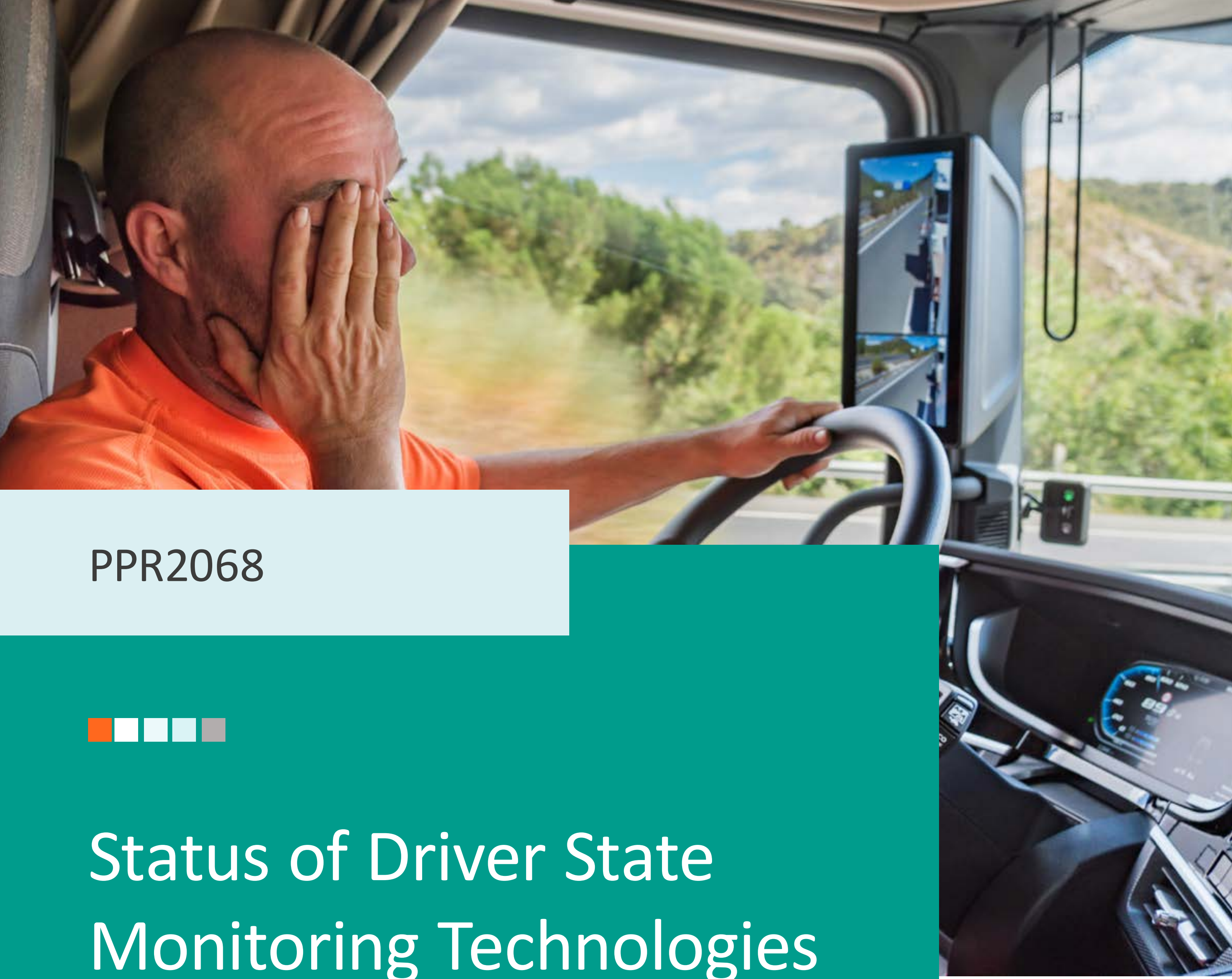

PPR2068

Status of Driver State Monitoring Technologies and Validation Methods

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Disclaimer

Executive Summary

Driver fatigue and distraction are highly associated with increased risk of a collision, and especially serious collisions due to late or absent pre-crash braking response from the driver. Recent STATS19 police-reported collision data shows that fatigue was a contributory factor in 3.3% of fatal collisions (and 2.2% of killed and seriously injured (KSI) collisions), and distraction was a contributory factor in 6.4% of fatal (and 4.3% of KSI) collisions. These percentages are almost certainly underestimated due to the difficulty of identifying these contributory factors in road collisions.

Vehicles, especially passenger cars (M1), have been fitted with fatigue monitoring systems for many years. The first system in a production car – the Volvo Driver Alert System – used a forward-facing camera to assess changes in lane position for signs of drowsy driving and inattention. Subsequently, many vehicles have had systems that primarily rely on interpretation of steering wheel inputs by the driver that are characteristic of fatigue and microsleeps, often with other parameters such as journey time and time of day. These systems have recently been made mandatory for all M- and N-category vehicles in the EU by Regulation (EU) 2021/1341.

Camera-based Driver State Monitoring (DSM) systems have undergone rapid development in recent years, covering a range of driver states related to fatigue and distraction, as well as driver availability. Basic driver distraction monitoring systems have been required for all new M- and N-category types in the EU since July 2024 and will be required for all vehicles in the EU from July 2026, implemented by Regulation (EU) 2023/2590.

Euro NCAP has been testing and rating DSM systems (called driver engagement monitoring) for passenger cars for several years, and updated protocols will be introduced in January 2026. These build on the foundations provided by the EU regulations and extend both the performance and testing of those systems. Euro NCAP also introduced basic driver monitoring requirements in their new Safer Trucks programme in late 2024.

This study undertook a rapid evidence review and stakeholder engagement exercise in order to:

- Identify the current status of technologies that could complement driver’s hours and tachograph legislative requirements in commercial heavy vehicle fleets to minimise the risk of drowsy and inattentive driving
- Identify requirements, test and validation methods for driver availability monitoring for application in conditionally automated self-driving vehicles (also known as SAE Level 3 automated vehicles)

Importantly, this includes the current status of standards and other test and validation protocols for establishing the performance of DSM systems that would help fleet operators to select high-performing systems for heavy duty vehicle fleets.

Stakeholders reported that the performance of DSM technology, especially camera-based systems, has improved greatly in the last 2-3 years, in part due to the need to meet regulatory and consumer information requirements, and in part due to the availability of greatly increased volumes of training data for camera-based detection systems, which

employ forms of machine learning to classify image content. Sensor quality, lens quality, and the ability to deal with difficult lighting conditions and other so-called ‘noise variables’ (such as sunglasses, facial hair, and mask wearing) have reportedly improved, although it is still challenging to ensure that systems can work for all drivers.

Currently, the EU regulations and Euro NCAP set the approach being used by vehicle manufacturers (Original Equipment Manufacturers; OEMs) and their suppliers. These are focused on supporting safe driving in conventional vehicles and not specifically intended to support the assessment of systems for SAE Level 3 conditionally automated vehicles. A number of foundational industry standards were identified that define terminology and concepts for DSM systems were identified, but none that relate to the testing and real-world validation of systems. This is particularly challenging for aftermarket systems that are commonly fitted to heavy duty fleet vehicles because the system often goes beyond providing an alert to the driver – and may include data reviews to validate alerts and integration with a wider fleet safety system that provides information on alerts to fleet managers. Stakeholders indicated that no industry consensus on approaches to testing and validation of aftermarket DSM systems has yet emerged and development of suitable standards is not expected in the next few years.

The report identifies active research and development activities the results of which should be monitored for further understanding of system performance and approaches to real-world validation of the effectiveness of DSM systems. Recommendations are also made for further studies that could accelerate the development of standards that could support the introduction of high-performance DSM systems in heavy duty fleets, and potentially be integrated into the DVSA earned recognition scheme in the future.

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Glossary of terms

Term	Definition
ADAS	Advanced Driver Assistance System
ADDW	Advanced Driver Distraction Warning
ADS	Automated Driving System
ALKS	Automated Lane Keeping System
ANPRM	Advance Notice of Proposed Rulemaking
AV	Automated Vehicle
DAMS	Driver Attention Monitoring System
DCAS	Driver Control Assistance System
DDAW	Driver Drowsiness and Attention Warning
DDT	Dynamic Driving Task
DMS	Driver Monitoring System
DSM	Driver State Monitoring
EU	European Union
Euro NCAP	An EU-based consumer information programme
FOV	Field of View
GB	Great Britain
HMI	Human-Machine Interface
IIHS	Insurance Institute for Highway Safety – a US-based consumer information programme
IWG	Informal Working Group
KSS	Karolinska Sleepiness Scale
M-category vehicle	Passenger-carrying motor vehicle with four or more wheels; M1 denotes passenger cars
N-category vehicle	Goods-carrying motor vehicle with four or more wheels; N1 denotes vans
NHTSA	National Highway Traffic Safety Administration – part of the US Department of Transportation
NI	Northern Ireland
OEM	Original Equipment Manufacturer – a term used in this report to refer to a vehicle manufacturer
RFC	Request for Comments

SAE Level	Level of driving automation as defined in SAE J3016: Level 2: partial driving automation; Level 3: conditional driving automation; Level 4: high driving automation
SDV	Self-Driving Vehicle
UN / UNECE	United Nations / United Nations Economic Commission for Europe
UK	United Kingdom of Great Britain and Northern Ireland
US	United States of America
VATS	Visual Attention Time Sharing

1 Introduction

Driver fatigue is estimated to be a contributory factor in 10-25% of all vehicle collisions in Europe and 20% in the US (Seidl *et al.*, 2021). Fatigue adversely affects the physical, cognitive, psychomotor, and sensory processing capabilities of a driver, all of which are necessary for safe driving.

Driver distraction is the diversion of attention away from activities critical to safe driving to a competing activity unrelated to the dynamic driving task. Driver distraction is estimated to be a contributory factor in 10-30% of vehicle collisions in Europe, with the National Highway Traffic Safety Administration[1] (NHTSA) estimating that distraction was a contributory factor in 8% of fatal, 13% of injurious, and 13% of all police-reported motor vehicle collisions in the US in 2023 (National Center for Statistics and Analysis, 2025). In GB, analysis of STATS19 police reported collision data shows that fatigue was a contributory factor in 3.3% of fatal collisions (and 2.2% of killed and seriously injured (KSI) collisions), and distraction was a contributory factor in 6.4% of fatal (and 4.3% of KSI) collisions[2]. These figures are likely to be an underestimate, given the difficulty in determining these contributory factors after a collision has occurred (Kinnear and Stevens, 2015).

Vehicles, especially passenger cars (M1), have been fitted with fatigue monitoring systems for many years. These systems primarily rely on interpretation of steering wheel inputs by the driver that are characteristic of fatigue and micro-sleeps. This approach uses the steering wheel angle sensor that is fitted to vehicles as part of the electronic stability control system (which is required for series production M- and N-category vehicles). The information from the steering wheel angle sensor is often supplemented with time of day, duration of drive and other parameters to improve the sensitivity and specificity of the system.

Recent advances and cost reductions in camera technology, largely driven by the mobile phone market, have led manufacturers to explore the use of camera-based systems to identify driver fatigue based on measurements of eye width, eye closure, head posture and other parameters. These systems can also be used to provide attention alerts to drivers, e.g. if they look away from the road ahead for an extended period of time, to support drivers in maintaining a safe attention to the dynamic driving task at all times. For example, a camera-based driver fatigue and attention monitoring system is fitted to the DS 7 Crossback, which was launched in 2018.

Recently, Reg (EU) 2021/1341[3] was implemented to ensure that fatigue monitoring technology is fitted across all series production M- and N-category vehicles (see Section 4.1.1). The regulation is technology neutral, allowing manufacturers to use conventional fatigue monitoring systems based on steering inputs, or take advantage of camera-based DSM.

[1] NHTSA | National Highway Traffic Safety Administration

[2] 5-year average between 2016 and 2021 (excluding 2020 data affected by COVID19)

[3] https://eur-lex.europa.eu/eli/reg_del/2021/1341/oj/eng

More recently, manufacturers have developed increasingly sophisticated driver assistance systems and even self-driving vehicles. A focus of advanced driver assistance systems has been on developing driver support for the longitudinal and lateral control of the vehicle (SAE Level 2 ‘partial driving automation’ systems, as defined in SAE J3016[4]), especially for driving on motorways. When using these systems, the driver remains fully responsible for the control of the vehicle and must monitor the driving environment at all times as if they were driving, and be prepared to resume full manual control at any time.

With the development of these SAE Level 2 systems has come the need to ensure that drivers do maintain that monitoring role at all times. Early systems did this by requiring the driver to keep both hands on the steering wheel, which was sensed via torque on the steering wheel. As evidence emerged of drivers subverting these systems and driving ‘hands free’, and as manufacturers developed intentionally hands-free SAE Level 2 driving systems (e.g. GM Super Cruise and Ford Blue Cruise – see Section 3.2), manufacturers have moved to more effective, camera-based driver monitoring systems to ensure driver attention to the driving environment.

In parallel, consumer information rating schemes, such as Euro NCAP (see Section 4.2.1) and the Insurance Institute for Highway Safety (IIHS; see Section 4.2.5), have developed test and assessment protocols designed to encourage the fitment of improved DSM systems. The protocols aim to encourage systems that ensure that drivers remain alert and attentive when driving, including for vehicles that do not have SAE Level 2 Advanced Driver Assistance Systems (ADAS). Driver distraction warning systems are now also required by Regulation (EU) 2023/2590 (see Section 4.1.2), and as part of a new UN regulation on Driver Control Assistance Systems (DCAS – UN Regulation No. 171 – see Section 4.1.3).

Many manufacturers are developing Automated Vehicles (AVs, also known as Self-Driving Vehicles (SDVs)), or vehicles with an automated driving function such as Automated Lane Keeping System (ALKS, defined in UN R157 – see Section 4.1.4). These vehicles are commonly described as Level 3 or Level 4 on the SAE J3016 scale, although that terminology is not used in UN, EU, or GB legislation.

For automated driving systems such as ALKS, the driver becomes a user-in-charge (as defined in the AV Act, also known as a fall-back ready user in SAE terminology) and does not need to pay attention to the driving environment. They can, for example, watch a film on the vehicle’s infotainment system or undertake other activities as allowed by local legislation. However, the ALKS system can hand back control to the user-in-charge at any time by issuing a ‘transition demand’, which requires the user-in-charge to resume the dynamic driving task within a set timeframe (e.g. 10 seconds).

In order to know that the user-in-charge is in a position to take over the dynamic driving task, these systems are required to monitor that the driver is in position (i.e. that they have not left the driver’s seat), awake, and responsive (have not been incapacitated e.g. by a medical episode). This is typically achieved with a camera-based DSM system, similar to those used for SAE Level 2 ADAS / DCAS.

[4] J3016_202104: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles - SAE International

1.1 Aims

This review seeks information on the performance of current DSM systems and evidence on how best to test and validate their performance. The project also aimed to understand the timescales for future developments in DSM technology and validation methods. Based on the evidence identified, a roadmap for the implementation of standards (regulatory or technical) for the performance of DSM was developed, as well as for the potential future use of the technology to complement current commercial vehicle driver's hours legislation and monitoring via digital tachographs.

2 Method

The project involved a series of rapid evidence reviews covering topics relevant to the aims of the project. This was complemented by a small programme of stakeholder engagement interviews to expand the information available to the project team and validate some of the initial findings from the rapid evidence reviews. The reviews were particularly focused on the approaches to testing and validating the performance of DSM systems, evidence for the performance of systems in the real-world (e.g. evidence for collision and injury reduction as a result of fitting systems), and how this aligns with testing and/or validation standards. In scope were DSM technologies relating to the monitoring of:

- Driver fatigue – which may also be known as drowsy driving
- Driver attention – which is also considered from the opposite perspective as driver inattention or distraction, and can include multiple types of distractions such as long-gaze, short gaze or mobile device use
- Driver availability – which could include seat adjustment, seat-belt use, and unresponsive driver detection (e.g. as a result of a medical episode)
- General occupant status – which could include out-of-position seating postures, such as a front seat passenger having their feet on the dashboard

More information on each element of the project can be found in the following sections.

2.1 Market Review

A rapid evidence review was undertaken to identify current technologies relevant to in-vehicle monitoring of driver fatigue, driver attention, and driver state more generally. The research questions addressed in this review are shown below, and these were also a basis for the research questions in the stakeholder engagement (see Section 2.3):

RQ1.1: What technologies are currently in use for monitoring driver distraction and drowsiness?

RQ1.2: Which technologies are most effective in detecting driver drowsiness?

RQ1.3: What are the most common causes of false detection (positive and negative)?

RQ1.4: What drowsiness monitoring products are available and how easily can they be used in commercial road transport?

RQ1.5: How is driver distraction and drowsiness monitoring being implemented in fleet management?

RQ1.6: What if any interventions do drowsiness monitoring systems used in commercial transport make?

Section 3.1 gives an overview of the technologies available for monitoring relevant driver states such as fatigue and distraction, as well as their relative merits. Section 3.2 gives a brief historical overview of development of OEM DSM systems, showing the different approaches used as the underlying technologies have developed. Finally, Section 3.3 gives a brief overview of the range of aftermarket DSM systems currently available.

2.2 Legislation, consumer information and standards review

A rapid evidence review was undertaken to identify current approaches to testing and validation of DSM systems in regulations and consumer information programmes' protocols. A review of existing and in-development technical standards was also undertaken, consisting of an on-line rapid review and direct engagement with relevant standards bodies, as well as informal engagement with industry experts to identify information sources and validate findings. Initial searching was broad-based; direct engagement with standards bodies subsequently focused on ISO and SAE as the most relevant standards bodies for automotive DSM systems.

The following research questions were addressed:

RQ2.1: What technical requirements are specified in GB, EU and UN type-approval regulations for DSM systems (fatigue, attention and availability to take control of the DDT)?

RQ2.2: What assessment criteria do Euro NCAP and IIHS apply for DSM systems?

RQ2.3: What technical standards are available defining procedures for testing, validation or evaluation of DSM systems?

Section 4.1 gives an overview of regulatory DSM system requirements globally, Section 4.2 gives an overview of consumer information protocols, and Section 4.3 shows the findings from the review of technical standards.

2.3 Stakeholder engagement

This task aimed to gather additional information from users (fleet operators) and developers (Tier 2 suppliers[5] to vehicle manufacturers and suppliers of aftermarket systems) of DSM systems. The engagement took the form of semi-structured interviews designed to identify additional information on:

- The current status of DSM systems and the driver states that can be monitored effectively
- The real-world performance of DSM systems and how this is validated
- Standards that can be used to support testing and validation of DSM system performance
- How DSM systems are integrated with fleet safety management systems
- How DSM systems are used in practice and their effectiveness

Stakeholders were identified from established industry contacts at TRL and DVSA. A topic guide was developed for each stakeholder group (fleet operators and system suppliers).

In advance of the interview, each stakeholder was provided with:

- A letter of invitation from the DVSA

[5] See How the Automotive Industry is Structured - Smart Eye for an overview of the automotive industry supply chain and supplier tiers

- An overview of the project aims, its aims and the objectives of the stakeholder engagement
- A topic guide, with background information on DSM, the aims and objectives of the project, and the research questions for the interview

All stakeholder participants were informed that the project, including the interviews, would result in a published research report, and that individuals and organisations participating in the stakeholder engagement would not be named in the report.

The research questions cover a range of topics relevant to the study, focusing in particular on the current state-of-the-art in DSM, evidence for the performance of DSM systems, standards to support the specification, testing and validation of DSM systems, and future developments expected for DSM systems. The research questions for suppliers are shown in Appendix A.1 and for fleet operators in Appendix A.1.

Overall, 8 stakeholders were engaged as part of this stakeholder engagement. The topic guide and structured questions were shared with each interviewee in advance of the meetings so that the meetings could be as efficient and productive as possible. Each interview was one hour long and held on Microsoft Teams.

The feedback from stakeholders is summarised in Section 4.4.

2.4 Steering Group

The project also benefited from the guidance of a Steering Group with members from the Department for Transport, the Driver and Vehicle Standards Agency, the Vehicle Certification Agency, and academia. The Steering Group provided a forum for additional input from across the Department for Transport and its relevant agencies, as well as experts from academia.

The approach and initial review findings were discussed with the Steering Group in December 2024 and interim findings were presented and discussed with the Steering Group in March 2025.

3 Market review

3.1 DSM technology overview

The detection of driver states, such as fatigue (drowsiness) or distraction, can in principle be achieved by four technical measures:

- Camera-based (or image-based) measures (e.g. eye-based, mouth-based)
- Vehicle-based measures (e.g. steering wheel-based, lane deviation-based)
- Biological-based measures (e.g. brain-signal based, heart-signal based)
- Hybrid-based measures (combination of two or three of the above)

Camera- and vehicle-based measures (and hybrid solutions of these two) are already commonly used in current vehicles, driven by recent regulatory requirements in the EU (see Section 4.1). Camera-based measures rely on driver-facing cameras (integrated in a vehicle's original equipment or installed as aftermarket equipment) which use infrared sensing technology to work independently from visible light sources. Vehicle-based measures analyse signals from existing vehicle sensors, most importantly the steering wheel angle sensor and the forward-facing camera of a lane support system.

Biological-based measures are studied in research contexts, but the intrusive and / or invasive character of most current sensing technologies (e.g. electrodes attached to the head) is prohibitive of in-vehicle use. However, more user-friendly sensors, integrated in smart watches or dedicated wristbands are being researched, which makes future use for drivers – especially those employed to drive for work – conceivable.

Albadawi *et al.* performed a review of drowsiness-detection measures in research and summarised the key characteristics (see Table 1).

Table 1: Characteristics of different driver state detection measures, based on Albadawi *et al.* (2022)

Type	Intrusive / invasive	Accuracy (drowsiness)	Cost	Ease of use
Camera-based	No	High	Low	Automatic
Vehicle-based	No	Low	Low	Automatic
Biological-based	Depends on method used	High	High when high quality sensors used	User set-up, intervention or sensor wearing required
Hybrid-based	Depends on method used	High	Depends on hardware used	User set-up, intervention or sensor wearing required

The different measures offer a different profile of advantages and technical challenges:

- Camera-based systems can work independently of driving speed and could therefore be useful for low-speed setting, such as urban driving (e.g. bus drivers). They may struggle with some 'noise factors' such as certain facial characteristics (such as skin colour or eye aperture), objects covering the face (glasses, sunglasses, facial hair) or varying driver posture and distance from the sensor.
- Vehicle-based systems, which are generally less accurate compared to other measures, typically only work at extra-urban driving speeds, and may be influenced by road conditions (e.g. bumpy road impacting the steering behaviour or lane accuracy) or environmental conditions (e.g. side wind impact steering behaviour).
- Biological-based systems can in principle achieve high accuracy and detect the onset of drowsiness at an earlier stage than image-based systems, but may struggle from hardware complexities with intrusive and invasive sensors; the accuracy of systems relying on sensors that would be practical in real-world use is not known.

A hybrid approach, using both camera- and vehicle-based measures, will likely provide the most robust systems for vehicle-integration, with higher accuracy rates reported in the literature, but camera-based measures alone (e.g. in aftermarket systems) can also be expected to achieve good results. Additional biological-based measures relying on wearable devices (such as wristbands or smart watches) could possibly increase accuracy and offer earlier detection of drowsiness during its onset. While it is not feasible to make wearables a requirement for every driver, in fleet settings use of such devices could be incentivised. If their real-world accuracy is proven it could, for example, become possible to consider modifying driver's hours restrictions based on driver state evidence.

3.2 DSM systems fitted by vehicle manufacturers

Vehicle manufacturers have provided fatigue alerts to drivers for many years. Many of these systems were based on driver steering inputs, using a steering angle sensor that was typically fitted to vehicles as part of the electronic stability control system, which has been mandatory in passenger cars since 2009 (UN Regulation No. 13-H Revision 1, Amendment 2 effective 22 July 2009, replaced by UN Regulation No. 140 from 22 January 2017). Patterns of steering input characteristic of fatigue and of micro-sleeps were identified by vehicle manufacturers and used to provide an alert to the driver – typically a coffee cup symbol or other visual and audible alert. Many systems combined steering input data with other information, such as drive duration and time of day, to improve the prediction of fatigue and minimise false alerts (Huysamen and Pistak, 2019).

Passenger car manufacturers have been fitting more sophisticated camera-based DSM systems since at least 2018. Additional to identifying signs of fatigue, camera-based systems have been developed to identify signs of distraction from the dynamic driving tasks, for example looking away from the road ahead for an extended time period, or visual attention time sharing (VATS) – short, repeated glances away from the road ahead that are characteristic of certain types of distraction, such as mobile phone use while driving. Camera-based systems may also be able to detect other safety critical events such as driver sudden sickness leading to an unresponsive driver who is no longer in control of the vehicle.

Fatigue alerting systems are required in the EU by Regulation (EU) 2021/1341 since 2021 (see Section 4.1.1). The regulation sets a performance requirement that can be met by traditional steering-based systems or by camera-based fatigue detection systems (or systems that combine both technologies).

Initially, these camera-based systems were designed to support safe driving by alerting the driver to fatigue and/or distracted driving. As ADAS developed, and as manufacturers have developed SAE Level 3 automated driving systems, camera-based driver monitoring systems have been developed to ensure that drivers are engaged with monitoring the driving environment (ADAS) or remain available to respond to a transition demand issued by the vehicle (SAE Level 3 automation). For example, a vehicle with advanced emergency braking and lane keep assistance may be able to bring a vehicle to a safe stop in its lane if an unresponsive driver, e.g. due to a serious medical episode such as a heart attack, is detected.

Some examples of vehicle manufacturer's DSM systems, illustrating how systems have developed over time, are provided in the following sections.

3.2.1 Volvo Driver Alert Control

Volvo launched a system for alerting tired and distracted drivers, known as Driver Alert Control, in 2007[6]. The system uses a forward-facing camera to assess the position of the vehicle in its lane; if inconsistencies in the lane position suggest that the driver may be fatigued or distracted, an audible and visual alert is provided to the driver. The system reportedly focused on higher speed roads, with increased risk of drowsiness and increased risk of severe consequences should a collision occur. The system initiated at 65 km/h and remained active as long as the vehicle speed exceeded 60 km/h. The same system also provided lane departure warning alerts if the vehicle crossed the lane markings without the use of the indicators. Volvo noted that an advantage of the system was that it monitored the behaviour of the vehicle, but with the disadvantage that availability of the system depended on the quality and availability of the lane markings.

3.2.2 Mercedes-Benz Attention Assist

Mercedes-Benz introduced driver fatigue monitoring based on driver steering inputs in 2009[7]. Called Attention Assist, the system analyses steering movements and the speed of those movements, along with over 70 other parameters including crosswinds, road smoothness, and how frequently the driver interacts with vehicle controls and switches. If the algorithm determines that the driver may be fatigued, an audible ("Time for a break") and visible (coffee cup symbol) alert is provided to the driver.

3.2.3 DS Driver State Monitoring

Since 2018, DS have offered DSM in the DS 7 Crossback. The system combines an infrared camera focused on the driver with continuous lane position monitoring from a forward-

[6] https://www.media.volvocars.com/global/en-gb/media/pressreleases/12130

[7] www.mercedesbenzofeaston.com/mercedes-benz-attention-assist/

facing camera (also used for advanced emergency braking and other ADAS features). The driver-focussed camera, mounted above the steering column, identify signs of distraction or drowsiness by monitoring the eyes, eyelids and neck[8]. The forward-facing camera simultaneously tracks the position of the vehicle in relation to lane markings, to identify sudden or unexpected steering movements, to provide additional assessment of possible distracted or drowsy driving. When distracted or drowsy driving is detected, an audible and visual alert is issued.

3.2.4 GM Super Cruise

GM launched the Super Cruise eyes-on, hands-off SAE Level 2 ADAS system on the Cadillac CT6 in 2018[9]. Super Cruise allows the driver to drive hands free on suitable roads (main highways that have been mapped in high detail, currently limited to the US and Canada), and includes an infrared driver-facing camera to monitor the attentiveness of the driver and ensure that they continue to monitor the driving environment. The driver attention system monitors the driver's head position and gaze, and can provide audio, visual and haptic alerts to the driver if they are not sufficiently attentive to the driving task[10]. The owner's manual for a vehicle with Super Cruise (Cadillac CT5 2024[11]) indicates that sunglasses, hats or other types of clothing may interfere with the performance of the driver attention monitoring camera.

3.2.5 Ford Blue Cruise

Ford launched the Blue Cruise SAE Level 2 eyes-on, hands-off ADAS in North America in 2021[12], and in the UK and other parts of Europe in 2023[13]. The system operates exclusively on suitably mapped, divided and access-controlled roads (in the UK, this means most of the motorway network). The system uses a driver-facing camera in the instrument cluster to monitor gaze direction and head position, to check that the driver's attention remains on the driving environment.

3.2.6 Mercedes-Benz ALKS

At the end of 2021, Mercedes-Benz became the first company to achieve type-approval under UN Regulation No. 157 (on Automated Lane Keeping System, see Section 4.1.4) for an SAE Level 3 conditionally automated driving system[14]. Initially limited to 60 km/h hour, the Mercedes-Benz Drive Pilot system allows the driver to disengage from the driving task and

[8] www.dsautomobiles.co.uk/ds-experience/discover/news/ds-automobiles-anti-fatigue-technology.html

[9] news.gm.com/home.detail.html/Pages/topic/us/en/2025/feb/0228-supercruise.html

[10] www.gm.com/innovation/av-safe-deployment

[11] Manuals and Guides | Vehicle Support | Cadillac

[12] www.ford.com/technology/bluecruise/

[13] www.ford.co.uk/technology/driving-assistance/ford-bluecruise

[14] First internationally valid system approval: Conditionally automated driving | Mercedes-Benz Group > Innovations > Product innovation > Autonomous driving

perform non-driving related tasks such as online shopping or processing emails via the in-vehicle display.

The supplementary manual for vehicles with the optional Drive Pilot system[15] describes the operating requirements for the system, including that the driver monitoring camera is switched on and able to detect the head and both eyes of the driver. The system cannot be engaged, or will become unavailable, if the driver monitoring system cannot capture the driver's eyes or parts of the face, or where the driver is wearing glasses with extremely dark or polarising lenses, or glasses that block infra-red light. The system also monitors that the driver's seat position remains set correctly for the user in charge (fallback ready user) to take back control of the vehicle at any time, and can prompt the user in charge if the seat is adjusted while Drive Pilot is engaged.

According to the manual, it remains the user in charge's responsibility to keep the seat correctly adjusted for safe control of the vehicle and wear the seat belt, ensure a clear view from the vehicle by using windscreen wipers and windscreen defrost function if necessary, and ensure appropriate lighting e.g. in fog. One reason for requiring the wearing of the seat belt, which may not be mandatory in some jurisdictions, is that the seat belt is tensioned as part of the transition demand escalation if the user in charge does not respond to the initial takeover request.

3.3 Aftermarket DSM systems

A variety of aftermarket DSM systems for fatigue and distraction are available. Some systems are offered as standalone units, others are integrated with suppliers' cloud platforms and dedicated event review processes and operatives to qualify reported events and raise bona fide fatigue incidents, notifying the operator as appropriate. One standalone and one integrated example system are described below. The key characteristics of five different systems are then summarised in the subsequent overview table.

Objective performance measures for these systems are not known because no standardised performance evaluation protocols for aftermarket systems are available. The authors understand that some aftermarket suppliers also supply to OEMs for series production vehicles, which indicates that the technology used in some aftermarket systems would be capable of meeting type-approval requirements.

3.3.1 Rear View Safety RVS-350

RVS-350[16] is an aftermarket driver fatigue monitoring system which provides alerts to the driver. It is an integrated unit with a driver-facing camera and GPS sensor to be installed on the windscreen or dashboard. It is a standalone system with no internet connection.

Fatigue detection is based on analysis of eye-closure duration. After startup, the system requires between one and five minutes of normal driving to become operational. When operational an audible warning is issued when the driver's eyes are closed for longer than

[15] DRIVE PILOT Automated Driving | Mercedes-Benz USA

[16] https://www.rearviewsafety.com/pub/media/amasty/amfile/attach/driver_fatigue_monitoring_system_rvs-350_installation_manual.pdf

two seconds, or longer than four to seven seconds if the driver made large movements or was talking before the eye closure began. It offers three sensitivity settings (not further specified) and allows selecting a speed threshold below which warnings are not issued (between 20 and 45 km/h). The product description also specifies that the system can detect fatigue before falling asleep based on analysis of the driver's "retina condition"; it is not further clarified what this entails or how reliable it is.

The system is specified to work in daylight and darkness (using infrared illumination) and for drivers with glasses, sunglasses or contact lenses. It does not work for "people who have only one eye, white eyebrows, rough scars or wrinkles around eyebrows".

The installation does not require tools or training, although 'professional installation' is recommended. The camera is mounted with a suction cup on the windscreen or dashboard at 60 to 90 cm distance from the driver's eyes at an angle of not more than 30 degrees. When positioned correctly, a status LED indicates that the driver's eyes have been detected.

3.3.2 Seeing Machines Guardian

Guardian Generation 3[17] is an aftermarket fatigue and distraction monitoring system. The system provides alerts directly to the driver and also provides information and footage to a human analysis centre, enabling fleet managers to intervene.

Guardian relies on a driver-facing infrared camera mounted on the dashboard to track head and eyes of the driver to detect fatigue and distraction. The algorithm includes an intermediate drowsiness classification considering the accumulation of events over time. Alerts provided can be audible, visual, and haptic (using a seat vibration motor).

The additional integration with a human analysis centre is a noteworthy feature compared to the standalone solution reviewed above. Trained human analysts review every risky driving incident captured by the system and if they confirm a fatigue event notify the fleet manager. While not explicitly specified, it is assumed that the analysts review footage from the driver-facing camera and a data stream, which has implications for privacy protection. Fleet managers/operators have access to a web portal to review events with the intention to enable them to make decision for the current drive (e.g. require driver to take a break or end the shift), make larger operational improvements or inform safety programmes.

The manufacturer claims a 93% reduction in fatigue-related events and a 68% reduction of driving while distracted for vehicle fleets with the system installed. These values and criteria used to determine them are not further specified, but it is notable that they appear to relate to real-world reduction of events rather than laboratory testing.

3.3.3 Key characteristics overview

Some of the key characteristics of the above systems, plus several others that were identified during the study, are shown in Table 2. No independent data on the performance of these or other systems was identified, so manufacturer's claims regarding system performance have not been included in the table.

[17] https://seeingmachines.com/products/fleet/

Table 2: Key characteristics of example aftermarket DSM systems

	Rear View Safety *RVS-350*	Speedir *Driver Alert Fatigue Monitoring System*	Seeing Machines *Guardian*	Datik *Magic Eye*	Exeros *Facial Detection System*
Driver states detected	Fatigue	Drowsiness Mobile phone use Eyes off road	Yawning Drowsiness Microsleep Distraction	Yawning Drowsiness Microsleep Mobile phone use Distraction	Yawning Fatigue Mobile phone use Smoking Distraction
Expert event review and operator alert	No (standalone)	No (standalone)	Yes	Yes	Yes
Driver alert types	Audible	Audible	Visual, audible, haptic (seat vibration)	Visual, audible, haptic (seat vibration)	Visual, audible, haptic (seat vibration)
Event portal for operator	No	No	Yes	Yes	Yes (in combination with other hardware)
Special features	–	Self-installation	Considers accumulation of events over time Fatigue intervention plan management service	Live fatigue-risk score displayed to driver Ranking of drivers based on distance travelled at risk Fatigue intervention plan management service	Flexible mounting location due to long detection range

3.4 Other reviews

In addition to the market review presented above, Prendez *et al.* (2024) performed a technology review for NHTSA to identify driver monitoring systems for vehicles with SAE Level 2 automated driving capabilities. They concluded that driver monitoring technologies were available, but they would not be able to fully capture all forms of driver inattention. The predominant monitoring strategies identified were hand placement on the steering wheel (torque input or capacitive sensing) and camera-based driver analysis (posture, body and head position, gaze location, blink frequency, eye closure rate). Steering input as an indicator of drowsiness was not considered suitable for SAE Level 2 automation system because the steering is performed by the vehicle systems, not the human driver. In expert stakeholder interviews, the main issues mentioned relating to the two strategies employed included:

- Some hand placement systems are vulnerable to misuse (e.g. fooling the system by attaching weights to the steering wheel)
- Hand placement on the steering wheel, in absence of other strategies, does not indicate whether a driver is visually attending the road
- Gaze direction of the driver is a more direct measure of attentiveness but also not perfect as it cannot detect cognitive distraction (e.g. mind wandering) or simply looking but failing to see

The authors did not perform testing or assessments of specific systems.

Albadawi *et al.* (2022) performed an in-depth review of drowsiness detection systems, many of which at an academic research state of development, with the aim of giving an overall picture of the driver drowsiness technology ecosystem at the time of writing. Figures produced summarise the overall quality of different systems, and this helps demonstrate where the market is currently moving in terms of technological advancements (Table 3). It should be noted that the accuracy levels quoted were produced mostly in laboratory settings following different, non-standardised protocols and using different datasets, many of which used artificial behaviours (e.g. test subjects pretending to yawn). How these numbers translate to real-world accuracy is not known.

Table 3: Summary of drowsiness detection systems, based on Albadawi *et al.* (2022)

Type	Accuracy (drowsiness)	Cost
Image-based systems	72.25%–99.59%	Generally low-cost
Biological-based systems	70%–97.19%	Expensive when high-quality sensors are used
Vehicle-based systems	as low as 62.1%	Mostly comes as an expensive car accessory
Hybrid systems	79%–99%	Cost depends on the used hardware

3.5 Summary of DSM technology status

Section 3.2 gives examples of the historical development of DSM systems fitted by vehicle manufacturers. The Volvo Driver Alert Control (Section 3.2.1) used a forward-facing camera to assess lane position and infer driver states such as drowsiness or inattention. The system is focused on high-speed roads, initiating once the vehicle exceeded 65 km/h, and requires clear lane markings. A forward-facing camera is typically used for advanced emergency braking and lane keeping assistance or lane departure warning functions, which are now almost standard across all M- and N-category vehicles. Similar approaches have been built into some aftermarket systems to add to a driver-facing camera-based system, giving an element of 'hybrid' approach as outlined by Albadawi *et al.* (2022).

From this initial system, developments initially included vehicle-based systems and more recently – as technology has developed – driver-facing camera-based systems. Vehicle based systems, such as the Mercedes-Benz Attention Assist (Section 3.2.2) have typically been based on assessment of steering inputs, often with additional parameters such as time of day and duration of drive. These systems form a basis for the requirements in Regulation (EU) 2021/1341, although camera-based systems may also be used.

In Europe in 2018, DS introduced a hybrid system with infrared driver-facing camera-based combined with lane position sensing from a forward-facing camera, to provide fatigue and inattention alerts to drivers (Section 3.2.3). Around the same time, GM introduced an SAE Level 2 eyes-on, hands-off ADAS (Super Cruise) that uses a driver-facing camera to ensure that the driver remains engaged in monitoring the driving situation at all times. Many manufacturers now offer similar systems (either hands-on or hand-off). As an example, Ford Blue Cruise was available in 15 European countries as of July 2024[18], as well as the US and Canada, on selected motorways and highways, and includes a driver-facing camera to ensure that the driver remains attentive to the driving situation. Most recently, manufacturers have started to gain type-approval under UN Regulation No. 157 (ALKS), which requires a system to ensure that the driver remains able to take back control of the vehicle if the Automated Driving System (ADS) issues a transition demand.

These developments imply that OEM DSM systems have reached a high level of maturity, although specific information on the performance and limitations of individual systems is not publicly available.

Many aftermarket DSM systems are available, either for fitment and use by individual drivers or for fitment by fleets. Systems intended for fleets range from standalone camera-based systems that can provide an alert to the driver, through to sophisticated camera-based systems that are integrated into a fleet-wide safety management system. Alerts range from drowsiness only, to a comprehensive suite of fatigue and inattention-based alerts, including different types of visual distraction and mobile phone use. Information provided to fleet managers can include alert type (e.g. fatigue, visual distraction, device use), video clips (interior and exterior) around the time of the alert, and even specialist data reviews by the DSM system provider so that only validated alerts are forwarded to the fleet manager.

[18] Ford BlueCruise Now Available to Use in 17 Countries | Ford Media Center

Performance of these systems is difficult to determine, and no independent assessment of aftermarket systems was identified. In part, this is hampered by the lack of agreed standards on the testing and validation of DSM systems, beyond the legislative and consumer information requirements covered in Section 4.2.

For the systems available on the market (Sections 3.2 and 3.3) no evaluations based on a standardised test method for accuracy are published and thus their performance cannot be compared. Development of a standardised evaluation protocol for detection accuracy with published results would allow consumers and regulators to compare the performance of systems, rather than just knowing that an OEM system passed the type-approval test or relying on claims of suppliers for aftermarket systems. Such evaluation protocol would ideally report a system's true positive rate or 'sensitivity' (i.e. the proportion of correctly identified drowsy/distracted drivers to those incorrectly labelled as alert) and also its false positive rate or 'precision' (i.e. the proportion of correctly identified drowsy/distracted drivers to those incorrectly identified as drowsy/distracted). This would allow comparing how likely a system is to detect when a driver is indeed impaired and how likely a system is to provide false warnings which may result in drivers losing confidence and deactivating a system.

Systems with an additional layer of human analysis may currently provide higher performance levels than fully automated systems and integration of any system with fleet managers may increase the effectiveness of interventions because fleet managers are enabled to engage appropriately with the drivers based on the specific circumstances. However, independent data on this was not identified. Relevant privacy protections should be taken into consideration for systems that rely on biometric data to identity individuals or systems connected to analysis centres and/or fleet managers which may receive in-cab video footage or data about the driver.

4 Testing and validation approaches for DSM systems

4.1 Regulations

4.1.1 Driver Drowsiness and Attention Warning Systems (Regulation (EU) 2021/1341)

Driver Drowsiness and Attention Warning (DDAW) Systems are systems to detect driver fatigue in conventional vehicles and provide warnings to the driver. The system is regulated for the EU and NI market in Regulation (EU) 2021/1341[19] with additional clarifications provided in FAQs[20] published by the European Commission. Regulation (EU) 2021/1341 is applicable to M- and N-category vehicles and applied to new types from July 2022 and all new vehicles from July 2024. Note that a UNECE informal working group (DDADWS) was established in 2024 with the aim to develop UN Regulations on driver drowsiness and driver distraction, respectively to be adopted in 2026. The EU regulations discussed here are likely to form the basis for the original version of the regulation with updates to be developed in later series of amendments.

DDAW is defined as "*a system that assesses the driver's alertness through vehicle systems analysis and warns the driver if needed via the vehicle's human-machine interface*", i.e. the systems can rely solely on indirect measurements of fatigue (e.g. based on steering input patterns by the driver) without direct observation of the driver's face. However, driver-facing cameras may also be used for detection, which makes a combined implementation with ADDW (Section 4.1.2) possible. The regulation specifies some relevant technical requirements (privacy and data protection, system deactivation, operating conditions, system performance, driver warnings) and a compliance demonstration procedure.

With regard to privacy and data protection, the regulation requires the system to not identify the person using it via biometric information and prohibits data recording. The regulation also requires the system to operate within a closed loop, which is interpreted by the authors to mean that data cannot be shared outside the vehicle. This may prohibit integration with a wider fatigue management system that involves, for example, information sharing with a fleet manager:

> *2.3.1. The DDAW system shall function in normal operation mode without the use of biometric information, including facial recognition, of any vehicle occupants.*
>
> *2.3.2. The DDAW system shall be designed in such a way that it shall only continuously record and retain data necessary for the system to function and operate within a closed-loop system.*

DDAW cannot be deactivated by the driver, but the warnings may be turned off for the rest of a journey:

> *3.1.1. It shall not be possible for the driver to manually deactivate the DDAW system.*

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[19] Commission Delegated Regulation (EU) 2021/1341, unamended

[20] Driver Drowsiness and Attention Warning (DDAW) - Frequently asked questions, dated 13/05/2022, available at: https://ec.europa.eu/docsroom/documents/50074

It may however be possible for the driver to manually deactivate the DDAW system HMI warnings. Following manual deactivation of the DDAW System HMI warnings, it shall be possible for the driver to re-activate the system HMI warnings by taking no more than the same number of actions as were required to deactivate it.

[…]

3.1.3. The DDAW system, including HMI warnings, shall be automatically reinstated to normal operation mode upon each activation of the vehicle master control switch. The vehicle manufacturer can choose to add a condition to such automatic reinstatement: upon the driver's door having been opened or the vehicle being switched off for a maximum period of 15 minutes.

The operating conditions under which the system needs to work are restricted to extra-urban driving speeds and road layouts, owing to technical limitations of indirect measurement approaches, which means the system does not provide a safety benefit for exclusively urban driving (such as urban delivery driving or taxi operations). Operation in both day and nighttime conditions needs to be assured:

3.1.4. The DDAW system shall be automatically activated above the speed of 70 km/h.

3.1.5. Once activated, DDAW system shall operate normally within the speed range of 65 km/h to 130 km/h or the vehicle's maximum allowed speed, whichever is lower.

The DDAW system shall not be automatically deactivated at a speed of above 130 km/h (although the system's behaviour can be adapted to the degraded situation).

3.2.1. The DDAW system shall operate effectively during the day and night.

3.2.2. The DDAW system shall operate in absence of weather conditions limiting the system's operation.

3.2.3. At a minimum, the DDAW system shall work effectively on a multi-lane divided road, with or without a central divide, when lane markings are visible on both sides of the lane.

The requirements governing system performance define a clear drowsiness threshold that needs to be detected, that is KSS[21] 8, i.e. "sleepy, some effort to keep awake" and systems may already warn at KSS 7, i.e. "sleepy, no effort to keep awake". The regulation also gives guidance on recommended indirect metrics to base the detection on, but does not make firm requirements, thus leaving the design to the discretion of the manufacturer. Note that the recommendations made (monitoring of lane position, physiological measures) leverage the sensors of lane departure warning systems and driver-facing cameras from ADDW which are mandatory equipment in the EU, but not GB:

3.3.1. The DDAW system shall provide a warning to the driver at a level of drowsiness which is equivalent to or above 8 on the reference sleepiness scale set out in the Appendix (Karolinska Sleepiness Scale, hereinafter referred to as 'KSS').

[21] The Karolinska Sleepiness Scale measures the subjective level of sleepiness on a 9-point scale ranging from 1 "extremely alert" to 9 "very sleepy, great effort to keep awake, fighting sleep"

The DDAW system may provide a warning to the driver at a level of drowsiness which is equivalent to level 7 on KSS.

In addition, manufacturer may implement an information strategy on the HMI prior to the warning. […]

3.3.2. The DDAW system shall analyse other vehicle systems for detection of drowsy driving indicators. Such driving indicators may include but are not limited to the following:

(a) a reduction in the number of micro-corrections within driver steering, paired with an increase in the number of large and fast corrections;

(b) an increase in the variability of a vehicle's lateral lane position.

It is recommended that the DDAW system analyses other vehicle systems to detect drowsy driving indicators by monitoring lane position, namely the position of the vehicle relative to the lateral lane markings, or a steering input, namely a quantification of the way the driver manipulates the steering wheel, e.g. steering wheel reversal rate, yaw rate, standard deviation of lane position, etc.

An alternative manner of measuring driver performance through vehicle systems analysis ('metrics') may be used, provided that it is an accurate and robust measure of driver drowsiness.

It is possible to use one or more secondary metrics in addition to the recommendation stated in the second subparagraph of point 3.3.2. to aid the reliability and robustness of the system. Examples of such metrics include: additional vehicle metrics, temporal metrics (a temporal measurement directly related to the driver's operation of the vehicle), physiological metrics and vehicle control metrics.

The driver warnings in case of driver drowsiness are defined as either a visual or acoustic warning of specific characteristics aimed at ensuring that warnings are noticed by the driver. The warnings are presented until acknowledged by the driver, either explicitly or by improvement of their driving behaviour:

3.4.1. Warning nature

3.4.1.1. Visual and acoustic or any other warning used by the DDAW system to alert the driver shall be presented as soon as possible after occurrence of the trigger behaviour and may cascade and intensify until acknowledgement thereof by the driver.

Can be accepted as acknowledgement by the driver: an improvement of the driving behaviour based on the input used for the DDAW system (strategy to be described in the documentation provided by the manufacturer).

3.4.2. Visual Warning

3.4.2.1. The visual warning shall be located so as to be readily visible and recognisable in daylight and at night-time by the driver and distinguishable from other alerts.

3.4.2.2. The visual warning shall be a steady or flashing indication (e.g. tell-tale, pop-up message, etc.).

3.4.2.3. Any new symbols developed for the purpose of a DDAW visual warning are recommended to be constructed using similar elements to and keeping coherence with ISO 2575:2010+A7:2017 K.21 and/or ISO 2575:2010 +A7:2017 K.24.

3.4.2.4. The contrast of the symbol with the background in sun light, twilight and night conditions are recommended to be in accordance with ISO 15008:2017.

3.4.2.5. The following visual alert and background colour combinations should not be used: red/green; yellow/blue; yellow/red; red/violet.

3.4.3. Acoustic warning

3.4.3.1. The acoustic warning shall be easily recognised by the driver.

3.4.3.2. A majority of the acoustic warning shall fall within the frequency spectrum of 200-8 000 Hz and amplitude range of 50-90 dB.

3.4.3.3. If speech alerts are utilised, the vocabulary used shall be consistent with any text used as part of the visual alert.

3.4.3.4. The audible portion of the alert shall last for at least the duration that allows the driver to understand it.

Unlike many traditional vehicle safety regulations, the compliance demonstration procedure set out in Part 2 of the regulation does not involve a detailed test procedure for the technical service. Instead, it relies on validation testing by the manufacturer, which is documented and compiled to a dossier of information. Criteria for the manufacturer's validation procedure are defined in Part 2 of the regulation, including use of the KSS (or an alternative valid and accurate metric) and a study size of at least 10 human participants (real-world or simulator testing). A statistical approach is defined to derive system performance metrics.

The technical service will assess this information to ensure that all criteria, including system performance are met, and will also carry out the manufacturer-defined procedure to verify the system performance.

4.1.2 Advanced Driver Distraction Warning Systems (Regulation (EU) 2023/2590)

Advanced Driver Distraction Warning Systems (ADDWS) are systems to detect visual distraction in conventional vehicles and provide warnings to the driver. The system is regulated for the EU and NI market in Regulation (EU) 2023/2590[22] with additional clarifications provided in FAQs[23] published by the European Commission. Regulation (EU) 2023/2590 is applicable to M- and N-category vehicles and applied to new types from July 2024 and all new vehicles from July 2026. See note on UNECE working group DDADWS in Section 4.1.1.

[22] Commission Delegated Regulation (EU) 2023/2590, unamended

[23] ADDW Q&A: Answers to the questions raised by Stakeholders on the application of the rules on Advanced Driver Distraction Warning set out in the Delegated Regulation (EU) 2023/2590, dated 13/02/2025, available at: https://ec.europa.eu/docsroom/documents/64714

ADDWS is defined as "*a system that helps the driver to continue to pay attention to the traffic situation and that warns the driver when they are distracted*". The regulation covers visual distraction only (as opposed to e.g. cognitive distraction), citing the relative market immaturity of existing technologies. Later updates to the regulation are foreseen. The regulation sets out relevant technical requirements (privacy and data protection, system deactivation, operating conditions, system performance, driver warnings) and an assessment procedure.

With regard to privacy and data protection, the requirements are similar to those for DDAW but more stringent in that the prohibition of facial recognition is not limited to 'normal operation mode' but applies universally:

> *2.3.1. The ADDW system shall function without relying on biometric personal data of any vehicle occupants. In this context, the biometric personal data is resulting from specific technical processing relating to the physical, physiological or behavioural characteristics of a natural person, which allow or confirm the unique identification of that natural person, such as facial images or dactyloscopic data. This requirement does not forbid the ADDW system to use data from the camera(s) equipped in the vehicle, it forbids the identification of the person by the ADDW system.*
>
> *2.3.2. The ADDW system shall be designed in such a way that it shall only continuously record and retain data necessary for the system to function and operate within a closed-loop system.*

ADDWS may be deactivated by the driver for the rest of a journey:

> *3.1.2. It shall be possible for the driver to manually deactivate either the ADDW warning or the ADDW system, depending on which of the two possibilities (or both) the vehicle manufacturer chose to make possible.*
>
> *3.1.6. The ADDW system, including human-machine interface warnings, shall be automatically reinstated to normal operation mode upon each activation of the vehicle master control switch. Other automatic reinstatement conditions may be introduced and added by the vehicle manufacturer.*

The operating conditions under which the system needs to work begin at driving speeds above 20 km/h and it needs to operate under both day and nighttime conditions:

> *3.1.1. The ADDW system shall be automatically activated above the speed of 20 km/h, unless specified otherwise by the requirements laid down in points 3.1.2 to 3.1.6. The vehicle manufacturer may choose to set the automatic activation of the ADDW system at a lower speed.*
>
> *A cumulative period of up to 1 minute of driving at speeds ≥ 20 km/h is permitted for the system to begin measuring the driver state and to calibrate itself.*
>
> *[…]*
>
> *3.2.1. The ADDW system shall operate effectively during both day and night.*

The system performance requirements stipulate that driver gaze direction is the criterion to monitor, and the regulation defines three 'areas of interest'[24] relative to the vehicle structure (roof, windscreen, side windows, etc.). After 3.5 or 6 seconds of gaze being directed into area 3 (looking down in front of the driver, e.g. phone use), warnings need to be provided:

> *3.3.2.1. A warning shall be provided to the driver as soon as both of the following conditions apply:*
>
> *(a) vehicle's speed at 50 km/h or above;*
>
> *(b) the gaze of the driver in the Area 3 last for a maximum time of 3,5 seconds in the nominal situation. Non-nominal situations set out in Part 3, point 1.3, may extend the maximum nominal situation's time limit by additional 1,5 seconds.*
>
> *Whenever the conditions listed in (b) are tested, they shall implement an additional buffer time to compensate for the technical measurement uncertainties.*
>
> *3.3.2.2. A warning shall be provided to the driver as soon as both of the following conditions are verified:*
>
> *(a) vehicle's speed at 20 km/h or above;*
>
> *(b) the gaze of the driver in the Area 3 last for a maximum time of 6 seconds in the nominal situation. Non-nominal situations set out in Part 3, point 1.3, may extend the maximum nominal situation's time limit by additional 1,5 seconds.*
>
> *Whenever the conditions listed in (b) are tested, they shall implement an additional buffer time to compensate for the technical measurement uncertainties.*
>
> *[…]*
>
> *3.3.2.6. The vehicle manufacturer may implement additional warning strategies, based on additional input which help the system understanding the driver's behaviour, cognitive distraction or immediate environment within the vehicle.*

The driver warnings required in case of visual distraction include a visual warning combined with an acoustic and/or haptic warning. The warnings are presented as long as the trigger conditions apply. The characteristics of the visual and acoustic warning are effectively identical to those for DDAW (see Section 4.1.1). The haptic warning is specified as:

> *3.4.4.1 The haptic warning shall be noticeable by the driver and be provided directly or indirectly through any interface expected to attract the attention of the driver back to the driving task.*

The assessment procedure defined consists of spot check tests carried out by the technical service to ensure that the system is operational and able to display all warnings. A test driver sitting in the vehicle directs the gaze at defined points while driving and it is assessed whether the warnings activate as required.

[24] Detail definition of these areas can be found in Paragraph 3.3.1 of Part 1 of the regulation.

4.1.3 Driver Control Assistance Systems (UN Regulation No. 171)

DCAS are a specific group of ADAS regulated in UN Regulation No. 171[25]. DCAS are driver-operated vehicle systems assisting a driver in performing vehicle dynamic control via sustained lateral and longitudinal motion-control support. DCAS provide support to the driving tasks and increase comfort and reduce the drivers' workload by actively stabilising or manoeuvring the vehicle. DCAS assist the driver but do not completely take over the driving task, thus the responsibility remains with the driver and no transfer of control takes place. DCAS would be classed as an SAE Level 2 driving system.

UN R171 provides minimum safety requirements for any DCAS which includes monitoring for driver disengagement (motoric and visual disengagement) and providing warnings to the driver. The monitoring criteria specified include 'hands-on' and 'eyes-on'. The 'eyes-on' criterion is intended to prevent disengagement by visual distraction, but the criteria outlined do not cover fatigue or other forms of disengagement, such as cognitive disengagement. The detailed design is left to the discretion of the manufacturer:

> *5.5.4.2.1.1. The system shall monitor if the driver is motorically (i.e., hand(s) on the steering control) and visually (e.g. gaze direction and/or head posture) disengaged.*
>
> *[…]*
>
> *5.5.4.2.4. Assessment of Motoric Disengagement*
>
> *5.5.4.2.4.1. The driver shall be deemed to be motorically disengaged when the driver has removed their hands from the steering control.*
>
> *5.5.4.2.5. Assessment of Visual Disengagement*
>
> *5.5.4.2.5.1. The driver state monitoring system shall detect the driver's visual disengagement at a minimum based on the detection of the driver's eye gaze Head posture may also be used if the driver's eye gaze cannot be determined, or where the head posture can determine the disengagement more quickly.*
>
> *5.5.4.2.5.2. The driver shall be deemed to be visually disengaged when the driver's eye gaze and/or head posture, as relevant, is directed away from any currently driving task relevant area. […] For the purpose of the assessment of visual disengagement, the dashboard and instrument panel shall not be considered as a driving task relevant area.*

The driver warning sequence is a series of escalating warning steps, with:

- hands on request: visual information after 5 seconds of motoric disengagement, escalation with acoustic and/or haptic information after further 10 seconds
- eyes on request: visual information plus one other modality after 5 seconds of visual disengagement, escalation with increased intensity of acoustic and/or haptic information after further 3 seconds
- direct control alert: visual warning plus one other modality 5 seconds after escalation of the eyes on request (i.e. 13 seconds after beginning of visual disengagement)

[25] UN Regulation No. 171, original version of the regulation

These warnings, if not responded to, are followed by a driver unavailability response 10 seconds after escalation of one of the requests, i.e. 18 to 25 seconds after beginning of disengagement.

Simple testing of the system is performed by the technical service to verify, under nominal conditions, that the system behaviour corresponds to the manufacturer's design. No specific test procedures are defined in the regulation.

4.1.4 Automated Lane Keeping Systems (UN Regulation No. 157)

ALKS are automated driving systems regulated in UN Regulation No. 157[26]. ALKS controls the lateral and longitudinal movement of the vehicle for extended periods without further driver command, i.e. the system is in primary control of the vehicle. The system can only be activated on dual carriageways/motorways and the driver needs to remain available to take over the driving task (with sufficient time) when the system transitions control back to them. ALKS would be classed as an SAE Level 3 driving system.

UN R157 requires the system to have a 'driver availability recognition system' to detect if the driver is present in a driving position, the safety belt of the driver is fastened, and if the driver is available to take over the driving task. The relevant aspect for this review is the latter, i.e. availability to take over the driving task, because it is related to attention and fatigue.

The technical requirements for detection give examples of 'availability criteria' that can be monitored by the system but leave the design to the discretion of the manufacturer. The system's capability must ultimately be demonstrated to the satisfaction of the technical service:

> *6.1.3. Driver availability*
>
> *The system shall detect if the driver is available and in an appropriate driving position to respond to a transition demand by monitoring the driver.*
>
> *The manufacturer shall demonstrate to the satisfaction of the technical service the vehicle's capability to detect that the driver is available to take over the driving task.*

The criteria specified stipulate that:

- the system needs positive confirmation that the driver is available, otherwise unavailability will be assumed,
- at least two criteria need to be positive for this confirmation, and
- the assumption of availability is valid for a maximum of 30 seconds:

> *6.1.3.1. Criteria for deeming driver availability*
>
> *The driver shall be deemed to be unavailable unless at least two availability criteria (e.g. input to driver-exclusive vehicle control, eye blinking, eye closure, conscious head or body movement) have individually determined that the driver is available in the last 30 seconds.*

[26] UN Regulation No. 157, 01 Series of amendments, Supplement 2

At any time, the system may deem the driver unavailable.

(…)

Justification for the number and combination of availability criteria, in particular with regard to the corresponding time interval, shall be provided by the manufacturer by documented evidence. However, the time interval required for any availability criteria shall not exceed 30 seconds. This shall be demonstrated by the manufacturer and assessed by the technical service according to Annex 4[27]*.*

The system reaction in case of driver unavailability is specified as a sequence of 'distinctive warning' followed by a transition demand to the driver. No details are laid down about the nature of the warning, so this is left to the design decisions of the manufacturer:

As soon as the driver is deemed to be unavailable, or fewer than two availability criteria can be monitored, the system shall immediately provide a distinctive warning until appropriate actions of the driver are detected or until a transition demand is initiated. At the latest, a transition demand shall be initiated according to paragraph 5.4.[28] *if this warning continues for 15s.*

No specific performance testing protocol is defined in the regulation.

4.1.5 Automated Driving Systems (future UN Regulation)

ADS will be regulated in a future UN Regulation, which is currently under development[29]. ADS are systems capable of performing the entire Dynamic Driving Task (DDT) on a sustained basis. ADS would be classed as SAE Level 3, 4 or 5.

The user is not required to monitor the driving environment but, for some features, is required to be available for a control fallback. For these features, the regulation requires a user-monitoring system:

5.3.2.1.6. While active, features that have a system-initiated deactivation of the ADS to a fallback user shall: (a) Continuously assess through a user-monitoring system whether the fallback user is available and in a position to resume the role of driver.

No more detailed technical stipulations are made in this draft, which would leave the system design to the discretion of the manufacturer. It is not known whether requirements will be further specified for the final version of the regulation, and test procedures are not yet defined.

[27] Annex 4 specifies general documentation and audit-type procedures for approval

[28] Paragraph 5.4. specifies in detail how a transition should take place, e.g. that the driver shall be given sufficient time to take over the driving task while the system continues to operate

[29] Draft reviewed: Document ADS-04-15/Rev.2, dated 8-11 October 2024

4.1.6 Automated Driving Systems (Regulation (EU) 2022/1426)

ADS as defined in the applicable regulation for the EU and NI market[30] only refer to systems for fully automated vehicles[31], i.e. systems that do not foresee control fallback to the user. Consequently, no requirements relating to driver/user monitoring are stipulated. These systems would be classed as SAE Level 4 or 5.

4.1.7 US advance notice of proposed rulemaking on Advanced Impaired Driving Prevention Technology (NHTSA-2022-0079-0015)

In January 2024, the US's NHTSA issued an advance notice of proposed rulemaking (ANPRM) on Advanced Impaired Driving Prevention Technology[32]. This step initiates rulemaking that would gather the information necessary to develop performance requirements and require that new passenger motor vehicles be equipped with advanced drunk and impaired driving prevention technology through a new Federal Motor Vehicle Safety Standard (FMVSS). In November 2024, NHTSA provided a status report to the US Congress[33] which largely stated that various reviews are underway, but did not provide an expected timeline for issuing a final rule. Such reports are required annually until a final rule is published, so another report can be expected in November 2025.

NHTSA considers three aspects of impairment in the context of the ANPRM: alcohol, distraction and drowsiness. The types of impairments are ranked in the order stated based on the casualty numbers associated with each. Given the high number of alcohol-related casualties occurring in the US, NHTSA is considering prioritising alcohol over other types of impairments and large parts of the ANPRM and the report to Congress are dedicated to this topic.

On available driver monitoring technologies to detect whether a driver is impaired, the ANPRM concludes that "*many driver impairment detection strategies use different combinations of measures, but the available documentation of multi-detection approaches is rare, and when present, details of the underlying algorithms are sparse. It is reasonable to assume that the combination of more sensors and driver metrics will improve the confidence in driver state inference. Little data is available, however, to inform NHTSA on which combination of sensors and indicators of driver state, if any, would achieve greater accuracy and reliability of impairment detection.*" The ANPRM contains a comprehensive catalogue of questions on such technologies as part of NHTSA's request for information. NHTSA have received over 18 thousand public comments which appear to largely be from members of

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[30] Commission Implementing Regulation (EU) 2022/1426, unamended

[31] Defined in Regulation (EU) 2019/2144: 'fully automated vehicle' means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

[32] ANPRM Advanced Impaired Driving Prevention Technology, available at: https://www.regulations.gov/document/NHTSA-2022-0079-0015

[33] Report to Congress: Advanced Impaired Driving Prevention Technology, available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/2024-12/report-to-congress-2024-advanced-impaired-driving-prevention-technology.pdf

the public expressing their personal view on the topic. Future NHTSA reports to Congress should be monitored for summaries of useful information received.

NHTSA are currently undertaking a stream of research that could feed into the final rule. In a Safety Research Portfolio meeting[34] in October 2024, NHTSA announced publication of a research roadmap containing the following topics relevant to this report:

- Driver Monitoring Systems: detect distractions in real time and deploy intervention strategies; research to include how to assess the effectiveness of DSM systems
- Partial Driving Automation Systems: support appropriate driver engagement during use of SAE Level 2 automation systems
- Secondary device usage: understand secondary device usage and ways to mitigate it
- In-vehicle interface design: reduce driver workload and eyes off road time

The full research roadmap has not been published at the time of writing this report.

Relevant ongoing human factors studies that were individually mentioned during the meeting include:

- Applied research to develop test procedures for drowsiness
  - Aim: to establish best practices, test procedures and objective measures to assess the ability of driver monitoring systems to identify drowsiness while minimising false positives
- Driver distraction mitigation technology
  - Aim: to learn about the performance of currently available US market OEM and aftermarket driver distraction mitigation systems
- Examining distraction and driver monitoring systems to improve driver safety
  - Aims: to explore alternatives to current common metrics of task-based eyes-on and eyes-off road time and explore how differences in driver monitoring systems impact ability of a system to reliably assess different driver states
- Driver monitoring systems in SAE Level 2 Driver Support Systems
  - Aim: to characterise approaches to driver monitoring systems in current SAE Level 2 equipped vehicles
- Driver interactions with SAE Level 2 automated systems
  - Aim: to examine SAE Level 2 system Human-Machine Interface (HMI) effectiveness and responses to take-over requests
- Updated exploration of eye glance metrics associated with crash risk and distraction state detection metrics
  - Aim: explore the research topic by literature review and analysis of naturalistic driving study data

[34] NHTSA Safety Research Portfolio Public Meeting: Fall 2024, https://www.nhtsa.gov/events/nhtsa-safety-research-portfolio-public-meeting-fall-2024

- Drive mode design best practice – Exponent
    - Aim: to identify the state-of-the-art in use of unpaired portable devices while driving

The results of these studies should be considered once available.

4.1.8 China Driver Attention Monitoring System (GB/T 41797-2022)

Driver Attention Monitoring Systems (DAMS) are camera-based systems to detect driver fatigue and distraction in conventional vehicles and warn the driver. The system is regulated for M- and N-category vehicles for the Chinese market in the recommended national standard GB/T 41797-2022[35], implemented in the year 2023.

DAMS are required to recognise five driver behaviours:

- Closed eyes
- Abnormal head posture
- Phone use
- Yawning
- Smoking

The system assessment consists of tests with a real driver and with a bionic robot which performs these behaviours inside a stationary vehicle in a test laboratory, with a solar simulator to generate varying lighting conditions.

The driver test is carried out to assess the basic capability of the system to identify the required behaviours. Each behaviour needs to be recognised at least once during the trial and the number of correct identifications is at least 2/3.

The robot test is carried out to determine the system's detection rate and accuracy, which needs to be at least 95%. The bionic robot is defined in the standard with regard to its design (dimensions, eyes, mouth, head range of motion, movements, accuracy, data recording, feature points and skin materials) and its installation (head, arms, hands, torso and robot movements).

4.2 Consumer information protocols

4.2.1 Euro NCAP Safe Driving – Driver Engagement Protocol

Euro NCAP introduced assessment of DSM systems in 2020, under the 'Euro NCAP Advanced' scheme and the 'Assisted Driving' protocol. This enabled Euro NCAP to award points to a manufacturer for a DSM system prior to the introduction of a specific test protocol, based on assessment of an information dossier provided by the manufacturer.

[35] National Standard of the People's Republic of China, GBT 41797-2022, unamended. The information on this standard available to the authors is limited and was extracted from UNECE document DDADWS-06-04, available at: https://wiki.unece.org/download/attachments/287179141/DDADWS-06-04%20%28China%29%20Introduction%20of%20the%20DAMS%20standard%20in%20China%20Rev.1.pptx?api=v2

DSM has been assessed using a specific assessment protocol (with a supplementary technical bulletin) since 2023.

An updated Euro NCAP Driver Engagement Protocol[36], to apply from January 2026, is designed to evaluate DSM systems, i.e. systems to detect driver fatigue and distraction and support the driver in conventional, ADAS-equipped vehicles. This consumer information protocol does not set out specific pass/fail criteria, as would be done in regulation, but defines system capabilities to detect certain driver states for each of which points are awarded which influence the system score and thus the overall vehicle rating. For assessment, the manufacturer submits a dossier of information which is assessed by spot checks of capabilities performed by a Euro NCAP test laboratory.

Guidance for the manufacturer dossier (including recommended performance levels) and the spot check procedure are detailed by Euro NCAP in two Technical Bulletins[37] accompanying the protocol.

This 2026-protocol builds on earlier versions, the evolution of which is briefly discussed at the end of this section. Note that the Driver Engagement Protocol also includes an assessment of the vehicle's driving controls, which is not reviewed for this report.

4.2.1.1 Technical requirements

The protocol stipulates that a DSM system shall cover a wide variety of drivers, occlusions and driver behaviours. Driver criteria for which a range of variety to be covered is defined in the protocol are:

- Age
- Sex
- Stature
- Skin complexion
- Eye lid aperture

Occlusion criteria are:

- Lighting
- Eyewear
- Facial hair
- Hand on wheel
- Facial occlusion

[36] Euro NCAP, Safe Driving – Driver Engagement Protocol, implementation January 2026, version 1.0, published March 2025

[37] Euro NCAP, Safe Driving – Driver Monitoring, Dossier Guidance, Technical Bulletin SD 201, version 1.0, published March 2025, and Euro NCAP, Safe Driving – Driver Monitoring, Test Procedure, Technical Bulletin SD 202, version 1.0, published March 2025

The only driver behaviour for which the system is required to remain functional is talking. For a range of other behaviours, the manufacturer shall report on the capabilities of the system for monitoring purposes:

- Eating
- Laughing
- Singing
- Smoking/vaping
- Eye scratching/rubbing
- Sneezing

The DSM system must be default on at the start of each journey, deactivation shall not be possible with a single button push and the system driver state detection sensitivity shall not be adjustable.

The driver states for the detection of which the system is awarded points are summarised Table 4. The vehicle response required when detecting any of the states specified in Table 4 are specified as warnings and changes to ADAS intervention strategies:

- Two or three warning modalities: Visual and haptic, or visual and audible, or visual and haptic and audible; for non-transient driver states, it is alternatively possible to implement countermeasures to mitigate impairment (e.g. lowering the climate control temperature, prompting rest areas in navigation system) with evidence of effectiveness
- Change in forward support sensitivity (forward collision warning and advanced emergency braking systems shall react at least 200 milliseconds earlier) and optionally change in lateral support sensitivity (lane departure warning and lane keeping assistance systems always active and sensitivity is increased)

Table 4: Euro NCAP driver states to be detected by a DSM system

Driver states			Notes
Transient driver states	Long distraction	Non-driving task related	Gaze away from road for 3 to 4 seconds
		Driving task related	
	Short distractions	Non-driving task related	Repeated glances away from road for 10 seconds with 30 second period
		Driving task related	
		Away from road (multiple locations)	
	Phone Use	Basic	Basic/advanced dependent on eye or head movement type and phone location
		Advanced	
Non-transient driver states	Impairment	Non-fatigue related	e.g. alcohol, drugs
		Drowsiness	KSS > 7, from 50 km/h
	Microsleep		1–2 seconds eye closure
	Sleep		≥ 3 seconds eye closure
	Unresponsive		≥ 6 seconds eye closure or not responding to warning within 3 seconds

4.2.1.2 Manufacturer test and documentation requirements, including recommended performance levels

Technical bulletin SD 201 sets out guidance on what level of information provided by the manufacturer to Euro NCAP is sufficient for an assessment. It requires the following technical detail:

- Description of each sensor used, including sensor type (camera, radar, etc.), the function served and it's mounting position
- Brief description of operating principle, triggering conditions and vehicle responses related to each transient and non-transient driver state supported by the system
- Information on the datasets used for a system assessment carried out by the manufacturer, including break down of test subjects by demographic characteristics, number of test cases for each occlusion criterion and driver state tested
- Results of the system assessment, including number of false alerts per hour of driving, and true positive rate of detections for each transient and non-transient driver state supported by the system

The technical bulletin indicates that the system assessment should be based on two different datasets:

- False positive dataset: Extended naturalistic driving recordings with no scripted driver behaviour
- True positive dataset: Not further specified, but it can be assumed that this dataset contains scripted behaviour where drivers experience or simulate the states to be detected

The guidance provided recommends the following characteristics of the datasets:

- False positive dataset: 3 test subjects, 30 to 100 hours total driving time
- True positive dataset: 10 test subjects, 43 test cases for each occlusion criterion and driver behaviour, 10 test cases for each driver state

With regard to results of the system assessment (i.e. system performance), the technical bulletin recommends:

- Number of false alerts per hour of driving:
    - Transient driver states: 0.05, i.e. one false alert for every 20 hours of driving
    - Non-transient driver states: 0.001 (unresponsive driver), 0.005 (sleep), 0.01 (microsleep), 0.5 (impairment, including drowsiness)
- True positive rate of detections:
    - Transient driver states: 80% (long distraction), 60% (short distraction, phone use)
    - Non-transient driver states: 40% (sleep, microsleep, drowsiness), 60% (unresponsive driver), not defined (non-fatigue impairment)

4.2.1.3 Spot testing procedure

Technical bulletin SD 202 details the spot testing procedure Euro NCAP carries out to verify the information submitted by the manufacturer. The test consists of a portion on a test track, where a test driver simulates states to be detected, and a portion of normal on-road driving to evaluate false positive activations.

The bulletin outlines track and weather conditions for the track tests as well as vehicle preparation including preconditioning during an initial drive of up to 100 km to allow collision avoidance sensors to calibrate and a one-minute drive right before the tests where the driver is fully attentive to allow the system time to identify the driver. The bulletin also contains instructions for the test driver regarding how to carry out the head, gaze and eyelid movements to simulate the various states to be detected. It is assessed whether the system provides warnings and/or successfully modifies the intervention performance of crash avoidance systems (the latter by performing activation tests of lane departure warning or advanced emergency braking systems on track), and whether the system recognises a degraded system state (when driver blocks camera view of their face).

For the on-road assessment, the bulletin only provides a brief outline, which states that the test driver manually notes occurrence of false positive detections. No driving duration or distance is specified.

4.2.1.4 Evolution of the protocol

Euro NCAP first included an assessment of driver monitoring systems in the year 2020. This initial version did not specify driver or occlusion criteria, driver behaviours or driver states to be detected but only required the manufacturer to provide a dossier of information containing technical detail about the system and the test procedures carried out by the manufacturer. Euro NCAP then detailed the requirements considerably more in the year 2023, with requirements in the protocol being similar to those applicable from year 2026 (summarised above). However, differences between the 2023 and 2026 versions arise from the contents of the technical bulletin, which applies only from 2026 and contains recommended performance levels for both true positive and false negative detection performance, which were not quantified beforehand. The overall focus on driver monitoring systems in Euro NCAP has also increased considerably in the 2026 version with it being worth up to 25 points for manufacturers (compared to only 2 points in the 2023 version).

4.2.2 Euro NCAP Safe Driving – Occupant Monitoring

From January 2026, Euro NCAP will increase the breadth and depth of its occupant monitoring protocols[38] and assessments.

Additional to its standard seatbelt reminder system reward, manufacturers will be rewarded for detecting seatbelt misuse such as having a separate seatbelt tongue fitted to the buckle (with no belt), the occupant sitting in front of the belt, and the occupant wearing only the lap portion of the seatbelt. Initially, only the driver seating position must be assessed, with other seating positions being considered for introduction in 2029.

Furthermore, manufacturers will be rewarded for correctly classifying a range of occupant characteristics including:

- Seat occupancy by adults and/or child occupants who may be using a child restraint system – this classification may be used to automatically set the passenger airbag status switch
- Out of position – this includes detecting that an occupant is leaning too far forward and in close proximity to a frontal airbag and that the front passenger has their feet on the dashboard – warnings must be provided to the occupants in either case
- Driver and front passenger stature classification – used to adapt the restraint system to at least 2 statures (typically used to tune the restraint system for shorter occupants sitting closer to the steering wheel or dashboard)

Finally, manufacturers can be rewarded for occupant presence detection including:

- Child presence detection – to provide alerts that a child has been left unattended in a vehicle or has entered the vehicle unaccompanied
- Seat occupancy status – to provide information on the number of belted occupants and children in child restraint systems with the standard eCall collision alert data

[38] Euro NCAP, Safe Driving – Occupant Monitoring Protocol, implementation January 2026, version 1.0, published March 2025

The protocol is technology agnostic, but – based on feedback from stakeholders (see Section 4.4) – it is likely that many of the functions will be provided by enhanced camera-based driver and other-occupant state monitoring systems, possibly including internal radar based systems.

4.2.3 Euro NCAP Assisted Driving – Highway & Interurban Assist Systems Protocol

The Euro NCAP Highway & Interurban Assist Systems Protocol[39] is designed to evaluate automated driving systems where the driver retains full responsibility and shares control with the vehicle which assists in both longitudinal and lateral control for a sustained time period. These would be classed as SAE Level 2 driving systems. The driver monitoring requirements contained in this protocol include hands-on monitoring and DSM for fatigue and distraction.

To be awarded points for hands-on monitoring the driver monitoring system must:

- Provide an optical warning 15 seconds after steering wheel has been released
- Provide an acoustic and a red optical warning 30 seconds after steering wheel has been released
- Deactivate the assist system after a further 30 seconds, preceded by 5 seconds of an additional acoustic warning
- Lock out the assist system for the remainder of the journey after three cumulative severe hands-off warnings (e.g. reaching system deactivation phase)

Hands-on monitoring gets awarded extra points if it detects steering wheel contact directly (e.g. via capacitive sensing as opposed to torque-based sensing).

The DSM requirements are very similar to those set out in the Euro NCAP Driver Engagement Protocol but currently references an older version of that protocol. The distraction warning thresholds (i.e. the duration of distraction after which a warning is issued) may be relaxed compared to unassisted driving.

4.2.4 Euro NCAP Safer Trucks testing programme

In November 2024, Euro NCAP introduced a new Safer Trucks assessment programme, giving star ratings to heavy goods vehicles for the first time. The protocol includes:

- Safe driving
  - Occupant monitoring – including seat belt use and driver monitoring
  - Vision – good direct and indirect vision
  - Vehicle assistance – speed assistance and adaptive cruise control
- Crash avoidance

[39] Euro NCAP Assisted Driving – Highway & Interurban Assist Systems Test & Assessment Protocol, implementation 2024, version 2.2, published September 2024

  - Frontal collisions – including advanced emergency braking, advanced emergency braking with pedestrian and cyclist detection
  - Lane departure collisions
  - Low-speed manoeuvring – turning across the path of a cyclist
- Post-crash safety
  - Rescue information – rescue sheets and external labelling
  - Post-crash intervention – enhanced e-Call
  - Vehicle extrication – occupant extraction

To date, ratings for 9 long-haul vehicles from 7 manufacturers have been published, ranging from 1-star to 5-stars.

Unlike the passenger car rating discussed in Section 4.2.1, the driver monitoring element of the rating does not include a formal test procedure. Manufacturers are asked to provide a dossier of evidence similar to that provided for type-approval to Regulation (EU) 2021/1341 (see Section 4.1.1), i.e. covering driver drowsiness and attention warning. The assessment protocol is not defined, but "*aims to reward systems that: exceed the minimum requirement for system sensitivity [in the EU regulation] in true positive situations; and exhibit a low number of false positive detections of driver inattention*".

Coverage of driver distraction warning systems (Regulation (EU) 2023/2590 – see Section 4.1.2) is not included in the assessment.

4.2.5 Insurance Institute for Highway Safety (IIHS) Safeguards For Partial Driving Automation Protocol

The IIHS Safeguards For Partial Driving Automation Protocol[40] is designed to evaluate the user safeguards that vehicles with partial driving automation (also referred to as SAE Level 2 driving systems) employ. To achieve a favourable rating, driver monitoring systems (DMS) need to ensure that the driver's eyes are directed at the road, that their hands are either on the steering wheel or ready to grab it, and that the monitoring system cannot easily be fooled. Escalating alerts and appropriate emergency procedures are required when the driver does not meet those conditions.

The protocol defines a series of DMS tests to be performed while driving on a flat, straight road, during daylight hours in good environmental conditions. The test driver performs a defined action, for instance covering their face or looking away from the road or attaching a weight to the steering wheel to fool the system into assuming hands on the steering wheel, and the test laboratory checks whether the system issues alerts or deactivates automated driving within a given timeframe (alerts after 10 to 15 seconds, disengagement after 35 seconds).

- Test 1a: DMS camera occlusion before activation of driving automation

[40] Insurance Institute for Highway Safety (IIHS) Safeguards For Partial Driving Automation – Test Protocol and Rating Guidelines, Version I, published March 2024

  - Documents whether the partial driving automation can be activated while the DMS camera is occluded
- Test 1b: DMS camera occlusion after activation of driving automation
  - Documents whether the partial driving automation remains active if the DMS camera is occluded
- Test 2a: DMS driver obscuration before activation of driving automation
  - Documents whether the partial driving automation can be activated if the driver's face is obscured
- Test 2b: DMS driver obscuration after activation of driving automation
  - Documents whether the partial driving automation remains active if the driver's face becomes obscured
- Test 3: DMS eye tracking
  - Documents whether the partial driving automation can detect if the driver's eyes are looking away from the road while the head is facing forward
- Test 4: DMS head tracking
  - Documents whether the partial driving automation can detect if the driver's head and eyes are directed away from the road
- Test 5a: DMS hand tracking/monitoring
  - Documents whether the partial driving automation can detect when the driver's hands become occupied, even in hands-free driving mode, as drivers must be immediately ready and able to perform their role in the dynamic driving task
- Test 5b: DMS hand tracking/monitoring with additional weight attached to steering wheel
  - Documents whether the partial driving automation can detect if the driver is trying to fool the system while their hands are occupied
- Test 6: Attention reminders, emergency escalation countermeasures, and lockout confirmation
  - Documents the attention reminder process and the start of the emergency escalation when the driver is looking away from the road and their hands are off the steering wheel and occupied

4.3 Technical standards

This review set out to identify technical standards from internationally recognised standardisation bodies, such as ISO, SAE or BSI, that define test methods for DSM systems. No such standards were identified, which is why the search was broadened to more foundational standards that could be relevant for future work developing such methods.

4.3.1 Definitions and terminology

Distraction, fatigue and drowsiness can all contribute to driver inattention, but they are difficult to differentiate, and clear definitions are paramount to ensure consistency of trial specifications and precise implementation of legislation. SAE J3198[41] offers definitions for 25 key terms in relation to these concepts, such as acute fatigue, chronic fatigue, drowsiness, driver distraction, fatigue, mental fatigue, microsleep, passive fatigue, physical fatigue and task-related fatigue.

In experimental settings, the effects of distraction, fatigue and drowsiness are commonly evaluated by measuring their effect on driving performance. SAE J2944[42] provides definitions and calculation instructions for driving performance measures, which can be used in a variety of studies, including in the context of distraction, fatigue and drowsiness. These include measures relating to the longitudinal positioning of the vehicle (such as distance gap, time gap, time to collision, response time until brake moved and required deceleration) and to its lateral positioning (such as steering reaction time, number of steering reversals, time to line crossing, lane change duration and lane change severity).

Visual distraction specifically is also studied by analysing the eye-glance behaviour of the driver in experimental settings. SAE J2396[43] defines key terms and measures used in video-based analyses, such as area of interest, direction of gaze, dwell time, glance duration, visual demand.

Driver distraction is widely assumed to be a key factor underlying collisions. While many metrics and procedures exist to relate specific distractions (for example caused by a certain HMI design or phone use) to driving performance measures and metrics (for example steering behaviour), it cannot be simply assumed that these changes are linked to changes in real-world collision involvement. SAE J3151[44] offers definitions of key terms required for research into these causal links, such as driver activity, driver behaviour, driving performance, driver distraction, driver state, metric and predictive validity.

In the context of automated driving, SAE J3016[45] and SAE J3114[46] provide a set of foundational definitions for terms related to automated driving systems and also associated driver monitoring systems, although SAE J3114 lists ‘driver monitoring and feedback’ as a

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[41] SAE J3198: Driver Drowsiness and Fatigue in the Safe Operation of Vehicles - Definition of Terms and Concepts; issued October 2020

[42] SAE J2944: Operational Definitions of Driving Performance Measures and Statistics; issued June 2015, reaffirmed February 2023

[43] SAE J2396: Definitions and Experimental Measures Related to the Specification of Driver Visual Behavior Using Video-Based Techniques; issued July 2000, revised May 2017, stabilised September 2023

[44] SAE J 3151: Relating Experimental Drive Distraction and Driving Performance Metrics to Crash Involvement - Definitions of Terms and Concepts; issued October 2018

[45] SAE J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles; issued January 2014, revised April 2021

[46] SAE J3114: Human Factors Definitions for Automated Driving and Related Research Topics; issued December 2016

topic that needs further investigation or research to define appropriate terminology and definitions. Defined terms include for example: automated driving system, dynamic driving task fallback, monitor the user, receptivity of the user, request to intervene, over-reliance, complacency, lack of receptivity, user state monitoring, user monitoring system, user monitoring and prompting system and driver engagement prompt.

With regard to driver monitoring in automated vehicles specifically, ISO/TR 21959-1[47] provides relevant definitions of terms and descriptions of concepts relevant to describe and design studies to assess the performance of drivers when transitioning from a higher level of automation to a lower one, including:

- General concepts for mental state related to automated driving (e.g. attention, task demand)
- Concept corresponding to automation related driver states (e.g. situation awareness, vigilance)
- Concepts corresponding to non-driving related driver states (e.g. visually distracted/loaded, mind wandering)
- Driving position and posture (e.g. hands occupied, out of driving position)

4.3.2 Research methods

The gaps identified in this report highlight that further research is needed before requirements can be implemented in law. Technical standards can enable consistent approaches to research in order to ensure high quality outputs of comparable nature between different studies.

SAE J2944 provides guidance for the measurement and reporting of driving performance measures, including considerations to be made when designing the research questions and when separating automated from driver actions, and guidance on how to perform accurate measurements and eliminate sensor noise, as well as good practice for reporting of results.

Similarly, SAE J2396, provides guidance on the design of experiments to measure visual distraction and on analysis techniques, including the development of a glance allocation measure database, specification of independent variables and short guidance on testing the validity of data.

SAE J3198 proposes a selection of metrics suitable to assess drowsiness and fatigue in research contexts:

- Subjective assessments (Karolinska Sleepiness Scale)
- Driver vigilance
- Driving performance metrics (steering behaviour, lane position, speed variability)
- Physiological measures (electroencephalography, electrooculography, heart rate, blood oxygen saturation, electrodermal activity)

[47] PD ISO/TR 21959-1:2020: Road vehicles — Human performance and state in the context of automated driving. Part 1: Common underlying concepts; published 31 January 2020

- Driver behaviour video monitoring (blinking and eye closure, head/facial movement and yawning, human annotation of video)
- Hybrid systems

SAE J3151 proposes a framework for conceptualising the relation between measures and metrics of driver distraction/driving performance and collision involvement. It defines terms and concepts to enable structured research to link distraction/driving performance metrics with separately studied collision involvement metrics. The standard also provides some general guidance for related research work.

ISO/TR 21959-2[48] provides information to enable research into driver's takeover performance when transitioning from a higher level of automation to a lower one. This could be useful in the context of developing evaluation procedures for DSM system in automated vehicles. The standard described human factors that influence driver readiness/availability for a request to intervene, including:

- Sitting position and posture
- Engagement in non-driving related activities
- Drowsiness
- Mind wandering
- Situation awareness
- Operating state/mode awareness
- Attentiveness
- Receptivity

The standard also provides considerations for the design of studies to evaluate human performance in safety-critical transitions scenarios, including:

- how to derive and document test scenarios,
- a taxonomy of human performance measures, and
- typical test environments.

4.4 Conclusions on testing and validation approaches

Various technical regulations and voluntary consumer information protocols relating to driver monitoring systems for conventional vehicles and automated vehicles (SAE levels 2 and 3, which rely on driver supervision or fallback readiness) were reviewed. These documents included requirements for the detection of various states of driver impairment and detection of driver availability to take over the driving task, specified the required system reactions to impaired or unavailable drivers (e.g. warnings) and set out test and

[48] PD ISO/TR 21959-2:2020: Road vehicles — Human performance and state in the context of automated driving. Part 2: Considerations in designing experiments to investigate transition processes; published 31 January 2020

assessment methods. The review did not, however, identify technical standards that define test methods or other performance evaluation methods for DSM systems.

The driver impairment states covered by the requirements in regulations and protocols were:

- Drowsiness/fatigue
- Microsleep, sleep
- Visual distraction
- Phone use
- General non-fatigue related impairment (e.g. alcohol, drugs)
- Unresponsiveness

Regarding distraction, it should be noted that the existing requirements only cover visual distraction (i.e. looking away from the road scene) and phone use, but not other types of distraction (such as cognitive distraction). The most specific requirements are contained in the EU regulation on Advanced Driver Distraction Warning Systems, which defines geometric areas for the gaze direction of the driver that indicate long-lasting distraction (longer than 3.5 seconds). The Euro NCAP Driver Engagement Protocol covers a wider range of distracted states (including short visual distractions and phone use) and leaves more freedom to manufacturers how exactly to detect these driver states (specified e.g. as 'glance away from road for 3-4 seconds rather than defining an exact geometric area). Other documents leave performance details to the manufacturers entirely.

Regarding fatigue, the EU regulation on Driver Drowsiness and Attention Warning Systems and Euro NCAPs Driver Engagement Protocol set out the most specific requirements with stipulating a drowsiness threshold that needs to be detected: KSS 8, i.e. "sleepy, some effort to keep awake". It is left to the manufacturers to decide how to achieve detection of these thresholds. Euro NCAP additionally requires detection of microsleep and sleep states based on duration of eye closure. Other documents leave performance details relating to fatigue entirely to the manufacturers.

The Euro NCAP Driver Engagement protocol (via Technical Bulletin SD 201) allows a relatively low rate of true positives – correctly identifying that a given driver state such as fatigue has occurred. These range from 40% for sleep, microsleep and drowsiness to 80% for long-duration distraction events. In contrast, relatively low rates of false alerts are encouraged, e.g. from 1 false alert per 2 hours of driving for drowsiness, and 1 false alert for every 20 hours of driving for long and short duration distraction, to 1 false alert for every 100 hours of driving for microsleeps. This implies that more weight is being put on avoiding false alerts, possibly due to concerns that the driver may deactivate the system, which would effectively drop the true positive rate to 0% and eliminate the safety benefits of the system – even compared with a 40% detection rate.

The criteria stipulated in the various regulations and protocols to assess driver availability included:

- Visual disengagement
- Motoric disengagement (i.e. hands off steering wheel)

- Lack of input to driver-exclusive vehicle controls
- Eye closure
- Lack of conscious head or body movement

Motoric disengagement is judged based on drivers holding the steering wheel, detected either via capacitive sensing in the steering wheel or detection of the torque created by driver's hands. The latter systems can sometimes be fooled by attaching a mass to the steering wheel; countermeasures against this system defeat strategy are tested in the IIHS Safeguards For Partial Driving Automation Protocol. Again, a lot of design freedom is given to manufacturers for system implementation.

System test and assessments are typically done via an audit and/or spot check approach, where the technical service or test laboratory reviews the design decisions of the manufacturer and checks that the system performs as expected. However, no specific performance thresholds are set in regulation or protocols for the detection of impairment of driver availability; i.e. no true positive or false positive rates under real-world conditions are stipulated. The EU regulation on Driver Drowsiness and Attention Warning stipulates a statistical method to derive system performance metrics, although only from a small group of test participants. The Euro NCAP Driver Engagement Protocol makes the most specific requirements regarding the diversity of drivers for which the system needs to be operational (relating to e.g. age, sex, skin complexion, etc.).

The interventions to be taken by the vehicle in case of driver impairment or driver unavailability include:

- In-vehicle warnings (visual, haptic, acoustic)
- Adaptations to safety system sensitivity (e.g. earlier intervention of advanced emergency braking system)
- Deactivation of automation system

The warning and deactivation strategies vary slightly between the individual regulations and protocols, and it is not documented how the warning strategies prescribed (warning modalities, time to warning, etc.) were developed and whether they were shown to be effective. It should be noted that none of the regulations or protocols reviewed included fleet management elements, where alerts would be transmitted to a back office and allow a fleet manager to address recurring issues. Euro NCAP's Driver Engagement Protocol is the only protocol that requires adaptations to safety system sensitivities.

This review did not identify technical standards that define test methods or other performance evaluation methods for DSM systems, neither in the context of automated driving nor fatigue or drowsiness monitoring in conventional driving. However, some foundational standards were identified and summarised that could be useful for future work developing such methods by providing definitions and descriptions of relevant research methods.

Additionally, two standards currently under development were identified that should be analysed for their relevance once published:

- ISO/AWI PAS 11585: Road vehicles --Partial driving automation — Technical characteristics conditional handsfree driving systems

- ISO/TS 5283-1 and -2: Road vehicles — Driver readiness and intervention management — Part 1: Partial automation (Level 2) / Part 2: Conditional automation (Level 3)

5 Stakeholder engagement

5.1 Introduction

A targeted stakeholder engagement was undertaken to provide additional insight into the state-of-the-art for DSM systems, and how the performance of DSM systems can be tested and validated. Ensuring a minimum performance of DSM systems is important for potential future initiatives to encourage fleets to fit and use DSM technologies, for example to ensure that systems deliver robust alerting to drivers (and potentially fleet managers) and that real-world reductions in the number of fatigue and/or distraction related incidents are achieved. Robust determination of system performance is also desirable to support the introduction of SAE Level 3 automated driving systems/features, helping to ensure that drivers meet the behaviours assumed in the manufacturers type-approval safety argument. The engagement with system developers and suppliers also provided an opportunity to get insight into the potential future development direction for DSM systems and whether the industry is likely to develop DSM standards beyond those identified in Section 4.3.

5.2 Type of behaviour detected by system

All of the suppliers interviewed had camera-based DSM products available in the market. The systems described by the stakeholders can detect a wide range of driver behaviours and states. These include fatigue and drowsiness (e.g. yawning, blinking, prolonged eye closure), attention and distraction (e.g. gaze direction, looking away from the driving environment), mobile phone use, smoking, and seatbelt use. Some systems also monitor driver availability and position, which could be used to adjust airbag deployment and restraint systems. The systems detect various types of visual distractions, including long and intermittent gaze away from the road, looking at a mobile phone, and looking in mirrors. They can also identify behaviours such as eating and watching videos on phones. The quality of the detection can depend on the camera's field of view (FOV): a narrower FOV may give more precision on gaze direction and eye-closing behaviour associated with fatigue, while a wider FOV may give more flexibility in covering different driver sizes and postures, and a wider range of behaviours such as being able to identify holding a mobile device. Configurable thresholds, such as distraction duration, help tailor the system to specific needs.

The systems measure driver availability, attention, and fatigue using a combination of methods. Gaze tracking, head position, eye closure patterns, and body posture are commonly used to infer attention and fatigue. Fatigue is measured through eye closure detection, yawning, and blinking patterns. In cases where eye tracking is blocked, systems may fall-back to head pose in order to estimate when the driver’s attention is away from the driving environment. Additionally, some aftermarket systems additionally use manager observation, telematics data, and cameras with views external to the vehicle (analogous to the system described in Section 3.2.1) to provide feedback on driver distraction and fatigue.

One operator stakeholder did not have in-cab cameras installed, but is working to introduce them in the future. Currently, they use external cameras and telematics systems to track behaviours like lane departure, harsh braking, and harsh cornering for signs of drowsy driving behaviours. The same operator’s fleet safety management protocols also include working with drivers on signs of drowsiness and the helping to address the causes of fatigue.

5.3 Information provided to drivers and fleet managers

The information provided to drivers varies. For OEM-systems (fitted as part of the production of a vehicle), the HMI is controlled by the OEM, not the supplier. This means that the type of alert (audible, visual and/or haptic) is determined by the OEM and may vary from manufacturer to manufacturer, or even for different models from the same manufacturer. The HMI and the information provided to drivers by OEM DSM systems is constrained to some extent by the need to comply with the EU regulations (see Section 4.1.1 and 4.1.2), and the desire to achieve points in the Euro NCAP rating. Additionally, systems can provide a driving ‘score’ (including other information such as harsh braking and harsh cornering). For the OEM market, such a score is most often used with novice drivers – for example, parents may be able to set limits on speed and power for novice teenage drivers, and view various driving metrics.

Aftermarket systems typically offer configurable alerts through visual, audible, and/or haptic feedback. Systems may provide alerts solely to the driver, or they can be configured also to provide information to a fleet manager. The information that can be provided fleet managers varies by supplier, by the configuration of systems, and the agreements between operators and drivers. Information may be as simple as a copy of the alert provided to the driver, through to comprehensive telematics data with video clips relating to detected events, categorised by event type (e.g. fatigue or distraction). Fleet managers may be able access reports and analytics on driver behaviours and receive customisable alert escalations. Real-time monitoring of driver alertness is available in some systems, though data sharing depends on privacy regulations and agreements. Telematics data provides insights into vehicle location, speed, and sudden manoeuvres, and helps track drivers' hours and compliance with working time regulations.

Suppliers noted that DSM system performance varies significantly depending on the type of alertness behaviour being detected. They reported that camera-based systems can offer higher sensitivity then systems based on steering inputs. The latter require an initial ‘learning’ phase each time the vehicle is started, which means they are not effective at the beginning of a drive – unlike camera-based systems, which can be effective immediately. Indeed, for system validation, Regulation (EU) 2021/1341 allows a maximum 30-minute learning phase following initiation of DDAW system, which itself occurs a maximum of 5-minutes after the vehicle first exceeds a speed of 70 km/h (see Section 4.1.1).

Most suppliers considered that visual distraction detection was more mature and robust, with drowsiness detection being more challenging. One supplier, however, reported that eye-closure based fatigue detection was highly robust compared with other driver states. Factors such as individual differences, camera resolution, and lighting conditions can impact performance. As noted above, some operators report using existing external camera and telematics data systems to support the identification of drowsy driving, e.g. by identifying sudden manoeuvres and position within the driving lane.

The stakeholder feedback suggests that the benefit of DSM systems in heavy vehicle fleet applications is attributed to both the direct monitoring of drivers and the follow-up actions by fleet managers, with one stakeholder indicating that approximately two-thirds of the benefit came from providing information to the driver and one-third from additional data to fleet managers. However, the variability of systems and their configurations, and the variability in the ways in which fleet managers use the information, makes it difficult to attribute specific benefit values to different aspects of the process.

While no concrete evidence linking DSM systems to behavioural changes was identified by stakeholders, a trend in Euro NCAP of moving towards system interventions and minimising false-alert warnings to drivers was reported – i.e. using knowledge on the alertness and attention level of a driver to adjust the sensitivity of collision avoidance systems such as advanced emergency braking and lane keep assistance. Real-time driver warnings combined with fleet manager intervention are considered most effective, with features like vibrating seat alerts reducing repeat fatigue events. Positive outcomes have been observed from external cameras, with drivers becoming more accepting of monitoring for protection in disputes. Managers play a crucial role in observing and following up on driver behaviour.

5.4 Industry standards and validation

Validation of system performance is primarily conducted in-house, with ongoing efforts to standardise methods for improved reliability. Real-world data collection, large-scale data analysis, and client-run trials are common practices. However, there is a lack of published data on collision or injury reduction, and most performance data is held by OEMs and fleet operators rather than the system manufacturers. Fatigue detection is particularly challenging to test in controlled conditions, often relying on indirect assessments like the Karolinska Sleepiness Scale (KSS). Some companies advocate independent third-party validation and standardised testing to ensure accuracy and effectiveness.

Currently, there are no widely accepted industry standards specifically for driver alertness monitoring. However, organisations like the UNECE WP.29, Euro NCAP, and ISO are actively developing regulations and high-level concept standards. Existing regulations, such as (EU) 2021/1341, set a baseline but more stringent requirements may be possible with modern systems. Some standards exist for OEM-integrated systems, and there is a general move towards camera-based monitoring due to its superior sensitivity and performance.

There is sufficient technical knowledge to support the development of standards, but achieving consensus on performance assessment methods is challenging. Ongoing discussions in UNECE and the European Commission aim to standardise testing methods, with expectations for more regulations by 2029. Industry collaboration is needed to develop performance benchmarks and ensure repeatable, standardised test procedures. Concerns remain about the quality of aftermarket safety system installations and the regulation of third-party systems.

5.5 Future directions

The performance of driver availability, attention, and fatigue monitoring systems is expected to improve significantly in the future. There will be a shift towards camera-based systems and away from steering-based monitoring (or possibly hybrid systems combining both for maximum effectiveness), with more integration with ADAS to dynamically adjust sensitivity. The fusion of internal and external sensors will enhance detection capabilities, and future systems may include alcohol or drug impairment detection and vital sign monitoring for medical emergencies.

Advancements in artificial intelligence training data and integration into vehicle dashboards will further improve accuracy, with OEM adoption expected to increase. More cameras in vehicles will enhance detection accuracy and help to overcome limitations such as infrared-blocking sunglasses. More broadly, future real-time occupant monitoring could improve restraint systems, adjusting airbag deployment based on driver positioning to reduce injury risk in crashes.

Fitment of DSM systems to heavy duty vehicles will become mandatory by 2027, with aftermarket systems being less integrated than OEM solutions (e.g. it is more difficult for an aftermarket system to interact with sensitivity settings for collision avoidance ADAS). Legal variations between countries impact system requirements, and there is a growing focus on HMI and driver acceptance to avoid system deactivation due to excessive warnings. Challenges include camera placement and variability in drivers, which affect system performance. Industry collaboration was encouraged to develop standardised testing and performance benchmarks.

Companies are exploring new sensor technologies to improve tracking and enhance restraint system performance. However, there is caution about the need to balance the safety benefits DSM with not being perceived as "spying" on drivers.

6 Roadmap

A review of information sources identified through the rapid evidence reviews was undertaken to identify likely timescales for the introduction of new DSM capabilities, testing methods, validation data and performance criteria. This was complemented by information from the stakeholder interviews to give an overview of expected developments and the likely timescales for those developments.

6.1 Euro NCAP

In September 2017, Euro NCAP published its 2020-2025 Roadmap[49]. The roadmap envisaged:

> *"An incentive for driver monitoring systems that effectively detect impaired and distracted driving and give appropriate warning and take effective action e.g. initiating a safe evasive manoeuvre, limp home mode, increased increasing sensitivity of Electronic Stability Control, lane support, speed, etc. Implementation in the overall rating is planned in phases, starting with systems that have already entered the market."*

The roadmap notes that the assessment will "evolve around how reliably and accurately the status of the driver is detected and what action the vehicle takes based on the information". It also notes the future potential to adapt intervention criteria to individual drivers, further enhancing the effectiveness of systems.

The Euro NCAP Vision 2030 roadmap[50], published in November 2022 (shortly before the Euro NCAP Driver Engagement protocol (see Section 4.2.1) was implemented) indicates the further plans for assessment of driver – and other occupant – state monitoring:

> *"A big leap in the assessment of in-cabin monitoring technology is planned with the addition of rating incentives for Child Presence Detection systems to protect children left accidentally in cars, and Direct Driver Monitoring systems, that monitor driver fatigue, distraction e.g. by phone use, and sudden sickness."*

Euro NCAP Vision 2030 details further developments in DSM beyond the requirements set out in their 2023 protocols:

- Enhanced detection of drowsiness
- More efficient and robust systems, encouraged by
    - Expanded 'noise variables' such as extreme seating positions and specific noise variables for each driver state
    - Alternative approaches to identifying mobile phone use and linking situation awareness to activation of advanced driver assistance systems
    - Ensuring that in-vehicle HMI minimises unnecessary distraction, builds user trust in systems, and promotes acceptance

[49] euroncap-roadmap-2025-v4.pdf

[50] Euro NCAP Vision 2030: a safer future for mobility

- Enhanced detection of impaired driving, especially due to alcohol and sudden sickness
- Possible future detection of cognitive distraction

More widely, the roadmap envisages increased scope for occupant classification:

- Adapting airbag and seatbelt load limiter parameters to occupant size, weight and body type
- Out-of-position optimisation of seatbelts and head restraints from detected occupant posture
- Enhanced occupant information for advanced eCall functionality
- Enhanced child presence detection to prevent heat stroke deaths

The roadmap notes that some of these future assessments, and indeed the driver engagement monitoring implemented in 2023, may prove challenging for manufacturers:

> *"During negotiations on these protocol updates, several items needed to be postponed to a rating revision at a future date and sometime requirements were softened to ease the introduction of a new technology. Nevertheless, the challenges of the 2023 rating requirements will still be insurmountable for some manufacturers."*

Driver awareness monitoring, including impaired driving and cognitive distraction are envisaged for introduction in the 2029-2032 timeframe, as part of planned updates to the Safe Driving element of the star rating.

6.2 NHTSA

6.2.1 Research

NHTSA have an extensive vehicle safety research programme, including a human factors research stream that includes topics relevant to driver fatigue and attention, for example:

- In-vehicle interface design – to reduce driver workload and eyes off road time
- Driver Monitoring Systems – to detect distractions in real time and deploy intervention strategies
    - Including how to assess the effectiveness of DSM systems
- Secondary device usage – to understand secondary device usage and ways to mitigate it
- Partial Driving Automation Systems – to support appropriate driver engagement during SAE Level 2 system use by drivers

A detailed overview of the research programme was provided at NHTSA's annual Safety Research Portfolio Public Meeting in October 2024[51]. Some of the research presented is

[51] NHTSA Safety Research Portfolio Public Meeting: Fall 2024 | NHTSA (see the Day 2: Human Factors session)

being undertaken by NHTSA, and some via contracts with research organisations. Highly relevant research strands include:

- Two projects on driver distraction monitoring, one for general vehicles and one for vehicles with SAE Level 2 driver support systems
    - It was noted that the research is being undertaken following the 'Bipartisan Infrastructure Law', which requires NHTSA to research on installation and use on motor vehicles of DMS to minimise or eliminate driver distraction, driver disengagement, automation complacency by drivers, and foreseeable misuse of ADAS
- Driver interactions with SAE Level 2 automated systems, examining SAE Level 2 system HMI effectiveness and responses to take-over requests
- A review of driver distraction mitigation technology available in the US market, including OEM and aftermarket systems
    - Including a small study to assess the performance of some systems
- Applied research to develop new test procedures for drowsiness monitoring technologies, including protocols, assessment metrics and performance criteria
    - The knowledge review was stated to be complete, with pilot driving simulator and track-based tests beginning autumn 2024
- An exploration of eye glance metrics associated with crash risk and distraction state detection metrics

It was noted that a roadmap for further work and application of DSM monitoring technologies would be published soon at the docket for the meeting[52], but this was not yet available at the time of writing. It is recommended that the NHTSA research programme is monitored to ensure that the expected research publications are taken into account.

6.2.2 NHTSA New Car Assessment Program (NCAP)

NHTSA recently published an updated rating scheme incorporating a number of advanced driver assistance systems (adding forward collision prevention, pedestrian advanced emergency braking, and blind spot technologies, and updating lane keeping support), as well as roadmaps for mid-term and long-term future NCAP developments[53] (NHTSA 2024). The long-term NCAP roadmap lists driver monitoring systems for distracted and drowsy driving as being in the research phase from 2023-2027, request for comments (RFC) phase in 2028, final decision in 2029 and implementation (if confirmed in 2029) in Q4 2031, as shown in Figure 1.

[52] Regulations.gov/NHTSA-2024-0040-0001

[53] www.govinfo.gov/content/pkg/FR-2024-12-03/pdf/2024-27447.pdf

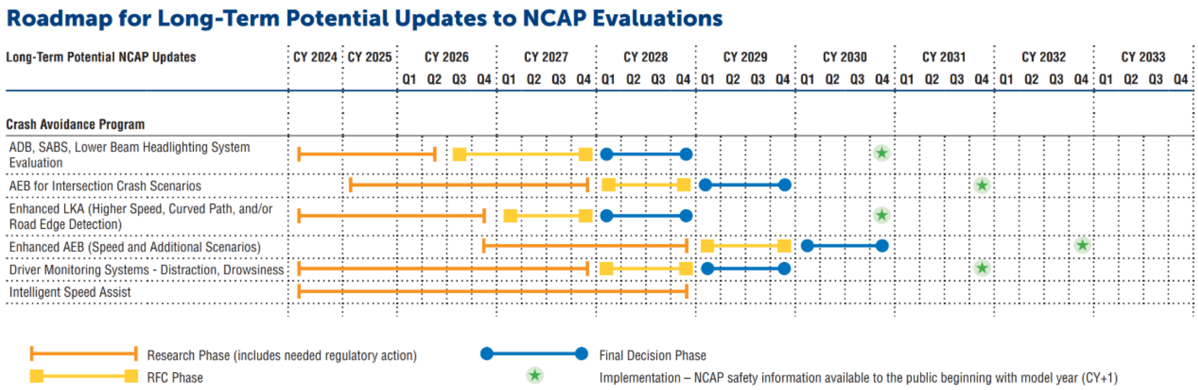

Figure 1: Excerpt from NHTSA long-term NCAP roadmap (NHTSA, 2024) showing timescales for evaluation and introduction of driver monitoring systems for distraction and drowsiness

The research and RFC phases will need to demonstrate the following four prerequisites (NHTSA, 2004):

1. The update to the program addresses a safety need
2. There are system designs that can mitigate the safety problem
3. Existing or new system designs have the potential to improve safety
4. A performance-based objective test procedure exists that can assess system performance

6.3 Stakeholder engagement

As noted in Section 5.5, stakeholders who develop DSM systems generally considered that detection of fatigue and distraction behaviours was well addressed by current systems and that only marginal improvements in performance could be achieved in the next few years. They expected that efforts over the next 1-3 years would focus on improving the implementation of DSM systems in vehicles, especially the improved integration of driver state classification and ADAS to adjust the sensitivity of ADAS systems when a degraded driver state is identified. For vehicles with advanced SAE Level 2 driver support systems and SAE Level 3 automated driving functions, this could include performing minimum risk manoeuvres in case of persistent fatigue, distraction, or if an unresponsive driver is detected. Other areas of focus would include research to optimise the HMI of systems to ensure driver engagement.

Unusually, the wider development of standards for the testing and validation of DSM system performance has lagged regulatory and consumer information developments. Those stakeholders who expressed a view did not expect significant activity to develop new standards over the next 12 to 24 months[54], especially given the focus on updating UN

[54] Note, however, the finding in Section 4.4 that two potentially relevant ISO standards (ISO/AWI PAS 11858 and ISO/TS-1 and -2 are listed as in development

regulatory requirements for drowsiness and distraction detection, and evolving Euro NCAP protocols.

6.4 Conclusions

Euro NCAPs roadmaps show intended and possible updates to DSM system evaluation between 2025 and 2030. These expand the scope of DSM beyond the remit of this study, e.g. to optimising restraint systems for different occupant statures and postures, including occupants who are out of position (e.g. front seat passenger with their feet on the dashboard). The new driver engagement protocols due to be implemented from January 2026 provide increased focus on minimising false alerts and indicate the expected true positive rate for different driver states. For fatigue, a true positive rate of only 40% is required, which may be indicative of the challenge of identifying drowsiness in vehicles in real-world driving. It is recommended that this requirement is monitored to track how it is adapted to improving system performance.

NHTSA's comprehensive research programme is expected to deliver a number of highly relevant results in the next 12-24 months, aligned with the published roadmap for US NCAP, and publication of results should be monitored. Nevertheless, even if the research shows that NHTSA should proceed to introduce DSM evaluation for drowsiness and distraction in US NCAP, a decision is not scheduled until 2029 and implementation in the star rating scheme would not happen until Q4 2031. It is not, therefore, assumed that US NCAP will push the development of DSM technology in the near- or medium-term.

Finally, stakeholders indicated that suppliers and OEMs are currently highly focused on evolving regulatory and Euro NCAP requirements and that development of other standards is not envisaged in the next 12-24 months. If a standardised approach to assessing aftermarket DSM systems for heavy vehicle fleets is desired, for example to support fleets in choosing systems with a minimum performance, specific activity to co-ordinate and encourage development of a standard is recommended.

7 Discussion

7.1 DSM technology status

As shown by the rapid deployment of DSM technologies in the passenger car fleet, and the rapidly developing regulatory and consumer information landscape for DSM systems in conventional vehicles, partially automated vehicles (SAE Level 2) and automated vehicles (SAE Level 3) vehicles, there is considerable interest in developing systems that can support drivers in paying good attention to the driving environment and avoiding drowsy driving, both of which increase the risk of a collision.

Drowsiness detection and alerting has traditionally focused on higher-speed roads such as main roads and motorways, which can involve long periods of driving with relatively low attention demand – i.e. ‘boring’ driving conditions that are considered more likely to lead to a drowsy driving state. Systems were typically not intended to operate in complex urban environments where the risk of drowsy driving was considered to be lower, at least for drivers of private passenger cars. In part, this also reflects the technology available when early DSM systems were introduced, because traditional vehicle-based drowsiness detection methods (e.g. based on steering inputs or lane position) are not as reliable at lower speeds. Camera-based drowsiness detection systems would not be subject to the same technical limitations and could support alerting drivers of drowsiness in a wider range of situations.

Drowsiness (or fatigue) detection as applied in road vehicles is generally indirect and is based on vehicle behaviours, steering inputs or image analysis. More direct measurement of drowsiness or fatigue may be possible in a laboratory setting, but generally requires action from the driver – e.g. wearing a device or participating in a calibration routine. This is unlikely to be practicable for OEM systems, but may be practicable in the future for fleet applications, and potentially could improve the accuracy of alerts.

Current DSM systems for vehicles with SAE Level 2 driver support systems (also known as partial automation) can assess driver engagement either via hands on the steering wheel or camera-based posture and gaze direction analysis. Having hands on the wheel is not a good indicator of attentiveness in itself, and it is widely reported that torque-based systems are easily fooled. Visual attention on the road, assessed by a camera-based system, is considered preferable – and essential for a hands-off partial automation system such as GM Super Cruise or Ford Blue Cruise. However, this is also not perfect, because drivers may ‘look, but not see’ – known as cognitive distraction. Further development of camera-based systems is envisaged to try and address cognitive distraction.

7.2 Vehicle regulations

The EU type-approval regulations on drowsiness DSM (Regulation (EU) 2021/1341) and distraction DSM (Regulation (EU) 2023/2590) for M- and N-category vehicles are being phased in since 2022. By mid-2026, these regulations will ensure that all new cars, vans, buses, coaches and trucks in the EU and Northern Ireland will have DSM for drowsiness and distraction, with a minimum level of performance defined for each; however, there is no requirement that they be fitted to vehicles sold in GB. It should be noted that there are no regulations applicable to systems sold on the aftermarket.

Regulation (EU) 2021/1341 is intended to allow manufacturers to continue to fit the kinds of fatigue detection and alerting systems that they have been using for many years, e.g. using steering inputs or lane positioning – the focus is on ensuring fitment to all vehicles rather than requiring a new technology to be developed and ensuring a minimum level of performance. The required sensitivity of the system at detecting a driver state defined as ‘sleepy, some effort to keep awake’ is at least 40%. Manufacturers are encouraged to reduce false positive detections but no quantitative limits on false alerts are applied. Manufacturers are able to combine the vehicle-based analysis with other approaches into hybrid systems to deliver the required performance. This means that as manufacturers increasingly fit driver-facing cameras for attention monitoring (either as required by Regulation (EU) 2023/2590 or in support of ADAS such as Ford Blue Cruise and GM Super Cruise), they may use the camera system to support fatigue detection. Based on the regulation, manufacturers may also use additional physiological measures, but no such system has been brought to market yet.

Regulation (EU) 2023/2590 does in practice require manufacturers to fit driver-facing cameras to analyse the driver’s gaze direction. The warning criteria are linked strictly to gaze duration directed at a defined geometric area. For type-approval, the system needs to demonstrate this reliably in a spot check procedure. Again, manufacturers are encouraged to reduce false positive detections but no quantitative limits on false alerts are applied in the regulation.

One potential limitation of the regulated DSM systems is that they must operate as a closed-loop system, which potentially limits fleet applications of the technology built into the vehicle. However, the guidance Q&A document[55] published alongside 2023/2590 includes the clarification that the restriction is only “*related to the ADDW System. It is not excluded that other systems uses the same hardware, e.g. Camera and if they are compliant with GDPR*”. In other words, a single DSM system can be used for compliance with Regulations (EU) 2021/1341 and 2023/2590 operating as a closed-loop system, and provide additional functionality – e.g. within a fleet management system – provided that the additional functionality operates within the wider legal requirements such as GDPR.

At UNECE level, the Informal Working Group (IWG) on Driver Drowsiness and Distraction Warning Systems (DDADWS) has been working since July 2024 to implement UN Regulations on drowsiness and distraction DSM systems. The 00 series of amendments are intended to be aligned with the EU type-approval regulations, with a target to deliver draft regulations to GRSG at its October 2025 session. It is intended that the UN regulations will include some clarifications with regard to the EU regulations (see the European Commission’s FAQs referenced in Section 4.1.1 and 4.1.2), but will be fundamentally be the same and with no increases in stringency[56]. 01 series of amendments are also envisaged, bringing improvements to the performance requirements and taking into account any relevant cost-benefit analysis. The 01 series of amendments are scheduled for delivery to GRSG at its

[55] ADDW Q&A on DocsRoom - European Commission

[56] See IWG DDADWS report to GRSG, 7 April 2025: Status Report Driver Drowsiness and Distraction Warning Systems

October 2026 session[57]. At the time of writing, the IWG have not defined what may be included in the 01 series of amendments, but based on the information in this review options could include limits on false-positive detections (false alerts to the driver) and integration with the ADAS of the sort that Euro NCAP is encouraging (increasing the sensitivity of advanced emergency braking and lane keeping systems when a distracted or drowsy driver state is detected).

In other world regions, China has a national regulation on DSM in place since 2023, and the USA are considering regulating on DSM systems for impairment by alcohol, distraction and drowsiness in the future, but possibly only in the 2030s.

For DCAS, i.e. SAE Level 2 driving automation systems, UN Regulation No. 171 requires driver monitoring for motoric engagement (hands on steering wheel) and visual engagement (for example based on gaze direction). For SAE Level 3 automated vehicles, UN Regulation No. 157 on ALKS requires a driver availability recognition system. The regulation only gives examples of 'availability criteria' that can be monitored by the system, but leaves the design to the discretion of the manufacturer. The system's capability must ultimately be demonstrated to the satisfaction of the technical service. The draft UN Regulation for ADS contains a simple stipulation for a monitoring system to assess whether the fallback user is available and in a position to resume control.

7.3 Consumer information protocols

While the DSM system regulations discussed above do not apply immediately in GB, Euro NCAP will encourage fitment of systems also in GB. Note, however, that none of the rating schemes apply to aftermarket systems and thus there is no mechanism for consumers (including fleet managers) to objectively compare the performance of such systems.

Euro NCAP's approach to assessing DSM technology and the interaction with the driver has progressed rapidly over recent years. DSM assessment was introduced in 2020 as 'Euro NCAP Advanced' reward, based on assessment of a technical evidence dossier provided by the manufacturer. This was followed by a specific DSM assessment protocol in 2023, with an updated assessment protocol published and due to be implemented in January 2026.

The Euro NCAP protocol pushes the technology beyond that of the regulatory baseline provided by the EU DSM system regulations. This includes the performance of systems compared to the regulatory baseline and the types of distraction to be detected by the system. In addition to warnings issued to the driver, the Euro NCAP protocol further encourages manufacturers to adjust the sensitivity of ADAS fitted to the vehicle. For example, forward collision warning and advanced emergency braking systems should react at least 200 ms earlier if an undesirable driver state is detected, and the sensitivity of lateral support systems such as lane departure warning and lane keeping assistance systems can also be increased. This is intended to account for longer driver reaction times when distracted or impaired.

[57] unece.org/transport/documents/2024/10/informal-documents/australia-draft-terms-reference-and-rules-procedure (GRSG-128-38-Rev.2)

With the 2026 protocol, Euro NCAP has introduced recommendations on the rate of false alerts (rate of false positive detections per driving hour) and on true positives (minimum percentage of distraction or impairment events that should be detected and alerted). The recommendations on false alerts attempt to ensure a low rate of false alerting, because false alerts may cause drivers to switch the DSM system off. All types of distraction have a maximum false alerting rate of once per 20 driving hours. Drowsiness and non-fatigue impairment have a maximum false alerting rate of once per 2 driving hours, microsleeps once per 100 driving hours, sleep once per 200 driving hours, and unresponsive driver once per 1000 driving hours. The recommended true positive rate is 80% for long distraction events; 60% for short distraction events (visual attention time sharing), phone use and unresponsive driver; 40% for drowsiness, microsleep and sleep; and undefined for non-fatigue impairment. Together, these recommendations encourage a good rate of alerting (and therefore a good safety benefit compared with not having a DSM system), while reducing the risk of false alerts.

Note that these accuracy levels are still considerably lower than rates described as achievable in research papers in laboratory tests. Further note that the Euro NCAP protocol is comprehensive in assessing the breadth of system capabilities (i.e. focus on a pass/fail assessment of which driver behaviours can be detected with a certain level of accuracy) but do not allow the consumer to directly compare the accuracy of different systems or encourage manufacturers to increase accuracy beyond the required level.

Some vehicles have ADAS that can respond safely to the extremely dangerous situation of an unresponsive driver, for example by bringing the vehicle to a safe stop in its lane when an unconscious driver is detected, which can further improve safety.

In the US, IIHS have published star ratings for ‘partial automation’ (SAE Level 2 systems with sustained lateral and longitudinal control of the vehicle – which are ‘eyes on’ and ‘brain on’ but may be hands on or hands off). The testing and rating protocols endeavour to promote systems that work with the driver to maximise engagement in the driving task and to minimise the risk that the driver over-relies on the partial automation system and minimise the possibilities of fooling the monitoring system.

Euro NCAP’s Highway & Interurban Assist Systems Protocol (applicable to SAE Level 2 systems) encourages hands-on monitoring and DSM for fatigue and distraction as described above. No protocol for SAE Level 3 systems, such as ALKS, exists in consumer information programmes. The testing and evidence Euro NCAP require for DSM systems could, however, provide an appropriate basis for future requirements in this area, with the focus being put on detecting states that would prevent a successful control fallback (such as sleep).

Euro NCAP have recently introduced a Safer Trucks rating scheme, and to date ratings for 9 long-haul trucks have been published, with ratings ranging from 1-star to 5-stars. Driver monitoring is included in the rating, but is relatively basic compared to the rating protocol for passenger cars. Currently, the driver monitoring for Safer Trucks does not have a formal test procedure but assesses an evidence dossier similar to that required for type-approval to Regulation (EU) 2021/1341. The assessment aims to encourage improved performance on correctly identifying drowsy driving compared with the regulation, while ensuring a low number of false alerts to the driver.

7.4 Driver variability and other noise variables

Euro NCAP assesses DSM systems' functionality within a wide range of 'noise variables' relating to driver characteristics (age, sex, stature, skin complexion, eye lid aperture), occlusion of relevant characteristics (lighting, eyewear, facial hair, hand on wheel, facial occlusion) and driver behaviours that may mask characteristics of fatigue or distraction (eating, laughing, singing, smoking/vaping, eye scratching/rubbing, sneezing). For some of these noise variables, Euro NCAP requires the system to remain fully functional; for some it requires to inform the driver if not functional; and for some (particularly most of the driver behaviours except talking), it only requires manufacturers to report on systems capabilities for protocol monitoring purposes.

The EU regulations for DSM systems do not include explicit requirements to that effect.

The original equipment DSM systems on the market for advanced ADAS (such as GM Super Cruise and Ford Blue Cruise) and SAE Level 3 conditionally automated vehicles (such as Mercedes Benz ALKS) all require to be able to determine head pose and eye gaze direction before the driving automation system can be engaged and throughout use of the system. Information available about the systems, e.g. in owner's manuals, note that very dark or infrared-blocking sunglasses may prevent the DSM system from working, and other noise variables such as hats or masks are also mentioned. If the driver monitoring camera is unable to identify the head pose and eye gaze direction due to noise variables, then the driver is unable to engage the ADAS or automated-driving function. This seems to be a common approach, relying on the fact that the relevant ADAS and automation functions are *optional* – that is, the vehicle manufacturer is not required to fit the systems, and the driver is not required to use them, so the manufacturer is able to rely to some extent on the driver fitting the technology, rather than the technology accommodating all drivers.

7.5 Evidence for the real-world performance of driver state monitoring systems

The comprehensive, large-scale reviews identified in the literature, e.g. Prendez *et al.* (2024) and Albadawi *et al.* (2022), identified a very large number of systems, using a wide range of different technologies. The reviews focused on the detection technologies available and their relative strengths and weaknesses (as determined from publicly available information), as well as measures and metrics that could be used to evaluate driver states. Some of the technologies were systems under development in academia, some were systems being developed for or deployed in production vehicles. Albadawi *et al.* quote accuracy levels of different technologies based on reported laboratory results by researchers, but neither Albadawi nor Prendez independently assessed the performance of individual systems.

For DSM system developers it is difficult to provide robust information on the real-world performance of their systems because the performance depends to some extent on the implementation of the system in a vehicle – and this is controlled by the vehicle manufacturer. For example, the effectiveness may depend on the ability of the DSM system to identify fatigue or distraction, and also on the HMI – the information provided to the driver and the way in which it is provided is likely to be influential on overall system effectiveness. OEM systems are also primarily informative, although they increasingly are used to tune the sensitivity of collision avoidance ADAS systems as well. Furthermore, real world testing of such systems is difficult because it would not be ethical for researchers to require participants to drive fatigued or inattentive on the public road.

Aftermarket systems were found often to be advertised with claims of strong reductions being observed in fatigue and distraction incidents after installation, but the scientific basis for these claims is generally not detailed and relies on non-public data. A public research project to assess the real-world effectiveness of aftermarket systems could be beneficial to allow fleet managers to compare the performance of different systems and also their overall benefit. Aftermarket systems directed at fleet users could allow a relatively straightforward study design with an easy way to compare the situation before and after installation with minimal confounding factors (e.g. no change to vehicles except system installation, predictable use patterns of fleet vehicles). However, large subject numbers would be required to arrive at a statistically significant assessment of the impact on collision event incidence because of the rarity of collision events.

In looking at research on driver engagement monitoring for SAE Level 2 automation systems (where the driver is still required to supervise the driving at all times), Prendez *et al.* reported studies showing that drivers using supervised automation 'frequently failed to respond promptly to an emerging threat, even if they had their eyes on the road and hands on the wheel', indicating that eyes on the road is not an assurance of cognitive engagement.

Prendez *et al.* also performed a technology review of six commercially available SAE Level 2 systems, and nine interviews with industry stakeholders (researchers and OEMs). The findings were complementary to the technology review and stakeholder engagement findings from the present study.

7.6 Stakeholder consultation

Stakeholders who supply passenger car OEMs indicated that testing and validation to ensure compliance with the EU regulations is a priority for their systems, along with compliance with upcoming Euro NCAP 2026 driver engagement requirements. One important element of this that stakeholders highlighted is further integration with existing ADAS in these vehicles, to increase the sensitivity of the ADAS such as advanced emergency braking and lane keeping assistance when distracted or drowsy driver state is detected. This is being encouraged by Euro NCAP, and consideration could be given to incorporating this in the 01 series of amendments to the upcoming UN regulations on drowsiness and attention warning. Of particular relevance would be consideration of application to heavy duty vehicles, which have mandatory advanced emergency braking and lane departure warning, because this approach could reduce the severity of (or even avoid) some very severe distraction and fatigue related collisions.

Aftermarket DSM in particular are very varied and highly configurable to meet the requirements of different fleet operators. Because systems vary and because individual systems may be configured to operate in different ways, it may be challenging to establish how DSM system performance relates to real-world reductions in collisions and other incidents related to fatigued driving or inattention. DVSA could consider working with aftermarket system suppliers to collect data that would help identify best-practice approaches and the relative benefits of different approaches.

The rapid evidence review highlighted the potential benefits of hybrid systems that integrate vehicle-based and camera-based systems to improve the robustness of driver state identification. Aftermarket systems are not integrated with the vehicle, so hybrid systems as envisaged in the review and implemented in some passenger cars would be challenging. One option is for aftermarket systems to include a forward-facing camera and use monitoring of lane position as a complement to a driver-facing camera-based system, thereby incorporating at least some elements of a vehicle-based system into a hybrid approach.

Given the lack of standards development expected by stakeholders over the next few years, DVSA may wish to consider encouraging and supporting the development of a test and validation standard appropriate for aftermarket systems. Such a standard could be used to help fleet operators select DSM systems with at least a minimum level of performance. Consideration could also be given to including fitment of DSM systems meeting performance requirements in the standard as part of the DVSA earned recognition scheme. One option for implementing this is to encourage aftermarket system manufacturers to provide a Euro NCAP-style information dossier for evaluation and spot-checking. Further research would be needed to determine how best to incorporate aftermarket-specific features such as fleet reporting and data review by trained alert validation specialists.

8 Conclusions and Recommendations

DSM, also known as driver engagement monitoring, has advanced rapidly over the last decade. Most suppliers interviewed and assessments identified in the literature reported that camera-based (and hybrid vehicle-based plus camera-based) systems are highly developed in terms of being able to detect fatigue and distraction states. Nevertheless, the true-positive rates encouraged by Euro NCAP are relatively low, at 40% for fatigue metrics, 60% for some distraction metrics (short-duration glances and phone use). This may indicate that system performance is still developing across the market, or it may be associated with a focus on minimising false-alerts to drivers – which is important, because there are no benefits from a DSM system that is switched off.

Less well developed are procedures to evaluate DSM system performance. The EU regulations and Euro NCAP protocol require a dossier of evidence from the vehicle manufacturer, with spot-checks performed by the test laboratory. The low rates of false positives for a number of relevant driver states that is encouraged by Euro NCAP would make some elements of testing very onerous for a test laboratory; for example, a false alert rate for unresponsive driver detection of 1 in 1,000 hours of driving is recommended. Drowsiness, microsleeps, and distraction may be more achievable, but it is difficult to safely assess fatigue detection in a test programme.

No standards for evaluating aftermarket systems were identified – these may incorporate features such as data review by a human operator and reporting of alerts to a fleet safety manager that are outside the scope of systems that are applied to private passenger cars or mandated by regulations. These additional features are reported to be beneficial, but no consensus on how to assess the additional benefit or performance was identified. This is a challenge, because it is not clear which systems should be encouraged to be fitted in heavy duty fleets. While aftermarket systems appear to have great potential to be a complementary tool to drivers' hours and tachograph requirements, this is currently difficult to evidence. Further work is needed to understand how to set and evaluate minimum performance requirements for aftermarket DSM systems to support fitment in heavy duty fleets.

Specific test standards, protocols and requirements for driver availability systems for SAE Level 3 automated vehicles were also not identified. However, the driver states that are relevant to these systems – such as remaining in the driver's seat, keeping the seat belt on and not falling asleep – may be more amenable to direct evaluation by a test laboratory.

The following recommendations are made for activities that would support DVSA in further considering DSM technologies over the next 1-2 years:

- Monitor and encourage the development of new industry standards for testing and validating the real-world performance of DSM systems
- Monitor developments in understanding how to optimise the HMI of systems to achieve the most effective driver engagement
- Monitor the recommended true-positive rates in the Euro NCAP driver engagement protocol, especially the 40% TP rate for sleep, microsleep and drowsiness, to track increases that may be indicative of improvements in detection rates (while maintaining low false-positive rates)

- Monitor the NHTSA research programme, which is expected to provide many relevant results over the next 12-24 months, as well as future NHTSA reports to congress
- Monitor the development of user-friendly biological / body-worn sensors, e.g. integrated in smart watches or dedicated wristbands, that could enhance fatigue detection in fleet applications
- Review ISO/AWI PAS 11585 and ISO/TS 5283-1 and -2 when they are published, to assess their relevance to DSM for heavy duty vehicles and/or driver availability monitoring
- Consider engaging with Euro NCAP (via DfT/IVS) to work towards enhancing the driver engagement monitoring in the Safer Trucks testing programme, to incorporate a wider range of relevant driver states and more explicit performance requirements
- Work with heavy vehicle OEMs and UN Informal Working Group on integration of regulatory DSM systems with ADAS, to increase the sensitivity of ADAS when a degraded driver state is detected, and potentially including limits of false-positive alerts to drivers
- Consider the potential benefits of encouraging integration of regulated DSM systems for heavy duty vehicles with fleet safety management systems, including possible requirements in GB regulations
- Given the lack of standards development expected by stakeholders over the next few years, DVSA may wish to consider working with suppliers to encourage and supporting the development of a test and validation standard appropriate for aftermarket systems
    - This could include the system beyond the cab e.g. expert review of alerts as part of an integrated driver state safety management system
    - Such a standard could be used to help fleet operators select DSM systems with at least a minimum level of performance
    - Consideration could also be given to including fitment of DSM systems meeting performance requirements in the standard as part of the DVSA earned recognition scheme
- Consider a public research study to assess the real-world effectiveness of aftermarket systems to better understand which aspects of system performance best influence improved driver performance and reduced collision risk
    - This could cover the HMI of alerts provided to drivers, integration with wider fleet safety management systems and driver state detection accuracy
    - Such a study would likely require working with system suppliers and fleets operators, and may require large-scale data collection to achieve statistically valid results

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Appendix A Research questions for stakeholder interviews

The following sections show the research questions used as a framework for the semi-structured stakeholder interviews conducted in the project.

A.1 Research questions for fleet operators

RQ1: What types of driver behaviours can your system detect?

- E.g. driver availability, fatigue, attention/distraction, mobile phone use, smoking, seat-belt use, …

RQ2: If your system detects visual distraction, what types of distraction are detected?

- E.g. intermittent gaze, long gaze

RQ3: Is system performance equivalent for all alertness behaviours?

RQ4: How do your systems measure driver availability/attention/fatigue (as applicable)?

RQ5: What information is provided to the driver?

RQ6: What information is provided to the fleet manager (if applicable)?

RQ7: How much of the benefit is because the driver is monitored, how much is due to the system as a whole including follow-up from the fleet manager?

- What is the evidence for this?

RQ8: How do you validate the performance of your system?

- Have you published data/findings e.g. collision reduction, injury reduction?

RQ9: Are there any industry standards available or in development that define performance for driver alertness monitoring (any aspects) or how to test this performance?

- If not, do you believe there is sufficient knowledge to support development of standards? Is the sufficient consensus on how to assess performance of systems?

RQ10: How do you see the performance of driver availability/attention/fatigue monitoring systems changing in the future?

- What are the likely timescales for this?

RQ11: Any other comments you wish to raise?

A.2 Research questions for suppliers

RQ1: What types of driver behaviours can your system detect?

- E.g. driver availability, fatigue, attention/distraction, mobile phone use, smoking, seat-belt use, …

RQ2: If your system detects visual distraction, what types of distraction are detected?

- E.g. intermittent gaze, long gaze

RQ3: Is system performance equivalent for all alertness behaviours?

RQ4: How do your systems measure driver availability/attention/fatigue (as applicable)?

RQ5: What information is provided to the driver?

RQ6: What information is provided to the fleet manager (if applicable)?

RQ7: How much of the benefit is because the driver is monitored, how much is due to the system as a whole including follow-up from the fleet manager?

- What is the evidence for this?

RQ8: How do you validate the performance of your system?

- Have you published data/findings e.g. collision reduction, injury reduction?

RQ9: Are there any industry standards available or in development that define performance for driver alertness monitoring (any aspects) or how to test this performance?

- If not, do you believe there is sufficient knowledge to support development of standards? Is the sufficient consensus on how to assess performance of systems?

RQ10: How do you see the performance of driver availability/attention/fatigue monitoring systems changing in the future?

- What are the likely timescales for this?

RQ11: Any other comments you wish to raise?

Status of Driver State Monitoring Technologies and Validation Methods

A review of technology maturity, legislation, and standards

Driver fatigue and distraction are highly associated with increased risk of a collision, and especially serious collisions due to late or absent pre-crash braking response from the driver.

This review seeks information on the performance of current Driver State Monitoring systems and evidence on how best to test and validate their performance. The project also aimed to understand the timescales for future developments in DSM technology and validation methods. Based on the evidence identified, a roadmap for the implementation of standards (regulatory or technical) for the performance of DSM was developed, as well as for the potential future use of the technology to complement current commercial vehicle driver's hours legislation and monitoring via digital tachographs.

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