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Transportation Research Procedia 00 (2026) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference of Transport Research, Toulouse 2026 (WCTR 2026 Toulouse)

# Advances in Advanced Driver Assistance Systems and Automated Driving technologies within the European Context

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**Abstract**

The present research provides a comprehensive overview of the evolving vehicle safety landscape in the context of Advanced Driver Assistance Systems (ADAS) and Automated Driving (AD) technologies, with a particular focus on regulatory frameworks, safety and behavioural implications, and emerging challenges within the European Union. ADAS and AD technologies offer significant potential to improve road safety, with evaluations indicating reductions of up to 50% in certain crash types. However, their effectiveness depends on driver behaviour, system reliability, and operational conditions. This paper also examines broader societal impacts, including behavioural adaptation, risk compensation, and accessibility, which must be addressed to ensure equitable and safe adoption of ADAS-equipped and Automated Vehicles (AVs). Existing regulatory frameworks, such as Euro NCAP and UNECE R155/R156, provide essential standards but are insufficient without continuous, harmonised post-market monitoring under real-world conditions. The current lack of EU-wide surveillance and open data infrastructures represents a critical gap in maintaining long-term safety and public trust. Ultimately, the successful deployment of ADAS and automation must align with Vision Zero and Safe System principles. Achieving this requires not only technological innovation but also inclusive regulation, transparent evaluation, and sustained public engagement to ensure safe, reliable, and socially acceptable adoption across Europe.



*Keywords:* Advanced Driver Assistance Systems; Automated Driving; Regulatory frameworks; Post-market monitoring; European Policy

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**Nomenclature**

| | |
|---|---|
| ACC | Adaptive Cruise Control |
| AD | Automated Driving |
| ADAS | Advanced Driver Assistance Systems |
| ALKS | Automated Lane Keeping System |
| AV | Automated Vehicle |
| BSM | Blind Spot Monitoring |
| CCAM | Connected, Cooperative, and Automated Mobility |
| CSMS | Cybersecurity Management System |
| DDAW | Driver Drowsiness and Attention Warning |
| DMS | Driver Monitoring System |
| EDR | Event Data Recorder |
| ELKS | Emergency Lane Keeping System |
| ERSO | European Road Safety Observatory |
| ETSC | European Transport Safety Council |
| FOT | Field Operational Test |
| GSR | General Safety Regulation |
| HMI | Human–Machine Interface |
| HUD | Head-Up Display |
| ISA | Intelligent Speed Assistance |
| IVI | In-Vehicle Infotainment |
| KPI | Key Performance Indicator |
| LKA | Lane Keeping Assist |
| LDW | Lane Departure Warning |
| NCAP | New Car Assessment Programme |
| OEM | Original Equipment Manufacturer |
| OTA | Over-the-Air (software updates) |
| SAE | Society of Automotive Engineers |
| SUMS | Software Update Management System |
| TOT | Take-Over Time |
| V2X | Vehicle-to-Everything Communication |

## 1. Introduction

Despite major advancements in vehicle safety, recent EU-wide data show stagnation in reducing road fatalities, with most Member States unlikely to meet the 2030 target of halving road deaths (European Transport Safety Council (ETSC), 2024). Advanced Driver Assistance Systems (ADAS), such as Autonomous Emergency Braking (AEB), Lane Departure Warning (LDW), and Driver Monitoring Systems (DMS), target human error, still the leading cause of over 90% of crashes. However, their real-world effectiveness varies considerably with driver behaviour, system performance, and environmental conditions.

The present paper provides an overview of the evolving vehicle safety landscape in the context of ADAS and Automated Driving (AD) technologies, focusing on their regulatory framework, safety implications, behavioural impacts, and emerging challenges within the European Union.

Europe's regulatory response, through the General Safety Regulation and UNECE vehicle regulations, mandates key ADAS features in all new vehicles from 2024. Market forecasts indicate rapid growth in ADAS and vehicle automation, supported by EU research funding and Connected, Cooperative, and Automated Mobility (CCAM) programmes.

Safety evaluations demonstrate that many ADAS functions can substantially reduce certain crash types (e.g., AEB lowering rear-end collisions by up to 52%), though limitations such as misuse, overreliance, and inconsistent performance persist. The transition to higher automation levels introduces new safety risks, especially during takeover phases in Level 3 (conditional automation) and above systems (SAE International, 2021). Key enablers and potential barriers to safe deployment include Human–Machine Interface (HMI) design, cyber-security, cost, and public trust.

The paper also examines broader societal effects, including behavioural adaptation, risk compensation, and accessibility challenges, which must be addressed to ensure equitable and safe adoption of ADAS-equipped and Automated Vehicles (AVs).

Following this Introduction (Section 1), Section 2 formulates the problem of adaptation to emerging ADAS and AD systems in the EU; Section 3 outlines current vehicle safety and technology trends; Section 4 assesses their crash-reduction potential; Section 5 discusses key risks, limitations, and human factor issues; Section 6 reviews the policy landscape; and Section 7 concludes with recommendations.

## 2. Problem formulation

Recent advances in ADAS and AD technologies have transformed vehicle safety, shifting emphasis from traditional passive safety measures, such as seatbelts, crumple zones, and airbags, which mitigate crash consequences, to active safety systems designed to prevent collisions altogether. This evolution raises new questions about regulation, effectiveness, and the tangible benefits of these technologies under real-world conditions.

While road fatalities in the EU declined substantially between 2001 and 2010, progress has slowed markedly over the past decade. According to the European Commission (2025), 20,384 road deaths were recorded in 2023—only marginally fewer than in previous years. Most Member States remain off track to meet the EU's 2030 goal of halving fatalities. Serious injuries, which are more difficult to monitor consistently, are estimated at 157,559 annually (European Transport Safety Council, 2025), with total injuries reaching around 1.14 million (European Commission, 2025). This stagnation persists despite rapid vehicle technology improvements and widespread deployment of ADAS-equipped vehicles.

As of 2024, the European Road Safety Observatory (ERSO) reports approximately 19,800 fatalities across the EU, which is only a 3% reduction from the previous year (European Commission, 2025c). This modest progress underscores the continuing stagnation in safety outcomes, with most Member States projected to fall short of the 50% reduction target by 2030.

Recent figures show that 21 countries achieved reductions in fatalities between 2023 and 2024, while eight experienced increases, reflecting significant variation among Member States. Sustained progress remains especially challenging in nations with higher motorisation rates. Lithuania was the only country to halve crashes over 2014–2024, and Norway recorded the lowest mortality rate—16 fatalities per million inhabitants in the latest year (European Transport Safety Council (ETSC), 2025).

Human error and risky behaviour remain major contributing factors, cited in over 90% of crashes (Khattak et al., 2021). ADAS technologies such as AEB, LDW, and DMS aim to mitigate human errors or unsafe behaviours (i.e. distraction, delayed reaction, and fatigue). Nonetheless, their success depends on human interaction and operational reliability under diverse road, lighting, and weather conditions.

Policymakers have introduced major regulatory measures to address these challenges. The General Safety Regulation II (GSR2) (EU 2019/2144) (European Parliament & Council of the European Union, 2019) mandates a suite of ADAS technologies as standard on all new vehicle types from mid-2024. This marks a significant milestone but also raises new questions: Will drivers understand and correctly use these systems? Are safety gains consistent across vehicle types and user groups? What are the implications when automation assumes core driving functions?

The EU's broader road safety framework has its foundations in the Vision Zero goal and the Safe System approach, and undoubtedly it must adapt to these emerging technologies. Vision Zero, adopted by the EU and several Member States, seeks to eliminate all road deaths and serious injuries by 2050, recognising them as preventable rather than inevitable. This strategy prioritises systemic transformation across infrastructure, enforcement, vehicle design, and user behaviour. The Safe System model, which assumes human error is unavoidable and advocates multi-layered protection, now faces new challenges from semi-automated driving systems. Consequently, it is vital not only to deploy such technologies but to ensure they align with long-term safety objectives and build sustained public trust.

## 3. Current Safety Status and Vehicle Technology Landscape

### *3.1. Definition of ADAS and Automation Levels*

ADAS encompass a range of technologies that assist the driver with specific tasks while maintaining human control of the vehicle. The internationally accepted classification of driving automation, developed by SAE International and revised in 2021, defines six levels of automation based on the respective roles of the driver and the system (SAE International, 2021).

Levels 1 and 2 represent advanced driver assistance functions that are already common in modern vehicles, such as Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA), and Intelligent Speed Assistance (ISA). At these levels, the driver must remain constantly engaged. SAE Level 3 systems, now emerging on European roads, can operate without continuous supervision under specific conditions, although the driver must be ready to retake control when prompted. Levels 4 and 5 correspond to higher automation, removing the need for driver input. While Level 5 remains theoretical, Level 4 systems are in limited deployment, mainly through robotaxi pilots operating in geofenced urban areas in the United States and China. These implementations remain experimental and largely confined to test zones.

Recent studies show a gradual increase in ADAS availability in European vehicles, reflecting ongoing developments in regulation and consumer adoption (Fundación MAPFRE, 2025). This incremental shift in vehicle capability underscores the need for updated frameworks to evaluate safety performance and operational limits.

### *3.2. Classification and Overview of Key ADAS*

ADAS belong to the broader class of active safety technologies that aim to prevent or mitigate crashes before they occur, in contrast to passive safety systems that reduce injury severity once a collision happens. Many ADAS technologies were initially conceived to enhance driver comfort by reducing workload and fatigue rather than to directly improve safety. For example, ACC was originally designed as a convenience feature to maintain a set speed and following distance, thereby easing the cognitive and physical strain of long journeys. However, Gulino et al. (2025) note that ACC and similar systems have since demonstrated significant safety benefits by reducing rear-end collision risks through improved longitudinal control.

Within the active safety domain, ADAS can be grouped by their functional role in assisting the driver during various phases of driving. The main categories are:

- Longitudinal control systems, such as AEB and ACC, which automatically adjust vehicle speed and following distance to maintain safe headway in dynamic traffic.
- Lateral control systems, including LDW and LKA, which help drivers stay within their lane by issuing alerts or applying corrective steering when unintentional lane departure is detected.
- Monitoring and awareness systems, such as DMS and Blind Spot Monitoring (BSM), which detect external hazards and monitor driver fatigue, distraction, or reduced alertness.
- Compliance systems, including ISA, which help drivers comply with speed limits by recognising traffic signs and issuing warnings or automatically limiting vehicle speed when necessary.

As previously mentioned, the General Safety Regulation II (GSR2) (2019/2144) mandates that several of these systems become standard in all new vehicles (European Parliament & Council of the European Union, 2019). As summarised in Table 1, a wide array of ADAS functions now support drivers across longitudinal, lateral, awareness, and compliance domains. While many are mandated under GSR2, others, such as Vulnerable Road User (VRU) safety features (for example, pedestrian detection), parking assist, and evasive steering, are assessed through Euro NCAP protocols or voluntarily implemented by manufacturers and Original Equipment Manufacturers (OEMs).

Table 1. Overview of Key ADAS Features, Functions, and Regulatory/Assessment Status

| ADAS feature | Primary Function | Status |
|---|---|---|
| Autonomous Emergency Braking (AEB) | Detects imminent frontal collisions and applies brakes automatically | GSR2 Mandatory from 2024 |
| Lane Departure Warning (LDW) | Warns the driver when unintentionally drifting out of lane | GSR2 Mandatory from 2024 |
| Lane Keeping Assist (LKA) | Provides gentle steering corrections to maintain lane position | GSR2 Mandatory from 2024 |
| Intelligent Speed Assistance (ISA) | Warns or limits speed based on recognised road signs | GSR2 Mandatory from 2024 |
| Driver Monitoring System (DMS) | Detects distraction or drowsiness via eye/head tracking | GSR2 Mandatory from 2026 |
| Adaptive Cruise Control (ACC) | Maintains safe following distance by adjusting speed | Recommended / NCAP assessed |
| Blind Spot Monitoring (BSM) | Alerts driver to vehicles in blind spot areas | Recommended / NCAP assessed |
| Traffic Sign Recognition (TSR) | Recognises posted road signs and displays them to the driver | Optional / NCAP assessed |
| Emergency Lane Keeping (ELK) | Automatically steers vehicle to avoid unintended lane departure in emergencies | GSR2 Mandatory from 2024 |
| Rear Cross Traffic Alert (RCTA) | Warns driver of cross traffic when reversing out of parking | Optional / NCAP assessed |
| Park Assist / Automated Parking | Helps with steering or full automation during parking manoeuvres | Optional / Widely deployed |
| Pedestrian / Cyclist Detection | Detects VRUs and triggers AEB or warning | Often bundled with AEB / NCAP assessed |
| Surround View Camera / 360° Sensors | Provides all-around visibility during low-speed manoeuvring | Optional / OEM-specific |
| Night Vision / Infrared Assist | Enhances visibility of pedestrians/animals at night | Optional / Premium models |
| Forward Collision Warning (FCW) | Alerts driver of imminent frontal collision | Standard with AEB |
| Intersection Assist | Detects hazards during turns at intersections, including side-approaching vehicles | Optional / OEM deployments |
| Evasive Steering Assist | Supports driver in safely steering around obstacles | Optional / Emerging feature |
| Dead Angle / Side Assist | Warns of vehicles approaching from adjacent lanes | OEM terminology for BSM |
| Highway Assist / Traffic Jam Assist | Combines ACC & LKA for partial automation on highways or in congestion | Level 2 systems / NCAP assessed |
| Automatic High Beam Control | Automatically toggles high beams based on surroundings | Optional / NCAP visibility scoring |

Although these systems differ in regulatory status and technical complexity, they share a common goal: reducing crash likelihood by enhancing driver awareness and reaction time. Alongside core safety-critical technologies, an expanding range of supporting ADAS functions, including Emergency Lane Keeping (ELK), Rear Cross Traffic Alert (RCTA), and Traffic Sign Recognition (TSR), further strengthen driver awareness and control in diverse traffic situations. Some of these systems are covered by upcoming regulatory mandates, while others are promoted through consumer safety ratings (EuroNCAP, 2024). As vehicle automation progresses, even traditionally optional systems such as automated parking and evasive manoeuvres are gaining importance for improving safety outcomes.

### *3.3. Automated Technologies and Market Penetration*

The European Automated Vehicle (AV) market was valued at approximately €12.2 billion in 2023. Significant expansion is projected, with a Compound Annual Growth Rate (CAGR) of 19.9% between 2024 and 2030. The heavy-duty AV segment alone was valued at €36.4 billion in 2023 (excluding the United Kingdom) and is expected to grow to €356.2 billion by 2032, reflecting a CAGR of 28.82% (Horizon Grand View Research, 2025).

To accelerate development, the European Commission has invested €159 million in research and innovation since 2021, supporting 19 projects under the Connected, Cooperative and Automated Mobility (CCAM) framework. Europe currently represents about 25% of the global automated and semi-automated vehicle market (Horizon Grand View Research, 2025) and is actively advancing higher automation levels (Level 3-4) through large-scale demonstrations, such as “highway chauffeur” systems on motorways and automated shuttle services in urban environments. Although precise data on the number of semi-automated vehicles in operation within the EU remain limited, global estimates provide a useful benchmark. In 2023, approximately 21,150 AV units were in use worldwide, with forecasts suggesting growth to 26,560 units in 2024 and 33,570 by 2025 (European Commission. Directorate-General for Research and Innovation, 2024).

## 4. Effectiveness and Potential for Crash Reduction

### *4.1. Safety Effectiveness and Known Limitations*

ADAS technologies have demonstrated measurable safety benefits, particularly in specific crash scenarios. Data from the PARTS consortium indicate that vehicles equipped with Automatic Emergency Braking (AEB) produced between 2021 and 2023 experienced up to a 52% reduction in rear-end crashes, compared with a 46% reduction in earlier models from 2015–2017 (PARTS, 2025). Real-world evaluations show that lane support systems significantly reduce severe crash types such as run-off-road and head-on collisions. Based on crash data, LDW systems lowered target crash involvement by 3% (±32%), while LKA systems achieved a 60% (±16%) reduction (Dean & Riexinger, 2022). The higher effectiveness of LKA is attributed to earlier evasive intervention compared with driver-initiated responses.

However, field performance varies widely. System effectiveness often depends on manufacturer calibration, driver settings, and environmental factors. AEB may perform less effectively at night or during heavy rain, while lane-keeping features can struggle with worn markings or complex intersections. ISA effectively limits excessive speed on highways, yet many drivers deactivate it due to perceived overcorrection or annoyance (ETSC, 2021).

A recurring challenge is misuse or overreliance. Drivers of Level 2 vehicles may treat ADAS as autonomous systems and disengage mentally, leading to delayed reactions (Sekadakis & Yannis, 2025). Research by Körber et al. (2018) confirms that drivers often misunderstand system capabilities, resulting in overconfidence or inattention. Many drivers are unaware of which ADAS features are installed or how to operate them effectively (Harms et al., 2020; Oviedo-Trespalacios et al., 2021). Moreover, a substantial proportion disable these systems permanently because they find them “annoying, distracting, or too sensitive” (AAMI, 2025).

From a policy standpoint, these findings underline the need for ongoing evaluation, better driver education, and transparent consumer ratings. While ADAS can significantly reduce crash risk, improper use limits their full potential and may introduce new safety concerns.

### *4.2. Safety Projections*

Connected and Automated Vehicles (CAVs) are expected to deliver major safety improvements by reducing human error, which contributes to over 90% of road incidents in Europe. The European Commission projects that automation could substantially lower fatalities and injuries, currently exceeding 40,000 deaths and 1.5 million injuries annually across the continent (European Commission, 2016). CAVs can react faster and drive more consistently, particularly when supported by Vehicle-to-Vehicle (V2V) communication (LEVITATE project, 2020). These capabilities promote strict compliance with traffic regulations, including speed limits and traffic signals, further reducing crash risks.

CAVs may also deliver indirect benefits. By removing reaction-time delays and enabling smoother driving, shorter and more stable following distances can improve traffic flow and reduce congestion-related crashes. However, realizing these advantages depends on several interlinked factors:

i. Market penetration across regions and vehicle types;
ii. Technological maturity, including sensor reliability, algorithm robustness, and Vehicle-to-Everything (V2X) integration;
iii. Infrastructure readiness, including mapping accuracy, road markings, and digital signals;
iv. Regulatory and policy frameworks, such as type approval, liability, and safety assessments; and
v. Human and societal factors, including behaviour, trust, and public acceptance (Gkoumas et al., 2019).

International data reinforce ADAS safety potential. Lane departure prevention systems could prevent 28–32% of road departure crashes in the United States, while forward collision warning systems have reduced front-to-rear crashes by 27% and related injuries by 20% (Center of Excellence on New Mobility and Automated Vehicles, 2025). AEB has produced a 38% reduction in rear-end collisions, with U.S. National Highway Traffic Safety Administration (NHTSA) projections showing that extending AEB to speeds up to 100 km/h by 2029 could save 360 lives and prevent 24,000 injuries annually (American Automobile Association, 2024).

While these results highlight the transformative potential of automation, real-world impacts depend on adoption rates, technology maturity, regulation, and integration within existing transport systems. Although expectations for AV safety gains are high (European Commission, 2018), the full scale of their benefits remains uncertain due to unresolved challenges. Issues such as sensor reliability, infrastructure adaptation, and public trust must be addressed before widespread deployment. The transition to full automation will likely be complex and gradual, reducing human driving roles while increasing reliance on automated systems. Success will require not only technological progress but also robust governance and public confidence.

Cybersecurity presents an additional challenge. Reliable network connectivity is essential for real-time communication between vehicles and infrastructure, yet vulnerabilities can undermine safety. The EU's digital strategy prioritizes strong protective measures to safeguard users and maintain trust in mobility technologies (Koon, 2023). The large volumes of data generated by AVs also demand secure, efficient management systems for processing and storage.

These challenges are particularly relevant within the European Union, where infrastructure and regulatory conditions vary across member states. The EU has recognized AV potential through initiatives such as the European Commission's Action Plan supporting AI-powered AVs (European Commission, 2025b). Achieving seamless deployment will require harmonized standards and interoperability across regions.

### *4.3. Opportunities and Challenges*

High automation (SAE level 4) combines high-fidelity sensing with rapid actuator control, enabling evasive steering or braking manoeuvres that surpass typical human reaction times. Real-world metrics from SAE Level 4 deployment demonstrate major safety benefits. According to Waymo's Safety Impact Website, its driverless vehicles exhibit 88% fewer serious injuries or worse crashes, 78% fewer injury-causing crashes and 79% fewer airbag-deployment incidents per approximately 1.6 million kilometers compared to corresponding human baselines, with particularly strong reductions in pedestrian (–93%), cyclist (–81%), and motorcyclist (–86%) crashes (Waymo, 2025).

Automation also offers the potential to reduce crashes involving impaired or fatigued drivers, especially under challenging conditions such as night-time or rural roads. For instance, fallback-capable Level 4 systems are designed to ensure safe operation, even in scenarios where the driver is unable to intervene, though quantifying exact crash-reduction percentages requires more comprehensive field data.

Automated systems continuously log high-resolution driving data. Secure Over-The-Air (OTA) updates enable manufacturers to rapidly address software issues, such as ADAS miscalibrations or Electronic Control Unit (ECU) bugs, remotely, often without a service visit. This capability turns individual incident learnings into immediate, fleet-wide safety enhancements, bypassing the slow, hardware-oriented upgrade cycle of passive systems. OTA updates are becoming critical for fixing safety-critical systems post-launch, offering significantly faster and more cost-effective remediation than traditional recalls or hardware "retrofits" (Himes, 2021).

While higher levels of vehicle automation promise safety benefits, conditional automation (SAE Level 3) introduces unique human–system interaction challenges, as it still relies on a human fallback driver. Empirical studies show that Take-Over Time (TOT) varies widely with non-driving related tasks, road type, traffic conditions, and alert modality, HMI technology ranging from 0.9s for simple visual cues to more than 10s when the driver is deeply engaged in a non-driving related task (Sekadakis & Yannis, 2025; Zhang et al., 2019). According to UNECE Regulation No. 157 on Automated Lane Keeping Systems, if the driver does not respond to a transition demand, the system must initiate a minimum risk manoeuvre no earlier than 10 seconds after the transition demand is issued (UN, 2021). Data from a recent meta-analysis indicate that during Level 2 and 3 deployments, some drivers respond significantly slower when the take-over request is unexpected, with response times reduced by 64.7% when an alert is provided (Sekadakis & Yannis, 2025). Poorly timed or inadequately designed transition protocols can result in critical moments where control of the vehicle is uncertain. During these handover periods, particularly at high motorway speeds, neither the automation nor the driver may be fully prepared to manage the vehicle safely, increasing the risk of a crash.

Field testing of prototype fleets highlights a significant number of disengagement events whenever sensor obstruction, map uncertainty, or software errors occur. Although the number of disengagements has decreased year-on-year, the severity of residual events remains high and many of the manual takeovers still require heavy braking or evasive manoeuvers to avoid a crash (California DMV, 2024; Khan et al., 2024). The unpredictability of these edge cases complicates driver trust calibration. Too many false handovers erode confidence, yet too few may foster over-reliance.

Clear and unambiguous status information is critical, but interface confusion can overload the driver. For instance, Shi et al. (2024) found that while peripheral HMIs can sometimes shorten takeover time, Head-Up Displays (HUDs) may actually create an "attention tunnel", capturing visual focus at the expense of environmental awareness, thereby increasing cognitive load availability during critical transitions. Human-in-the-loop experiments show that multimodal takeover alerts (visual + auditory + haptic) significantly outperform single-modality signals, delivering faster response times and better physiological engagement, but may provoke surprise responses that temporarily delay control resumption (Yun & Yang, 2020). Harmonising HMI standards across Original Equipment Manufacturer (OEM) brands remains an open research and regulatory question.

As vehicles become rolling networks, software vulnerabilities can translate directly into safety hazards. UNECE Regulations R155 and R156 require a cyber-security management system and secure update processes (UNECE, 2020b, 2020a). However, penetration testing of aftermarket and OEM infotainment systems continues to uncover exploitable pathways, especially in In-Vehicle Infotainment (IVI) firmware, where reverse-engineering has revealed the ability to install custom, malicious firmware via vulnerabilities in the update chain (Costantino et al., 2024).

## 5. Risks, Limitations and Human Factors

### *5.1. Driver Behaviour and Risk Adaptation*

The introduction of ADAS and AD has led to notable changes in driver behaviour, particularly regarding trust, overreliance, and misuse of technology. These behavioural adaptations play a central role in shaping the real-world safety performance of such systems.

Trust in ADAS is essential, but misplaced trust can undermine safety. A large-scale survey of 369 ADAS users found that drivers with higher baseline trust, especially those familiar with technology, were more likely to place excessive confidence in automated features, sometimes overlooking their operational limits (DeGuzman & Donmez, 2024; Dunn et al., 2019). Human-in-the-loop studies further show that greater trust in systems such as ACC can reduce situational awareness and slow reaction times, particularly when drivers engage in non-driving tasks or when system warnings are insufficient (Yang et al., 2023).

Beyond trust, drivers often subconsciously adapt their behaviour in compensatory ways. According to risk compensation theory, the perceived safety provided by automation may encourage riskier actions. Naturalistic and observational driving studies show increased engagement in secondary tasks such as texting or interacting with infotainment systems while using ADAS or AD, nearly doubling distraction rates compared with manual driving (Dunn et al., 2019).

Drivers also tend to overestimate system capabilities, often believing that ADAS can fully manage driving tasks. Surveys show that many learn to use these features through trial and error rather than formal training. One study found that while 70% of drivers actively used ADAS, 40% felt less safe when the systems were active due to poor understanding of reliability and limitations (Page et al., 2019; Pradhan et al., 2022). Consequently, many drivers are unprepared to respond appropriately when systems reach their operational limits or conditions change unexpectedly.

### *5.2. Public Acceptance and Inclusion Issues*

The broad adoption of ADAS and AD technologies depends not only on technical capability but also on public acceptance, digital literacy, and equitable access. Vulnerable groups such as elderly drivers, low-income households, and residents of rural areas with limited infrastructure may face barriers to adopting or benefiting from these technologies, potentially worsening existing mobility inequalities. Digitally disadvantaged populations may also be hindered by insecurity, limited experience, or pessimism toward emerging technologies (O'Hern & St. Louis, 2023).

Promoting societal readiness requires comprehensive public education on the safety and functionality of ADAS and AD, as well as targeted support for digitally disadvantaged users. Inclusive design strategies that accommodate different levels of technological comfort are equally important. Without deliberate action to address these inclusion challenges and foster inclusive dialogue (Jiang et al., 2022), the transition to automated mobility risks producing a two-tier transport system where safety and efficiency benefits are unevenly distributed.

Public acceptance of Automated Vehicles (AVs) also depends on factors beyond safety alone. Research indicates that acceptance is strongly influenced by the vehicles' driving range, assumptions about whether an AI navigator can replicate human judgement without compromising safety, overall trust in the automotive industry, and personal driving style (Ziakopoulos et al., 2023). While safety remains a decisive factor, public acceptance will ultimately reflect a combination of performance, perceived reliability, and user confidence in automation.

## 6. Regulation, Standards, and Policy Landscape

### *6.1. Current Standards and Legal Frameworks*

The deployment of ADAS and AD technologies in Europe is governed by a rapidly evolving regulatory framework. Several key regulations and testing protocols at both the European Union and international levels define the minimum technical requirements, performance standards, and type-approval procedures for these systems. This section presents the main regulatory pillars shaping the current landscape, including the EU General Safety Regulation, UNECE vehicle regulations, and Euro NCAP assessment protocols.

#### *6.1.1. General Safety Regulation II (EU 2019/2144)*

The EU's General Safety Regulation II (GSR2), formally Regulation (EU) 2019/2144 (European Parliament & Council of the European Union, 2019), serves as the foundation for the mandatory integration of advanced safety technologies in new vehicles. It requires all new vehicle types approved from July 2022 and all new vehicles sold from July 2024 to include a suite of ADAS features such as AEB, ISA, Driver Drowsiness and Attention Warning (DDAW), Emergency Lane Keeping Systems (ELKS), and Event Data Recorders (EDR). These technologies are designed to support the EU's Vision Zero target of eliminating road fatalities and serious injuries by enhancing active safety performance across the vehicle fleet.

#### *6.1.2. UNECE Vehicle Regulations and Type Approval*

The EU type-approval system is harmonised with United Nations Economic Commission for Europe (UNECE) regulations under the 1958 Agreement. Several UNECE regulations have direct relevance to ADAS and automation (UNECE, 2025):

- UNECE Regulation No. 131 mandates AEB systems in passenger and commercial vehicles.
- UNECE Regulation No. 152 covers advanced driver distraction warning and emergency lane keeping.
- UNECE Regulation No. 155 introduces requirements for a Cybersecurity Management System (CSMS), covering threats and mitigation strategies throughout the vehicle lifecycle.
- UNECE Regulation No. 156 governs Software Update Management Systems (SUMS), including over-the-air updates and secure installation protocols.
- UNECE Regulation No. 157 establishes the framework for Automated Lane Keeping Systems (ALKS), which represents the first legally approved Level 3 automated driving systems for public roads. ALKS is limited to highway driving and includes fallback procedures, driver monitoring, and data storage requirements.

These regulations form the legal and technical basis for European type approval of partially automated vehicles.

*6.1.3. Euro NCAP Protocols*

The European New Car Assessment Programme (Euro NCAP) (EuroNCAP, 2025), although voluntary, plays a crucial role in accelerating the adoption of ADAS technologies through its star-rating system. Since 2014, Euro NCAP has progressively expanded its evaluation protocols to cover AEB for pedestrian and cyclist detection, lane support systems, and driver monitoring technologies. The 2025 roadmap introduces new assessment criteria for occupant status monitoring, automated driving functions, and Vehicle-to-Everything (V2X) readiness, underscoring the growing emphasis on HMI and related interactions and system robustness in vehicle safety evaluations.

*6.2. Gaps in Data, Evaluation, and Monitoring*

Despite the strong regulatory foundation supporting ADAS and vehicle automation, significant gaps remain in evaluating real-world performance, establishing standardized assessment methods, and ensuring continuous safety monitoring.

Current ADAS safety evaluations often rely on simulation, field operational tests (FOTs), or pilot deployments. While these methods offer controlled and reproducible conditions, they are not always representative of real-world traffic complexity, limiting their external validity. Although virtual assessments provide valuable insights, real-world performance data remain scarce. Sharath & Mehran (2021) highlight the lack of harmonized reporting on Automated Vehicle (AV) performance, particularly regarding pre-crash events, which often leaves critical safety information unreported. The same study stresses the need for threat-level metrics and human-like driving assessments to better quantify AD system behavior under real-world conditions.

Recent initiatives such as PARTS in the United States (PARTS, 2025) have begun aggregating large-scale real-world crash and vehicle data to evaluate outcomes, including reductions in pedestrian and cyclist collisions. However, comparable EU-wide data-sharing mechanisms are still limited.

Moreover, current systems lack continuous post-market monitoring, which is essential for identifying performance degradation, software update effects, and evolving usage patterns. In contrast to highly regulated sectors such as aviation, where continuous safety reporting is mandatory, automotive ADAS and AD systems largely depend on voluntary disclosures, media coverage, or academic research. The absence of a centralized EU-level repository for crash and near-miss data involving semi or fully automated vehicles hampers timely detection of emerging safety risks.

## 7. Conclusions and Policy Recommendations

The increasing deployment of ADAS and AD technologies represents a pivotal moment for road safety in Europe. These systems hold considerable potential to reduce crash risk by addressing human error, which continues to contribute to over 90% of road incidents. Yet, despite wider availability and supportive regulations, overall reductions in EU road fatalities have plateaued in recent years, highlighting the gap between technological promise and real-world impact.

Empirical evidence shows that ADAS such as AEB, LKA, and DMS can significantly mitigate specific crash types. However, their effectiveness depends heavily on system calibration, driver understanding, and the operational context. At higher automation levels, particularly SAE Level 3 and 4, new safety challenges arise, including delayed driver takeover, interface confusion, and misaligned trust. Without proper safeguards, handover periods in conditional automation may present critical safety vulnerabilities.

A coordinated policy approach is essential, as existing regulatory frameworks, such as the General Safety Regulation and UNECE vehicle standards, provide an important foundation, but additional measures are required. Post-market monitoring remains limited, and no harmonised EU-wide system currently tracks crashes and near-misses involving semi- or fully-automated vehicles. Moreover, many drivers receive minimal formal training on ADAS, often relying on trial and error, which can lead to inconsistent use and undermine trust in the technology.

Legal and ethical considerations further complicate the landscape. Liability regulations for crashes involving semi- and fully-automated vehicles are still evolving, highlighting the need for clear, comprehensive legal guidance. Simultaneously, fostering public acceptance is crucial: transparent policies, clear communication, and meaningful public engagement are necessary to build trust and encourage informed adoption. The EU's CCAM strategy must carefully balance technological advancement with ethical responsibility and societal confidence.

When considering future developments, integrating safe automated mobility into Europe's transport systems must align with Vision Zero and Safe System principles. Achieving this requires not only deploying technology but embedding it within a broader safety ecosystem supported by inclusive design, robust cybersecurity, interoperable infrastructure, and equitable access. The long-term success of automated mobility will depend on sustaining a balance between innovation, regulation, and human-centered implementation.

## Acknowledgements

This document is based on the following thematic report commissioned by the European Commission, Directorate General for Transport, and produced by the same authors:

European Commission (2025). Road safety thematic report – Vehicle Safety ADAS & Automation. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport.

Related research was conducted in the framework of the EC Service Contract MOVE/C2/SER/2022-55/SI2.888215.

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