DEVELOPMENT OF A DIRECT DRIVER STATUS MONITORING ASSESSMENT SCHEME

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ABSTRACT

Analysis of naturalistic driving behaviour shows that engaging in visually demanding tasks and driving while drowsy results in higher near crash/crash risk. In addition, increasingly busy global traffic environments, the trend of vehicles being marketed on their connectivity and ever growing screens loaded with potentially distracting features, it becomes necessary for technology to encourage safe and attentive driving.

Indirect monitoring systems have featured in vehicles for many years, identifying decaying control accuracy and advising the driver to take a break. A new development is direct driver status monitoring, typically using infrared camera technology to directly observe the driver's facial orientation, glance behaviour and eyelid aperture, enabling real time assessment of attentiveness.

The aim of this research was to develop a test and assessment protocol grounded in real world data to guide the development and evaluate, in an objective and repeatable format, the performance of systems targeted at addressing the most common attributes of the inattentive driver problem to the benefit of road safety.

A test and assessment scheme were developed that was proven to successfully enable the differentiation of pioneer direct driver status monitoring systems for inattention in the form of distraction, fatigue and unresponsive driver. This has been adopted by Euro NCAP to guide the development of new systems entering the market. providing consumers with independent information supporting them making safer vehicle choices.

Parameters for warning and intervention strategies were carefully considered to balance the desire for effectiveness in test scenarios with driver acceptance to achieve real world effectiveness. The testing requirements for driver status monitoring systems were novel in that the test driver is necessarily the test subject triggering the system. Therefore, research testing was conducted to refine the driver glance behaviours, necessary measures and associated instrumentation to deliver repeatable testing.

This initial iteration of the scheme was guided by nascent market technology enabling direct monitoring of the drivers face and eyes, and to a certain extent, seating posture. Future technical innovations will see the monitoring scope increase from that of the driver's face to the cabin of the vehicle, and it is recommended that a future generation of the scheme take full advantage of the opportunities of understanding not only the driver attentiveness, but their seating position and posture, hand position and occupancy etc. as well as the presence and attributes other passengers in the vehicle.

INTRODUCTION

Analysis of driver attentiveness in naturalistic driving studies [1] shows that engaging in visually demanding tasks (even for two second glances) and driving while drowsy result in higher near crash/crash risk [2]. The National Highway Traffic Safety Administration (NHTSA) term distracted driving as 'risky driving' and cite it as 'dangerous', claiming 3,142 lives in the United States in 2020 [3].

Allied to this, there is the continuing global megatrend towards urbanisation and an increasingly busy global traffic environment [4]. In the developed world there is a diverse mix of traffic participants including a growing proportion of Vulnerable Road Users (VRUs) in line with the sustainable transport agenda. Considering the vehicles themselves, there is the trend towards cars being marketed on their connectivity and screen-based user interfaces are being employed not only for infotainment, but also for everyday controls, necessitating driver direct attention to manipulate because of their absent tactility. Some even enable internet browsing whilst the vehicle is in motion! Acknowledging these factors competing for driver attention, in parallel with the proliferation of mobile device use whilst driving, it has become necessary for technology to encourage safe and attentive driving to maintain and improve road traffic safety.

Figure 1 illustrates how inattentiveness to driving can be split into two headline categories: distraction and impairment. In the context of driving, both distraction and impairment affect the driver's ability to perceive the surrounding vehicle, road and traffic environment. Impairment also challenges driver's ability interpret and respond appropriately because cognitive processes and actuation capabilities are also affected, whereas a previously distracted driver has the ability to quickly redevelop situational awareness and maintains the interpretation and actuation capabilities. Therefore, specific strategies were developed to support drivers exhibiting distraction and impairment behaviours.

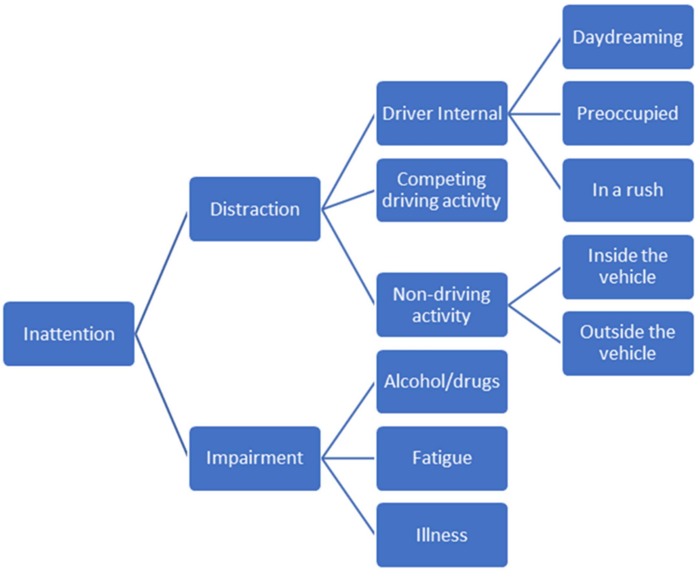

Figure 1 – Categorisation of driver inattentiveness

Indirect driver attentiveness monitoring systems have featured in vehicles for many years, typically observing journey duration, driver inputs or vehicle control (e.g., lane positioning consistency) to identify decaying control accuracy, subsequently advising the driver to take a break. The advantage of indirect monitoring is it can be readily implemented using existing modern vehicle hardware, requiring the engineering of an appropriate interface. It can be effective at discerning the characteristics of impaired driving by observing poor dynamic control e.g., in the case of substance abuse, and as they develop over time e.g., in the case of fatigue. However, its ability to detect distraction or illness is limited because these inattentions present momentarily rather than exhibit over an observable history.

Figure 2 – A typical indirect driver status monitoring output (Ŝkoda)

A new development is direct driver status monitoring, driven not only by the potential safety benefit of addressing inattentive driving, but also the need for observing the driver status to safely implement automated driving. Such systems typically use infrared camera technology, mounted immediately in front of the driver in the instrument panel or offset to one side in the central infotainment stack, to directly observe the driver's facial orientation, glance behaviour and eyelid aperture opening. The benefit of direct monitoring over indirect is the ability to determine real time attentiveness, and therefore support addressing the momentary distracted driver and illness related safety issues. However, its effectiveness relies on the ability to accurately detect and classify the driver status acknowledging their personal characteristics e.g., facial and eye shape, skin tone etc., occlusions e.g., facial hair, makeup, head and face wear etc. and under the wide range of conditions in which vehicles are used e.g., lighting and temperature etc.

Figure 3 – An example of a direct driver status monitoring system (Valeo)

AIM

The aim of this research was to develop a test and assessment protocol grounded in real world data to guide the development and evaluate, in an objective and repeatable format, the performance of systems targeted at addressing the most common attributes of the inattentive driver problem to the benefit of road safety. It will provide the consumer with information describing the system capability, performance and limitations in use, and help them understand the system and how to use it effectively and responsibly.

SCOPE

An analysis of Britain's official Road Accident Statistics (STATS19) for 2018 identified that for factors relevant to driver status monitoring (highlighted rows in table 1), inattention was identified as a contributory factor in 14 per cent of all road traffic collisions, rising to 26 per cent of fatal collisions. Approximately half were alcohol or illicit/medicinal drugs related across all severities, with the remainder distributed across sudden illness, fatigue and distraction.

Table 1: STATS19 2018 data for impairment or distraction contributory factors

Contributory factor reported in accident	Fatal accidents		Serious accidents		Slight accidents		All accidents	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Impairment or distraction	**390**	**26.8**	**3,089**	**16.6**	**9,137**	**14.1**	**12,616**	**14.8**
Driver/Rider impaired by alcohol	117	8.0	1,186	6.4	3,048	4.7	4,351	5.1
Driver/Rider impaired by drugs (illicit or medicinal)	80	5.5	404	2.2	837	1.3	1,321	1.6
Fatigue	62	4.3	339	1.8	1,127	1.7	1,528	1.8
Uncorrected, defective eyesight	3	0.2	53	0.3	140	0.2	196	0.2
Driver/Rider illness or disability, mental or physical	110	8.0	584	3.1	1,395	2.2	2,089	2.5
Not displaying lights at night or in poor visibility	4	0.3	87	0.5	201	0.3	292	0.3
Rider wearing dark clothing	6	0.4	88	0.5	314	0.5	408	0.5
Driver using mobile phone	25	1.7	92	0.5	306	0.5	423	0.5
Distraction in vehicle	68	4.7	540	2.9	2,039	3.1	2,647	3.1
Distraction outside vehicle	17	1.2	236	1.3	984	1.5	1,237	1.5

It is anticipated that the data related to impairment by alcohol and drugs are representative because presence can be confirmed by laboratory testing if suspected as a contributory factory. However, those pertaining to fatigue and distraction, and in some cases illness, are anticipated to be underestimation because physical they are transient states: tests to confirm do not exist, and identification as a contributory factor is reliant upon witness evidence or confession by the culprit if they are able to do so, potentially incriminating themself in the process.

The accident data indicates for an assessment of systems addressing inattentive driving to have effective real world performance it must cover both distraction and impairment, with impairment including alcohol and drug driving, fatigue and illness.

Identification of alcohol or drug impaired driving by a driver status monitoring system during a journey poses the question regarding reliability of detection and what action the vehicle should take given that it is illegal to be in control of a motor vehicle whilst impaired to a greater or lesser extent. In this initial step, it was decided that because the behaviours and driving performance exhibited by the driver under the influence of alcohol or drugs can be similar to those pertaining to fatigue, deployment of the same warning and intervention strategies were considered as being acceptable. This will be reviewed when developing the scheme in the future acknowledging the latest developments in sensing and interpretation capability and warning and intervention strategies.

The road safety issue of distraction associated with the use of nomadic devices (mobile/cell phones and tablets etc.) whilst driving is of increasing societal interest because of the perceived risk and media reporting of high profile road traffic collisions. Numerous national and state governments have focused attention on the topic, initiating or ratcheting up penalty schemes for drivers caught using nomadic devices whilst driving to deter use. Practically speaking it makes little difference whether the driver is distracted by a nomadic device, vehicle-borne aspects or an external factor, yet given the high profile nature of the topic, it was decided to specifically address it as a distinct element of the testing and assessment scheme to promote the concept and acceptance of driver status monitoring systems across all road users.

ASSESSMENT SCHEME DEVELOPMENT

Background

Given the emerging nature of driver status monitoring technology, no published literature existed illustrating the nature of the driver inattention to the level of detail necessary to develop an effective test and assessment scheme. To gain the necessary information a process of liaison with relevant research and automotive industry stakeholders was pursued under the auspices of the Euro NCAP Occupant Status Monitoring (OSM) Working Group, with:

- The European Automobile Manufacturers' Association (ACEA) representing Original Equipment Manufacturers (OEMs)
- The European Association of Automotive Suppliers (CLEPA) representing the automotive supply chain
- A sub-group of the supply chain specifically representing global driver status monitoring system technology providers

Given the proprietary nature of the information shared it remains confidential to the Working Group, however the decisions it informed are illustrated. Only previously published information is referenced in this paper.

Noise Variables

An initial priority was to identify the noise variables necessarily covered to promote robust driver detection and status classification. It was deemed that to be effective, the system must 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 coverage requirements vary between 'Must', 'Inform driver if degraded', and 'Information only'.

Driver attribute ranges necessarily covered to promote robust driver detection and status classification were identified as:

- Age — Youthful (16 to 18) to aged (≥80)
- Sex — All
- Stature — AF05 to AM95
- Skin complexion — Fitzpatrick skin type 1 to 6
- Eyelid aperture — From 6.0mm up to 14.0mm

A number of typical real world driving variables were identified that may affect driver status monitoring system performance. These occlusions were classified as those potentially obscuring the driver's facial features, for which the system must work:

• Ambient lighting	<1 lux to >100,000 lux
• Eyewear	Clear glasses and sunglasses with transmittance >70%
• Facial hair)	Short <20mm in length

and those potentially obscuring the driver's face, in which case the driver must be informed within ten seconds if the system performance is degraded:

• Hand on wheel	One hand on steering wheel at 12 o'clock position
• Facial occlusion	Facemask, hats, long head hair fringe obscuring eyes
• Eyewear	Sunglasses with a transmittance <15%
• Eyelash makeup	Thick eyelash makeup
• Facial hair	Long >150mm in length

Other driver activities e.g., eating, talking, laughing and singing and smoking/vaping etc. were also considered to understand the effect that may have on the driver status monitoring system.

Driver State

The industry consultations were also used in conjunction with the real world data to identify the inattentive driver states presenting the greatest risk to road safety, considering the eyes off forward road view time, the nature of the glance behaviour and the ability to recover safe control of the vehicle. Three headline driver states were defined:

• Distraction	For the purposes of the initial scheme, eyes off forward road view.
• Fatigue	Builds up over time from drowsiness, through micro-sleep and to sleep
• Unresponsive driver	Onset of sudden illness, or failing to recover from distraction or fatigue

<u>Distraction</u>

Distraction was categorised into three types, with eyes off the forward road view:

• Long distraction	Continuous glance to a single fixed location
• Short multiple distraction	Also known as Visual Attention Time Sharing (VATS) – repeated short duration glances to the same or different locations
• Phone use	Basic (not within the driver's view of the windscreen) and advanced (within the driver's view of the windscreen)

Two types of gaze movement were defined, acknowledging the overt and covert nature of driver glance behaviour, with a view differentiating the ability of systems to discern between facial orientation eye gaze vector [5]:

• Owl type movement	A shifting of visual attention away from the road and forward-facing position that is primarily achieved by head rotation followed by the eyes
• Lizard type movement	A movement in which the driver focuses on a task by moving primarily their eyeline away from the road with their head/face remaining in the forward-facing position.

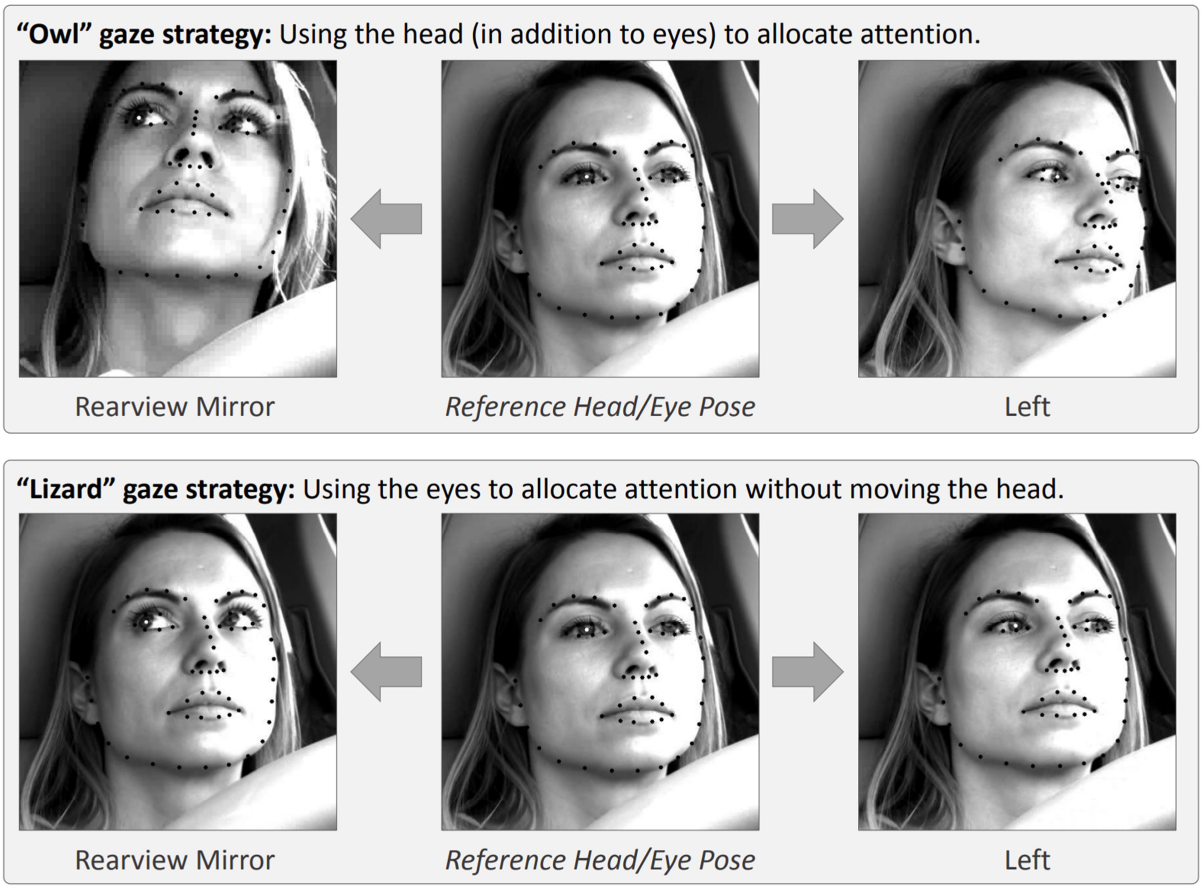

Figure 4 – An illustration of owl and lizard gaze strategies

A range of common gaze locations were identified based on naturalistic driving studies, differentiated by whether they were non-driving related locations e.g., side windows or in-vehicle infotainment system, or driving related tasks e.g., rear view/door mirrors on instrumentation cluster. See the Euro NCAP assessment protocol [6] and technical bulletin [7] for full details.

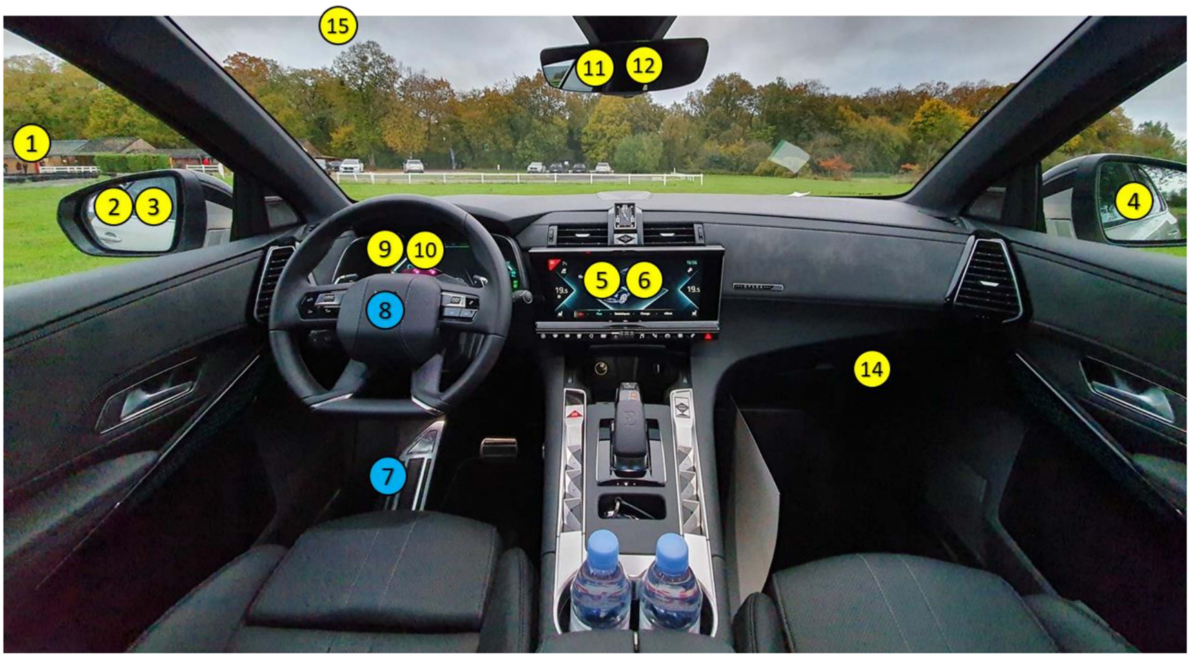

Figure 5 – Example distraction gaze locations (Euro NCAP Technical Bulletin 039)

Regarding long distraction, a critical aspect of the real world effectiveness and acceptance of driver status monitoring systems regarding distraction is the timing of the distraction classification. Too short timing will likely annoy the driver because of perceived unjustified activations, eroding their confidence in and acceptance of the system, ultimately resulting in system deactivation. Conversely too long timing risks only addressing the longest of eyes off forward road view events, limiting system effectiveness in potentially critical situations, and limiting any coaching effect of the driver. Research [8] indicates drivers exhibit a consistent metronomic glance tempo i.e., similar duration on road and other location glances when attending to secondary tasks, however the variation between individual drivers is large, with the slowest tempo being three times slower than the fastest.

Acknowledging this evidence, the timing for classifying long distraction was set at three seconds from the gaze landing on the location, with a tolerance of plus one second where compelling evidence is provided justifying why a later classification was employed. The time taken for gaze to transition from the forward road view to the location is not considered within these three seconds, hence the time for eyes off forward road view is greater than three seconds, falling further into line with the research data.

Figure 6 – Timeline for long distraction classification

Short distraction was considered to be repeated glances away from the forward road view either repeated towards one location, or to multiple different locations. A short distraction event is a build-up of multiple glances away from the forward road view and is considered to end when the driver's attention returns to the forward road view for a period long enough for the driver to fully interpret the road situation.

Numerous algorithms for classifying short distraction have been proposed based on cumulative eyes off road time, either allied to current glance location and associated transitions or in conjunction with a buffering and reset concept, as well as considering other information sources available within the modern vehicle. For the purposes of the scheme, a simple example of when a driver glances away from the forward road view for a cumulative period of ten seconds within a thirty second time period was illustrated, where the time period is reset if the driver's glance returns to the forward road view for a period greater than two seconds. However alternative approaches will be considered where compelling evidence illustrating and justifying their efficacy is provided.

Phone use was considered to be a specific type of short distraction event where the driver's repeated gaze is towards their mobile phone, hence the detection and classification requirements mirror those set out for short distraction, albeit with dedication gaze locations for basic and advanced detection.

Fatigue

Fatigue was categorised into three stages, representing the natural development over time:

- Drowsiness — Classification when KSS level greater than seven at the latest, or an equivalent measure
- Microsleep — Eye closure of less than three seconds with loss of conscious control
- Sleep — Continued eye closure greater than three seconds

Acknowledging that as drowsiness develops, its effects are observable over a history, both direct and indirect means of sensing systems are recognised as being suitable to detect the onset, and indeed encouraged to achieve a robust and effective system.

The microsleep threshold of eye closure of less than three seconds was selected based on data illustrating microsleep events whilst driving can be as short as one to two seconds in duration, and to drive technical innovation acknowledging the potential road safety risk associated with even short periods of inattention. It is acknowledged that non-eye closure microsleep events are possible, however given the nascence of driver status monitoring, detection and classification of such events is beyond the current state of the art. For systems less sensitive to short duration eye closure indicating microsleep, the sleep detection threshold was set at greater than three seconds, and up to a maximum of six seconds is permitted to classify a driver as sleeping to promote timely detection and response.

Unresponsive Driver

The unresponsive driver classification is designed to capture the sudden onset of illness. It is likely, but not certain, that initially an unresponsive driver will be display behaviours akin to and be classified as either distracted or asleep. For the purposes of the scheme, unresponsiveness is classified by the driver not returning their gaze to the forward road view within three seconds of an inattention warning being issued, or when the driver gaze has been away from the forward road view or has been eyes closed for greater than six seconds.

Vehicle Response Requirements

The vehicle response requirements illustrate warning and/or intervention strategies to apply in case the driver is classified as inattentive. These strategies vary depending on the type and duration of inattention, with the intention of providing optimised support to the driver in case a critical traffic situation arises whilst they are inattentive, and warning them to reengage if they remain inattentive for an extended period. This warning process may also have a training effect identifying what is an unacceptably long eyes off forward road view glance.

The warning timings for distraction and fatigue were fixed as illustrated previously. More flexibility has been permitted in the intervention requirements acknowledging the nascence of the technology and to encourage the automotive industry to develop innovative strategies. Strategies proposed include:

- High sensitivity FCW setting, to be activated after greater than one second of continuous gaze away from forward road view, until driver attention is restored, or
- Low level braking intervention, where low level braking begins immediately after the driver is classified as distracted and continues until driver attention is restored, or
- Any other intervention that the OEM considers to be appropriate and can justify with supporting evidence as being effective

It is anticipated that the major benefit of driver status monitoring systems will not come from warning the driver in case of inattention, especially distraction, but in incorporating this new knowledge of the driver status into the decision making process when considering how and when to operate active safety warning systems to reengage the driver or intervene on their behalf.

RESEARCH TESTING

With requirements set for driver inattention classification and associated vehicle response, a testing mission was undertaken to develop testing methodology to evaluate the performance of driver status monitoring systems. It was imperative that this methodology enabled repeatable and reproducible testing results to be obtained and was technology independent, to encourage innovation and not favour one type of implementation over another without good reason.

The testing requirements for driver status monitoring systems are novel in that the test driver is necessarily the test subject triggering the system. The behaviours requiring performing are not aligned with safe driving practices on the test track, therefore to manage risk, a lookout was required, either in the vehicle, or externally and in direct communication with the test driver.

The testing requirements for distraction are relatively basic because of the momentary nature of the behaviour, namely recording data to confirm:

- Straight driving at a constant speed
- The driver delivering the appropriate distraction scenario to the gaze location using the appropriate movement type (owl or lizard)
- The timing of the warning or intervention relative to the driver glance

The testing requirements for fatigue proved more complex because of the developing nature of the behaviour, and also depended on the architecture of the driver status monitoring system. Systems that responded to sudden, acted microsleep and sleep were no more difficult to test than for distraction, but arguably potentially less sensitive to the real world naturalistic decay in responsiveness and control. Some required a historical drive cycle of inert driving, maintaining at least moderate speeds with limited dynamic interactivity, reminiscent of highway driving, to establish a potentially drowsy driver scenario ahead of issuing fatigue warnings. Such systems proved particularly challenging to assess repeatably on the test track, both in terms of time taken and consistency of results achieved given the acted driver state. However, the test data requirements for such systems were no more complex than those for distraction, hence distraction scenarios were used to develop the testing methodology and more complex fatigue driving requirements were handled on a case by case basis liaising with the original equipment manufacturer and/or supplier.

Initial testing was completed with a synchronised dual GoPro camera setup, with one rearward facing camera observing the driver glance behaviour and a second fixed observing the instrument panel to identify the warning. Vehicle dynamic data was recorded using a GPS corrected inertial dynamic measurement system. Operating the cameras at 25 frames per second enabled the warning timing to be determined to the nearest four hundredth of a second, adequate given the timeframes involved.

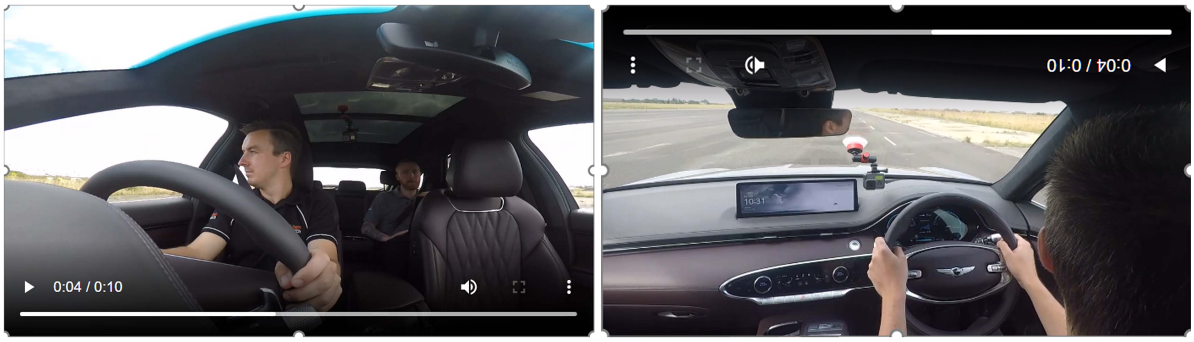

Figure 7 – Example camera views for initial testing

Whilst the camera configuration proved effective at determining the long distraction warning timing for the initial testing, inconsistencies were apparent in the results, both for individual drivers and when comparing between drivers. Reviewing the testing in more detail, three key contributory factors became apparent:

- Although attempting to mimic naturalistic behaviour, the time taken to transition from the forward road view to the gaze location differed between drivers
- With repeated manoeuvres, individual drivers tended to slow their glance transition after delivering the test numerous times
- Using the two camera setup, it was difficult to determine the timing of the driver's glance fixing on the gaze location as required for consistent warning timing analysis

Acknowledging the above findings, the camera setup was developed to include a third camera. Camera one was fixed, observing the driver's gaze on the forward road view and its initial departure. Camera two travelled to each individual gaze location to determine the when the driver's glance arrived at the location. Camera three remained the same as in the initial setup, observing the vehicle warning timing.

Testing was also undertaken with a range of participants and considered by the Working Group to determine typical glance transitions times for the owl and lizard movement types, set at 0.48 and 0.16 seconds respectively. A transition time of one second was also developed for the body lean and viewing the rear seat scenarios, both of which involve greater body movement than the owl and lizard glances.

One vehicle tested was equipped with an almost real time attentiveness meter. It was found that during the normal testing operations e.g., confirming the test scenario, setting cameras recording and checking speed etc. unsurprisingly a reduction in driver attentiveness was recognised, which in turn affected the distraction warning timing. Therefore, to achieve consistent testing, a time period of four seconds eyes on forward road view was specified ahead of initiating the gaze transition. See figure 6 for the complete testing timeline.

With the additional glance timing control limits, refinements to the instrumentation configuration and analysis process, and some test practice delivery by the engineers, repeatably testing was achieved. Owl and lizard glance transitions were being delivered repeatedly to specification and warning timings with a typical spread of

±0.1 seconds around the mean value were consistently measured. The recommendations were wholly adopted into the Euro NCAP testing methodology for driver status monitoring systems [7].

LIMITATIONS

This first iteration of a test and assessment scheme for driver status monitoring systems focuses on tangible forms of inattention, namely distraction, fatigue and unresponsive driver based on the driver's facial orientation, gaze vector and eye opening. The societal issue of mobile phone related distraction is also considered in the scheme. It has been guided by nascent market technology enabling direct monitoring of the drivers face and eyes, and to a certain extent, seating posture.

However inattention whilst driving can take many other forms as illustrated in figure 1 e.g. cognitive distraction such as being preoccupied with one's thoughts, daydreaming, engaging in a conversation with a passenger or on a mobile phone etc., physical distraction such as eating or drinking, holding something, attending to personal hygiene or grooming/preening etc. or impairment through alcohol or drug use. For a future generation of the scheme, expansion to cabin monitoring is recommended and indeed already under consideration to improve the efficacy of driver and occupant status monitoring.

The wider scope may also enable the realisation of benefits beyond those related to driver attentiveness, for example using the additional source of information for more robust confirmation of appropriate seatbelt wearing, optimisation of restraint system deployment acknowledging occupant presence, posture and stature etc. Knowledge of the status of the driver is also a key element of achieving safe automated driving and hand back process to manual driving.

The ultimate achievement for driver status monitoring would be to understand the cognitive state of the driver, e.g., understanding whether not only they have observed something, but have they correctly interpreted it and are they making an appropriate response, to address the so-called 'looked but failed to see' conflicts. An interpretation of the cognitive state of the driver could also enable vehicle parameters to be adapted to their current state of mind to the benefit of all road user safety.

CONCLUSIONS

A test and assessment scheme were developed that was proven to successfully enable the differentiation of pioneer direct driver status monitoring systems for inattention in the form of distraction, fatigue and unresponsive driver. This has been adopted by Euro NCAP to guide the development of new systems entering the market. providing consumers with independent information supporting them making safer vehicle choices.

Parameters for warning and intervention strategies were carefully considered to balance the desire for effectiveness in test scenarios with driver acceptance to achieve real world effectiveness. There is potential for driver status awareness to not only drive performance in critical situations in which the driver is inattentive, but to also quell perceived unnecessary warnings in cases where a driver is attentive and successfully addressing the issue.

The testing requirements for driver status monitoring systems were novel in that the test driver is necessarily the test subject triggering the system. Therefore research testing was conducted to refine the driver glance behaviours, necessary measures and associated instrumentation to deliver repeatable testing.

This initial iteration of the scheme was guided by nascent market technology enabling direct monitoring of the drivers face and eyes, and to a certain extent, seating posture. Future technical innovations will see the monitoring scope increase from that of the driver's face to the cabin of the vehicle, and it is recommended that a future generation of the scheme take full advantage of the opportunities of understanding not only the driver attentiveness, but their seating position and posture, hand position and occupancy etc. as well as the presence and attributes other passengers in the vehicle.

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