EURO NCAP'S CURRENT AND FUTURE IN-CABIN MONITORING SYSTEMS ASSESSMENT

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ABSTRACT

Informed by international research and crash data, Euro NCAP has developed a Test and Assessment protocol to measure the performance of direct Driver State Monitoring (DSM) systems, which is implemented from January 2023 as part of the Safety Assist – Safe Driving protocol of the star rating. This protocol was developed in collaboration with experts from several OEMs and Tier 1 and 2 suppliers, and it is aimed at promoting standard fitment of driver monitoring systems that effectively detect impaired and distracted driving, eventually triggering the appropriate vehicle response strategies to warn driver and/or mitigate risks. Getting the full score in the Occupant State Monitoring (OSM) area will only be possible with direct monitoring systems. The protocol describes the DSM system requirements across three areas: Sensing (system performance degradation in the presence of several noise variables such as stature, light, facial features); Driver State (system capability to effectively deem the driver as distracted, fatigued or unresponsive); and Vehicle Response (vehicle deploying timely and appropriate response strategies, eventually avoiding the accident or mitigating its severity).

This paper discusses the rationale behind the assessment methodology and the resulting protocol, and how Euro NCAP envisions DSM as an effective tool to reducing/mitigating a wide variety of traffic accidents. Over the course of 2023 test campaign, Euro NCAP will collect extensive insights from both a practical implementation and technology capability perspective, opening the door for on-going improvements and further requirements. In the coming decade, Euro NCAP expects Driver (or Occupant) State Monitoring systems to tackle areas such as driver engagement, intoxication, optimized passive restraints, child presence detection, optimized passive safety, as well as enhancing the performance and intuitiveness of other ADAS by making them work in synchrony with the driver behavior – eventually increasing driver acceptance [1]. Lastly, the 2023 requirements for direct DSM are based on parameters related to eye gaze and head posture – these are subject to be expanded, allowing for new methods and systems to be used in future.

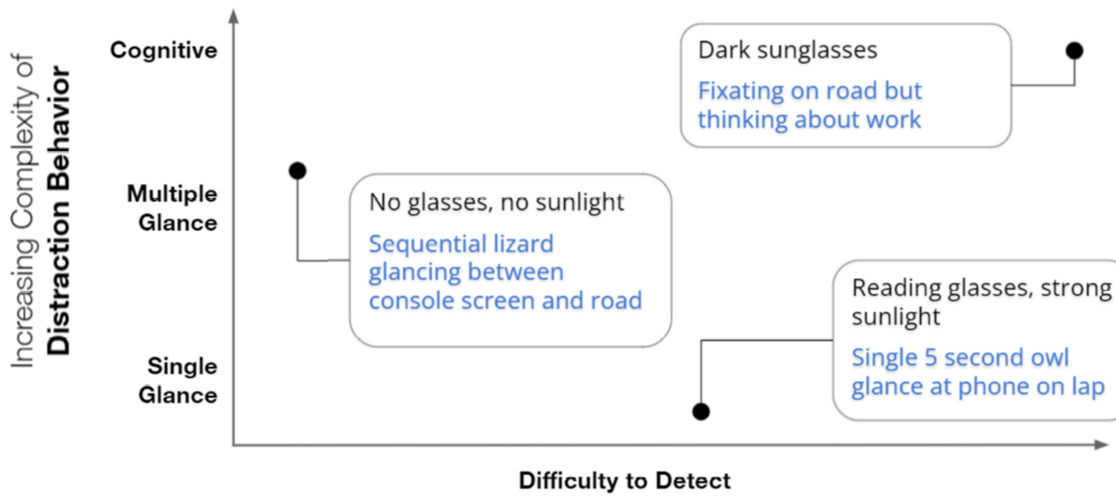
BACKGROUND

Distracted and drowsy driving are major contributors to global road trauma. Crash data from around the world suggest that up to 25% of crashes are caused by drowsiness, and that distraction and inattention accounts for nearly half of injury crashes [2, 3]. Sudden sickness resulting in the driver losing control of the vehicle is another factor contributing to serious and fatal road accidents [3, 4]. Issues such as distraction and drowsiness have been constants in road safety strategies around the world for many years. The OSM class of technology offers for the first time the opportunity to capture these risks when they occur. Euro NCAP recognizes this and is supporting this new push to advance road safety by rewarding vehicle manufacturers that adopt these technologies, especially in a time of ever-increasing sources of distractions while driving.

SYSTEM REQUIREMENTS

To understand the capabilities of an Occupant Status Monitoring system (OSM) two main pillars are considered: detection difficulty and behavioural complexity. On that basis, the protocol requirements are defined to encourage systems that can detect the driver state in a wide variety of circumstances (e.g., under challenging light conditions, wearing facial occluding elements) and regardless of the driver physical attributes (e.g., facial hair, skin type, stature, etc.) eventually ensuring the driver is protected for the longest possible time. Subsequently, the driver state is to be determined through a correlation with a set of behaviours (e.g., long distraction correlated to a single long glance away from the forward road view). As a result, a good system will combine a high situational coverage while featuring a robust behavioural correlation to determine the driver state – as illustrated in the difficulty-complexity matrixes of Figure 1.

Below paragraphs provide a background for the rationale followed in defining measurable parameters for the protocol that enable the determination of defined driver states, alongside a high-level summary of the system requirements. The 2023 protocol is available online [20] and it describes in detail the assessment criteria.



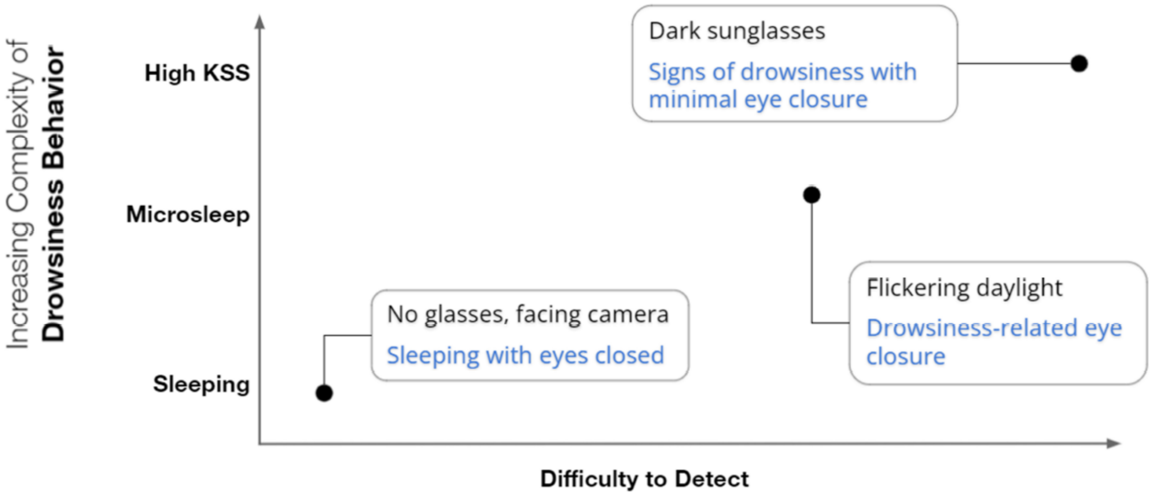


Figure 1 Behaviour-technology matrix for distraction and drowsiness [17]

Sensing

The first step in determining the driver state is the ability of the system to sense the behavioural metrics (e.g., eye gaze, head movement, eye closure) across the defined extremes of driver characteristics (e.g., age, gender, stature, skin, eye shape), and in the presence of a set of noise variables such as challenging lighting conditions and facial occlusions (e.g., sunglasses, hats, long hair). Given the different challenging nature of the defined occlusion elements, these are split between Prerequisite (i.e., the system shall detect) and Inform (i.e., the system shall inform the driver if the performance is degraded). As for secondary behaviours, these are defined for monitoring purposes only.

Table 1 Sensing requirements

Driver Characteristics	Occlusion		Other Behaviours
Prerequisite	**Prerequisite**	**Inform (if degraded)**	**Monitoring**
• Age (16-80) • Gender (All) • Stature (AF05-AM95) • Skin (Fitzpatrick type 1-6) • Eye lid aperture (From 6.0 mm to 14.0 mm)	• Lighting (Daytime-Nighttime) • Eyewear (Clear glasses, light shades) • Facial Hair (short facial hair)	• Hands on wheel • Eyewear (Dark shades) • Facial Hair (Large beard) • Facial occlusion (Face mask, hats, long hair)	Secondary behavior: • Eating, • Talking • Singing, • Smoking/ Vaping, • Eye scratching/rubbing • Sneezing

Driver State

Once the sensing performance is ensured, the system shall be capable to accurately determine the defined driver states in the protocol: distraction, fatigue and unresponsive driver. Some of the defined driver states are subdivided in different types, and for each type, there is one or more scenarios (see Figure 2).

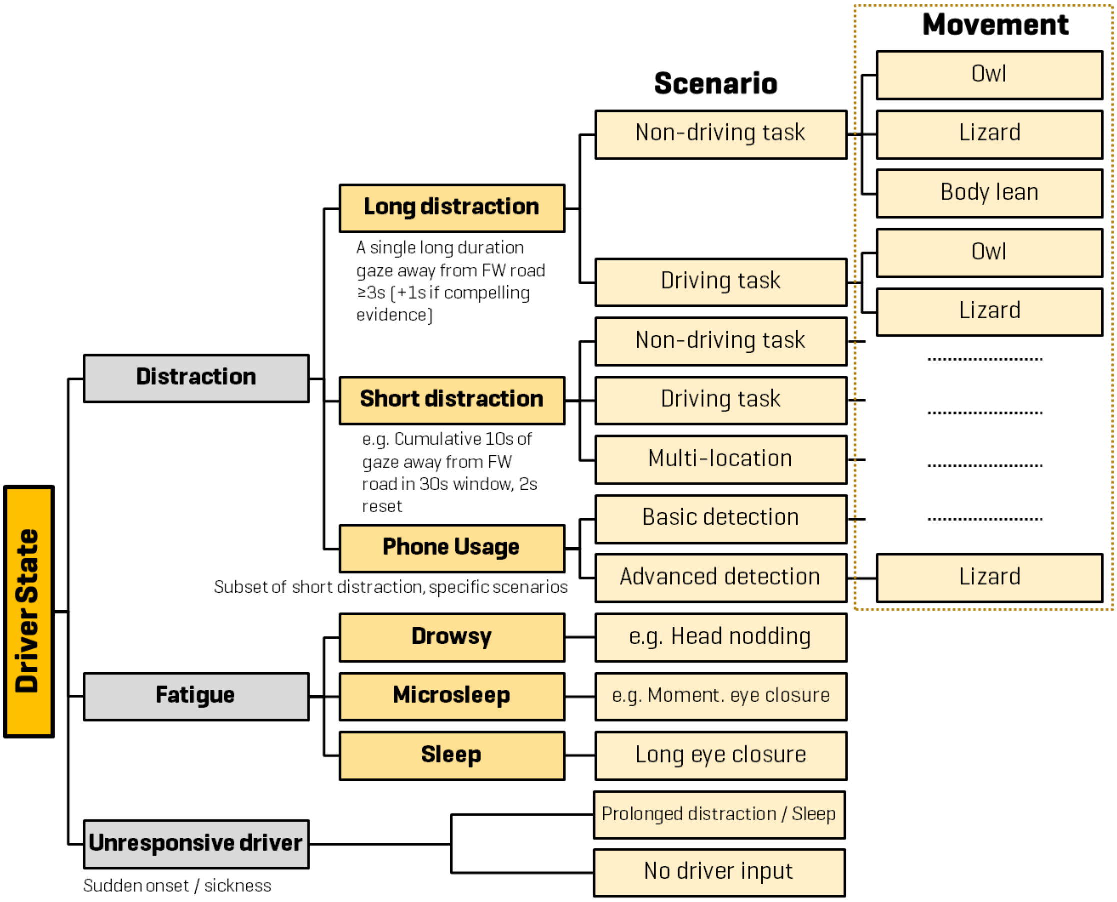


Figure 2 Summary of Driver States

Distraction: For distraction, the starting point was identifying the behaviours associated with the highest risk, one single long glance away from the forward road view being the most well understood in relation to the relationship with crash risk. [5]. Behaviours of increasing complexity are also considered to recognise that visual time sharing does occur and does increase crash risk at some point. These are situations where attention is split between the primary driving task and a secondary task [6] – defined as Visual Attention Time Sharing (VATS). This indicative model of time sharing and attentional requirements for safe driving is recognized by several studies [7],[8].

Understanding how drivers usually engage in distraction behaviours is important to define the primary parameters to be monitored, i.e., motion of head and eyes, being the fundamental behaviours that are observed when drivers are distracted. The relationship between head and eye movements when distracted typically falls within two extremes: "lizard" and "owl" behaviour. For small visual angles between the forward road view and the secondary glance target, drivers are usually engaging in a "lizard" glance behaviour, where the head position is relatively fixed, and the eyes are moving [9]. When the visual angle is larger, the typical glance behaviour is achieved by a head rotation, followed by the eyes, "owl" glance behaviour. Accounting for eye gaze metrics, beyond indirect measures or head pose alone, improves the reliability of determining distraction behaviours. Where a basic technology could detect head motion and therefore owl glance alone, a more advanced technology could also detect eye gaze and lizard glance. If both these extremes can be covered it is believed that combinations in between also could be covered.

The protocol lists the following Distraction types:

- Long distraction: single long glances directed to driving related and non-driving related gaze locations. The requirement is ≥ 3 seconds glance away from the forward road view (+1 second if OEM provides justification and evidence that safety is kept).
- Short Distraction: multiple short glances (VATS) targeted to engagement in secondary activities, e.g., glances away from the forward road view for a cumulative 10 seconds within a 30 second time, where the time period is reset if the driver's glance returns to the forward road view for a period of ≥ 2 seconds. In spite of the added value of identifying and defining VATS a high risk behaviour in the protocol, it may prove as a complex one to achieve consistently – reason why the AttendD-inspired buffer algorithm [25] (see Figure 3) was kept as an example for implementation, and the protocol remains open for similar or other approaches if compelling evidence to demonstrate comparable safety benefits can be provided.
- Phone use: A subset of VATS, with specific glance locations.

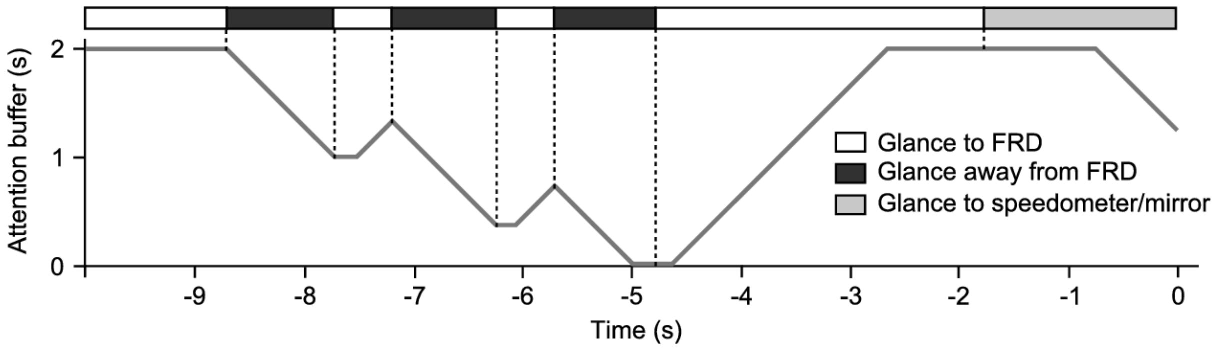


Figure 3 AttenD example [0]: development of the time buffer for three consecutive one-second glances away from the field relevant for driving (FRD), marked dark grey, with half-second glances back to the FRD in between. Note the 0.1 s physiological adaptation delay.

There is a total of 43 test cases – gaze locations – split into Driving vs Non-Driving tasks (see Table 2), which are to be accomplished by means of Owl, Lizard and Body Lean glance movement types. The test cases were defined with the premise to be highly repeatable, while ensuring a broad situational coverage by accounting for different types of glance strategies. For each of the movement types in the Long and Short Distraction types to be awarded a PASS, all gaze locations shall be covered. For Phone Use, the distraction scenarios are awarded a PASS only when all movement types and all gaze locations are covered.

Table 2 Gaze locations used to assess distraction types

Distraction Type	Distraction Scenario	Movement type	Gaze Location	
Long Distraction	Non-Driving Task	Owl	• Driver Side Window • Passenger Side Window	• Passenger Footwell • Passenger Face • IVI Display
		Lizard	• IVI Display	• Glovebox
		Body Lean	• Passenger Footwell	• Rear Passenger
	Driving Task	Owl	• Rear Mirror	• Passenger Side Mirror • Driver Side Mirror
		Lizard	• Instrument Cluster	• Driver Side Mirror • Rear Mirror
Short Distraction (VATS)	Driving Task	Owl	• Passenger Side Mirror • Driver Side Mirror	• Rear Mirror
		Lizard	• Driver Side Mirror • Rear Mirror	• Instrument Cluster
	Non-Driving Task (Single Target)	Owl	• Passenger Side Window • Passenger Footwell	• IVI Display
		Lizard	• Driver Side Window	• Passenger Footwell • IVI Display
	Non-Driving Task (Multiple Targets)	Lizard	• Any combination of non-driving task locations	
Phone Usage	Basic	Owl	• Driver Side Knee • Passenger Side Knee • Driver Lap	• Driver Side Dashboard • OEM Charging dock
		Lizard	• Driver Side Knee • Passenger Side Knee • Driver Lap	• Driver Side Dashboard • Upper Wheel Rim • Center Steering Wheel • OEM Charging dock
	Advanced	Lizard	• Held At On Road • Held At Instrument Cluster	• Mounted At On Road

Fatigue: Drowsiness state can be captured through direct or indirect measurement methods. Indirect methods such as vehicle positioning in-lane and steering behaviour over time fail to reliably detect a drowsy driver, and even direct methods such as the eyelid closure percentage (PERCLOS) have demonstrated not offering the best true positive rate [10]. In general, approaches for drowsiness detection that account for single metrics are less efficient [11], whereas combined approaches accounting for multiple metrics (e.g., blink duration, amplitude-velocity ratio, and frequency), prove to be more robust [12], [0], [14].

Microsleep is typically a complex state to be determined, with the Electroencephalography (EEG) as the most reliable method in the laboratory [15]. Since EEG proves impractical in automotive applications, several behaviours have been correlated to a Microsleep, such as long eye closure (>500ms) [16]. Many behaviours such as yawning or squinting situations can lead to false positives that will impact driver acceptance. Aa complex approach combining several behaviours could lead to a more reliable detection method, for instance with a prior determination of drowsiness.

The defined fatigue driver states in the protocol are split in drowsiness, microsleep and sleep. Sleep state is typically presented as a long eye closure (>3 seconds), therefore simple do be determined. However, when it comes to the more behaviourally complex drowsiness-related events, there is no single and repeatable pattern across individuals [18], [19], and hence makes them hard to reproduce consistently. Here, genuinely drowsy drivers should be used by a system to correlate a given metric (e.g., Karolinska Sleepiness Scale – KSS) to a certain drowsiness-related behaviour.

<u>Unresponsive Driver:</u> Sudden sickness can present itself in various and unpredictable forms, (e.g., seizure, epilepsy, etc.), and data that helps correlating it to certain behaviours is still scarce. Thus, a reasonable approach that may be taken in the early stage of the protocol implementation is assuming that sudden sickness as a subset of unresponsiveness, in which the driver would either fail to respond to escalating warnings such as take-over-request (TOR), or not be actively performing a driving task for an extended period.

Vehicle Response Requirements

Once the system can detect an impaired driver in the form of distraction, fatigue or unresponsiveness, the safety benefit will be eventually brought by an appropriate vehicle response that promotes safe driving, prevents an accident, or mitigates the damage associated with it. The protocol provides a list of warning and intervention strategies that are required per driver state (see Figure 4), while allowing flexibility for other OEM-specific strategies.

The premise for adjusting the sensitivity to some of the ADAS in the vehicle when a driver is deemed impaired, is to address the safety benefit while ensuring driver acceptance – beyond a typical approach of a simple warning. The underlying thought is that the best system should have both warning and intervention capabilities.

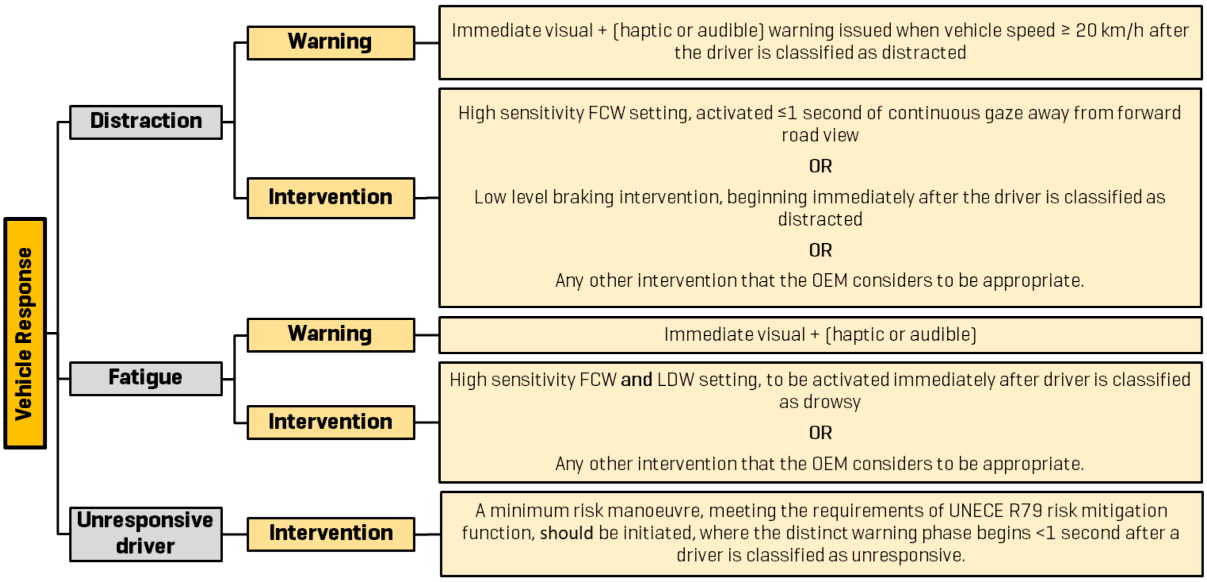


Figure 4 Vehicle Response requirements

ASSESSMENT AND VERIFICATION PROCESS

Given the large amount of test cases resulting from the DSM requirements (i.e., set of distraction, fatigue and unresponsiveness elements conducted with a sufficiently large demographic dataset, across a wide range of noise variables), it becomes necessary to define an assessment and verification process that fits within the limitations of Euro NCAP Test Programme. To that end, a 2-stage approach is taken: First, the OEM provides the Euro NCAP Secretariat with a comprehensive dossier documenting the DSM system performance with all necessary supporting evidence; secondly, the approved test laboratory in charge of the whole Euro NCAP Test Programme for the vehicle will 'spot-test' a set of randomly selected scenarios where system the system claims functional. The dossier provides guidance to the OEM according to the system requirements, while remaining as flexible as possible to foster innovation: alternative approaches to meet requirements are permitted for as long as the OEM justifies that the safety benefit is kept. The following sub-chapters describe the approach in more detail.

DSM Dossier
Euro NCAP elaborated a Technical Bulletin [21] that provides guidance to OEM in the format and contents of DSM dossier document. Some of the minimum contents and structure of the document are described below.

System Overview: Summary of the main system functionalities, compliance of the minimum system requirements, sensors involved in the system, their role and relevant specifications, and details explaining the constituent elements of the different system warnings;

Noise Variables: The OEM should provide compelling evidence that the system can monitor a population constituted of different types of drivers, with a range of facial occlusions and driver behaviours. Depending on the complexity of the noise variables, the requirement vary between 'Must', 'Inform driver if degraded', and 'Information only';

Detection of driver state: The OEM should provide evidence demonstrating that the system can effectively classify the driver state in the minimum required categories:

- Distraction: further classification of distraction includes 'long distraction, 'short distraction', and 'phone usage'. As distraction is heavily linked to gaze location, the OEM is required to specify in the dossier a drawing the delimited gaze areas/regions which the system considers to assess distraction;
- Fatigue: further classification of fatigue includes 'drowsiness' 'microsleep' and 'sleep'. Euro NCAP gives freedom to the OEM to include in the dossier other methods to assess fatigue other than the ones specified in the protocol;
- Unresponsive driver: details of how the driver status is deemed unresponsive (or sudden sickness) by the system.

Vehicle response requirements: The OEM should provide details on how the sensitivity of ADAS is increased (e.g., Forward Collision warning – FCW; Lane Departure Warning – LDW) when driver is deemed distracted, fatigued, or unresponsive. The OEM is free to stick to the protocol requirements or justify other vehicle response methods.

DSM Spot Testing
Complementary to the information provided by the OEM in a dossier, the spot testing is the second stage in the assessment of the DSM performance. Euro NCAP has consolidated a comprehensive guideline [22] with the necessary provisions on how the spot testing is to be conducted across official test laboratories, described in the paragraphs below.

Test Provisions: The test conditions are defined to maximize reproducibility and repeatability across test laboratories (e.g., uniform surface with consistent slope, at daylight without direct glare or strong light transitions, avoiding strong precipitation).
The vehicle under test (VUT) is to be instrumented with a simple measuring equipment, recording at a defined sample rate (>25Hz): the VUT speed, driver's gaze location and DSM warning(s). Time variables are defined to ensure consistency and are to be used later for analysis purposes. Furthermore, prior to the test, the timing of FCW and LDW are to be checked at their minimum operational speed without signs of driver inattentiveness, so that the sensitivity increase can be later assessed. It is also important to ensure that previous system learnings on driver drowsiness are reset.

Test Execution: The test laboratory in charge of the assessment will randomly pick a test subject (a qualified driver from their staff) whose variables and ranges are within the protocol specifications. The driver will then adjust the seat in the preferred position and proceed with the test after the vehicle preparation.
Euro NCAP secretariat will ask the test laboratory to spot test a number of distraction, fatigue, and unresponsive driver areas of the DSM system, which performance has been claimed in the dossier by the OEM. While the vehicle is in motion at a defined constant speed deemed adequate for the test, the driver shall keep a defined head and body posture while looking to the road ahead, until the manoeuvre begins.
For distraction scenarios, the driver will proceed with moving the head, eye gaze or body posture (depending on the scenario) towards the target area (e.g., glovebox, side mirror, rear passenger seat, etc.), and hold the position

for a defined time as required in the protocol. An extra time of +1 second is added to the required time, to ensure that the system reaction is captured during the assessment.
For the assessment of Fatigue and unresponsive driver, Euro NCAP reserves the right to investigate it in practice, although it should rely on the evidence reflected in the dossier. For microsleep, sleep and unresponsive driver scenarios, the metrics by default for assessment are eye closure timing and eventually head nodding forwards; however, a different OEM strategy is allowed for as long as it is justified; later, for each of the areas where the system was functional, the scenario will eventually have to be repeated with different occlusions (cap, hat, sunglasses, facemask). Furthermore, the assessment includes a 'hands on 12 o'clock position' check for sensors located in the instrument cluster. Finally, the FCW and LDW sensitivity change is checked based on the Euro NCAP Car-to-car rear stationary (CCRs) assessment and LDW assessment, respectively.

OUTLOOK

For future protocol developments, it is envisioned an expansion of the driver states related to impairment (chiefly intoxication and cognitive distraction), but also refining existing ones such as an accurate determination of sudden sickness by means of extended metrics. To that end, it is expected that in the years to come, starting from the 2023 test campaign, the Euro NCAP Secretariat will gather a substantial amount of information out of the DSM dossiers from the vehicles to be assessed. Gathering insights from state-of-the-art technologies will be an essential input toward refining the current provisions and expanding them above and beyond. The work will be done within the framework of the Occupant Status Working Group, with the principle of maintaining a balance between an ever-increasing safety requirements and a manageable process by OEMs.
Moreover, the group is tasked to define a framework that rewards efficient and intuitive HMI approaches while ensuring opportunities for differentiation – a fundamental pillar for DSM efficacy which will ultimately make drivers see the system as a partner that understands and helps, as opposed to irritate. All in all, as it is the case with other driver advisory systems such as Speed Assistance Systems (SAS), ensuring a good system accuracy is and will continue to be the main aspect toward maximizing driver acceptance (i.e., low false positive rate).

Intoxication

The European Commission attributes 25% of the fatal crashes in Europe to alcohol and other drugs. In view of these figures, intoxication is the most critical issue to tackle next. There are solid prospects for future DSM systems in detecting a certain level of impairment resulting from the use of drugs and/or alcohol, beyond the more intrusive methods (e.g, direct Blood Alcohol Concentration measurement by means of an alcohol interlock). For instance, as of today there is ample evidence of alcohol altering eye movements and visuospatial attention, with a few studies demonstrating some of these effects with simulated driving tasks: acute alcohol consumption altering oculomotor functioning [23]; and gaze entropy measures correlated to alcohol-induced driver impairment [24], [25], [26].

Cognitive distraction

Cognitive distraction / inattention is a state in which the driver's mind wanders off for a certain period, while the eye gaze may still be directed toward the forward road view [28]. As a result, the driver capability to appropriately perform the driving tasks is degraded and the current DSM approach fails to detect distraction. At this stage, cognitive distraction is well documented in driver simulator studies, however the amount of evidence reported from real crash data which could be linked to such condition is still scarce. All in all, it is expected that in-cabin technologies will be able to tackle this more technology challenging condition in the long term.

Occupant Status Monitoring

The Euro NCAP Occupant Status Working Group will continue to find use cases leveraged by in-cabin monitoring technologies, expanding to all the vehicle occupants beyond driver. Determining the presence, sitting posture and size of the occupants will enable an optimized use of passive systems (e.g., advanced airbag deactivation or modified pressure, adaptive seatbelt load limitation and head restraints, advanced emergency call, etc.). Finally, the prevention of injuries related to child left alone in vehicles is a challenge to be addressed. The first-ever provisions for Child Presence Detection (CPD) have been defined by Euro NCAP in the 2023 implementation of the protocol [29], which will reward both indirect and direct systems, and from 2025 only direct systems will be rewarded.

Assisted and Automated Driving
The coming years will see an uptrend of vehicles offering certain levels of assistance to the driving task under defined conditions, with a resulting change in which drivers behave compared to manual driving. Assisted Driving systems are primarily designed to provide safety and comfort, however as the driver is always entirely responsible for the driving task, it will become critical to consider how OSM can best support the associated risks, namely ensuring driver engagement caused by overreliance on the system. Vehicles featuring Assisted Driving systems are being assessed by Euro NCAP since 2021 under the Assisted Driving Grading programme [30], which focusses on two areas: Assistance Competence – a balance between Vehicle Assistance and Driver Engagement, and Safety Backup, the car's ability to tackle critical situations. This assessment will gradually evolve, and starting from 2026, it will have a direct influence on the Safe Driving area of the new Rating Scheme [1], introducing a penalty if the Driver Engagement component is rated poor.
When it comes to Automated Driving, provisions to assess the driver readiness prior to take-over-request are likely to be defined.

System requirements
In general, the system requirements defined in the 2023 protocol were designed around detecting high risk behaviours related to distraction, fatigue, and sudden sickness, supported by research papers looking into these – the most significant reflected above in chapter "System Requirements". There is a focus on facial landmarks such as gaze and head posture since, still as of today, it is the most suitable and effective way to measure high risk behaviours as defined in the protocol. This was also supported by feedback from industry; this technology being the most feasible and available at this point. In the coming period, Euro NCAP will open up to other approaches which could potentially accommodate other parameters associated with such behaviours, such as explicitly holding a cellphone or detecting sudden sickness with other more biometric means.

CONCLUSIONS

As technologies able to capture driver state improve, Euro NCAP deems it essential to encourage their fitment in vehicles as standard, hence reducing injury caused by fatigue and distraction-related crashes. Euro NCAP made a first step toward promoting the widespread adoption of in-cabin monitoring starting with the 2023 implementation of the DSM assessment protocol. Over the next decade, the protocol will evolve to accommodate advanced technologies able to detect additional driver states associated with risk of unsafe driving and defined appropriate vehicle responses that avoid or mitigate accidents.

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