the impact of the high penetration rate of CAVs with an Intelligent Speed Adaptation system on learning accuracy and loss reduction. Generally, connected vehicles facilitate reduced congestion and optimized routing by communicating with each other and exchanging information about speed, position, maneuvers and traffic infrastructure. Additionally, they enhance logistics operations through improved delivery schedules, leading to cost reduction and increased productivity. Furthermore, connected vehicles enable early hazard detection and proactive accident prevention, thereby significantly enhancing overall road safety for drivers, passengers, and pedestrians. CAVs are anticipated to improve traffic efficiency through reduced time headways and enhance traffic safety by decreasing reaction times [46].

The disadvantage of the above-proposed solution is that such CAVs maybe require a separate traffic lane (i.e., dedicated lane) for the optimal effect of CAVs, which may affect the flow capacity of vehicles with the lowest levels (SAE0-SAE1) of automation, i.e., manually driven vehicles (MVs) on other lines that are not networked. Although the necessity of a dedicated lane for CAVs remains uncertain, findings from a simulator study [47] reveal that within a mixed-traffic context featuring CAV platoons, MV operators displayed limited behavioral adaptation concerning car-following and lane changing dynamics at a moderate penetration rate (43%) of CAVs. However, the introduction of a dedicated CAV lane amplified the density of CAV platoons, thereby enhancing their perceptibility to MV drivers. Consequently, this heightened perceptibility prompted MV drivers to emulate the behavior of CAV platoons, resulting in closer car-following and reduced gaps during lane transitions.

CAVs in this paper refers to connected and automated vehicles corresponding to SAE4 and SAE5. Therefore, without major and synchronized interventions in the transport infrastructure in several segments, which will require large investments, it will not be possible to achieve logistical, transport and safety benefits for all road users.

But the question arises of whether the poorer MSs will be able to maintain the simultaneous investment in the expansion of transport infrastructure with needed infrastructure maintenance which covers spending on preservation of the existing transport network.

CAVs can maintain a reduced and constant distance headway at higher speeds, which increases the CAV traffic flow. The distance headway is the bumper-to-bumper gap between the lead vehicle and the following vehicle. It is common knowledge that, if we compare MVs (lowest levels SAE0 and SAE1) with CAVs (SAE4 and SAE5), reduced distance headway between the lead CAV and the following CAV vehicle will be preserved and constant if the speed of the CAVs increases. A consequence of the above is the increased traffic flow of CAVs at higher speeds compared to MVs with lower levels of automation (SAE2) when a human driver operates them without automation support.

It is also important to add that the trajectory of automated vehicle (AV) adoption primarily depends on various economic scenarios due to the complex interplay between economic factors and AV adoption patterns. For example, the paper by Alatawneh et Torok [48] mentions that under optimistic circumstances, it is projected that 90% of Hungary's passenger vehicles will be automated at a GDP of USD 85,000, reaching 100% automation at approximately USD 111,000 GDP, which corresponds to the year 2072. When comparing Hungary and Croatia, using only GDP figures from recent years (assuming that circumstances in Southeast Europe do not significantly deteriorate in the coming years), expectations for the trajectory of AV adoption in Croatia must be much more modest. The average share of the projected Croatian GDP in the projected Hungarian GDP is 38%, according to Table 4, based on a 6-year comparison (according to Statista projections for the period from 2024 to 2029) [49]. Hungary's estimates cannot be used for Croatia in a way that they are weighted according to this average GDP percentage (e.g., by this very simplified method, Croatia should reach a minimum of 38% automation by the year 2072 in an optimistic scenario). It is necessary to consider the broader context.

Table 4. Average percentage share of Croatian GDP in Hungarian GDP, based on Eurostat GDP projections for Hungary and Croatia over the next six years.

Year	GDP Projection (in Billions of U.S. Dollars)		% GDP
	Hungary	**Croatia**	
2024	223.41	88.08	39.43
2025	240.12	92.52	38.54
2026	254.15	97.05	38.17
2027	269.15	101.63	37.76
2028	285.53	106,43	37.27
2029	302.46	111.29	36.79
Average amount of percentage share of Croatian GDP in Hungarian GDP			37.99

Source: Prepared by the authors using publicly available materials from [49].

Croatia has 2.5 times less of a population than Hungary [50], a significantly weaker economy, and, most importantly, Croatia has a negative birth rate trend (data for the year 2024) [51] with the emigration of highly educated labor and the simultaneous import of low-skilled labor. Furthermore, all projections based on time spans of 10 or more years are highly risky and should be taken with great caution because, e.g., Croatia in the past 5 years has been exposed or is still exposed to the negative impacts of several destructive forces (three strong earthquakes, the COVID-19 pandemic and the war in nearby neighborhoods in Ukraine).

6. Discussion of Initial Legal and Infrastructure Upgrades for AVs and CAVs

The initial legal and infrastructure upgrades for CAVs and AVs in Croatia should commence with legal reforms, followed closely by infrastructure development.

However, for highly automated and fully autonomous vehicles to be operationally permitted on Croatian roads—and, prior to that, to be insurable, which is a prerequisite for mandatory vehicle registration—the Law on Obligations [3] must first be amended in provisions concerning road liability, as analyzed and discussed in Chapter 3. Our recommendations advocate for the strict (default) liability of software and/or hardware manufacturers for fully autonomous vehicles, as well as presumed liability of the owner, operator, service provider or software and/or hardware manufacturer for highly automated vehicles.

It is neither just nor ethically sound for the owners of fully autonomous vehicles (Level 5) to bear full material and/or criminal liability for damages, injuries or fatalities resulting from traffic accidents involving such vehicles, especially in scenarios where they are merely passengers—or even absent from the vehicle—and thus incapable of influencing its performance. Ultimately, under such conditions, who would willingly purchase fully autonomous vehicles?

The total length of highways in Croatia is approximately 1423 km, of which 20.8 km (1.46%) consists of highways with three lanes in each direction, designed to accommodate higher traffic volumes on busy routes [52]. Due to the increased average annual daily traffic (AADT) exceeding 35,000 vehicles per day on the 39 km section between Zagreb and Karlovac, there are publicly available plans to build a dedicated third traffic lane to accommodate the higher traffic volume [53]. In the Republic of Croatia, there are no publicly available plans to build a dedicated third lane for AVs and CAVs, because there is not any real traffic demand for it. It is known that AVs and CAVs have the ability to maintain a reduced and constant distance headway at higher speeds, which can increase the AVs' and CAVs' traffic flow in dedicated traffic lanes (exclusive lane) but will not necessarily increase the total traffic flow in all lanes.

From a road management perspective, installing exclusive AV lanes at low Market Penetration Rate (MPR) levels may not be optimal [54]. A study from S. Korea [54] concludes that the introduction of AV-exclusive lanes is unlikely to be effective at MPR levels below 20–30%, given the capacity gains assumed in the Highway Capacity Manual. The study took into account benefits analyzed in the categories traffic volume, travel speeds, vehicle kilometers traveled (VKTs) and total travel time saved (TTS). According to the study, there are certain differences depending on the individual urban expressway. For example, on the Olympic Expressway, traffic volume decreased at 10% MPR, contrasting with results for other MPR levels that led to an increase in traffic volume. In the second related study [55], different proportions of CAVs were simulated, related to exclusive CAV lanes. As a result, exclusive CAV lanes are not suitable under low MPR levels of CAVs. At an MPR level of 10% CAVs, having no exclusive CAV lane maximizes traffic flow. While CAVs can maintain high speeds at low penetration rates, normal lanes accommodate a large number of MVs, quickly leading to congestion in those lanes. As a result, exclusive CAV lanes are not suitable under low MPR levels of CAVs. The authors of a paper from 2024 warn that human drivers' behavior near AVs is unpredictable, posing risks during the transition to mixed-traffic scenarios [56]. For example, the authors of a 2023 paper [57] highlight gender differences in MV drivers in mental effort, especially near 12 ft exclusive AV lanes on the right, compared with 9 ft exclusive AV lanes. Male MV drivers demonstrated better lane centering, while female MV drivers tended to drive farther from the center. The presence of Avs as right-lane traffic pushed MV drivers toward the left side of their lane. Shorter AV headways caused drivers to steer further away from the AV lane. Narrower (9 ft) lanes resulted in poorer lane centering by MV drivers.

Therefore, for Croatian operators, building a third dedicated lane (not an AV- or CAV-exclusive lane) represents a significant cost and would only be cost-effective on a smaller number of road sections, such as the previously mentioned upgrade on the Zagreb–Karlovac route, due to real traffic demands for vehicles up to SAE3. Furthermore, advocating for a separate road lane for AVs and CAVs is not a good infrastructural upgrade, at least not at present. From the perspective of overall traffic flow, it is not rational to provide a separate lane solely for autonomous vehicles and CAVs due to the small percentage of such vehicles in the overall traffic flow on Croatian roads. In the future, one of the possible solutions is for AV and CAV software and hardware manufacturers, in collaboration with global operators of autonomous vehicles wishing to bring such vehicles into Croatia at higher percentages (car-sharing platforms, intercity delivery logistic services, rental cars, etc.), to self-finance or co-finance a separate road lane for such vehicles, but exclusively on sections where there is real traffic demand for AVs and CAVs (for MRP levels of 10% or more)

Considering the circumstance that low levels of automated SAE2 vehicles and a very small number of SAE3 vehicles exist in real traffic in Croatia, although equipped with driver fatigue detection and prevention systems, the authors consider SAE3 vehicles to be the most dangerous in exceptional situations where automation cannot function. As the level of automation in such vehicles increases, the driver's workload with driving tasks decreases, negatively affecting the performance and behavior of such drivers. It is highly debatable whether drivers of such vehicles will be able to respond quickly enough and effectively to the vehicle's demands in a traffic situation where a particular scenario is not predefined. When discussing vehicles up to SAE4 that combine human drivers and automation, we consider SAE4 vehicles to be the most dangerous in exceptional situations. This is because, in SAE4 vehicles, the driver has no physical or sensory workload, leading to an expected and significant loss of fundamental driving skills due to the minimal percentage of time spent in manual driving mode.

Croatia is still aligning with EU regulations for CAVs. In July 2022, amendments to the Road Traffic Safety Act [2] introduced a definition for automated vehicles but did not include detailed rules for their operation on public roads. As of January 2024, a comprehensive legal framework for self-driving vehicles is still missing, although amendments to the Road Transport Act [1] are expected to address this gap. In November 2024, these amendments were adopted, but their specific details have not yet been disclosed. Since August 2023, automated vehicles have only been permitted in designated testing areas under strict conditions. While progress has been made, further legislative development is essential for the full integration of autonomous vehicles into Croatia's transport system.

7. Conclusions

The authors are mostly focused on legal segments of the application of highly automated vehicles (SAE4) and fully autonomous vehicles (SAE5) since the only changes in Croatia were in the legal segment, and they were minimal and only formal. The legislator has inadequately amended the Road Traffic Safety Act and the Road Transport Act. Fastly approved amendments are unusable because they will not enable the operation of SAE and SAE5-level vehicles in Croatia. SAE5 vehicles cannot be insured at the moment for the simple reason that there is no driver in them (because the driver/operator is liable for criminal liability). Road liability for different level vehicles was discussed and compared with legal practice in Germany and France, and the presumed liability of all road traffic participants for highly automated vehicles and the strict (default) liability of manufacturers of fully autonomous vehicles were recommended for use in Croatia. Recommendations were also provided on how the Croatian Law on Obligations should be amended and which articles should be modified accordingly. EU Regulation (EU) 2019/2144 established a legal framework for the approval of automated and fully autonomous vehicles at the EU level, but only from August 2023, and automated vehicles in Croatia are permitted only in designated testing areas under strictly controlled conditions.

Currently, there are no infrastructure preparations for SAE4- and SAE5-level vehicles in Croatia; only 1.46% of highways in Croatia have three lanes and an emergency lane. Various safety and traffic aspects of the design, construction and integration of exclusive highway lanes, solely for SAE4 and SAE5 vehicles, were analyzed. In conclusion, planning and building exclusive CAV and/or AV lanes is not recommended for MPR levels of 10% or lower. When operators design an exclusive CAV and/or AV lane in mixed-traffic scenarios, the width of the exclusive CAV and/or AV lane (MV drivers prefer 12 ft AV lane) should be taken into account, among other important factors, due to the possible positive impact on the behavior of MV drivers in the left lanes, in terms of better lane centering.

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