Defining Safe Automated Driving

Insurer Requirements for Highway Automation

Thatcham Research

ABI

Contents

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Glossary

ABI	Association of British Insurers
AD	Automated Driving
ADAS	Advanced Driver Assistance Systems
ADIG	Automated Driving Insurers Group
ADS	Automated Driving System
ADSE	Automated Driving System Entity
AEVA	Automated and Electric Vehicles Act
BSI	British Standards Institution
DDT	Dynamic Driving Task
DfT	Department for Transport
DVLA	Driver & Vehicle Licensing Agency in the UK
EC	European Commission
EU	European Union
FMS	Failure Mitigation Strategy
GDV	Gesamtverband der Deutschen Versicherungswirtschaft (German Insurance Association)
HMI	Human Machine Interface
ISO	International Standards Organisation
IWI	Information, Warning, Intervention
MRC	Minimal Risk Condition
MRM	Minimum Risk Manoeuvre
MUSICC	Multi User Scenario Catalogue for Connected Autonomous Vehicles
NCAP	New Car Assessment Programme
NHTSA	National Highway Traffic Safety Administration
NTC	National Transport Commission
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OTA	Over-The-Air
PAS	Publicly Available Standard
PTI	Periodic Technical Inspection
RTA	Road Traffic Act
SAE	Society of Automotive Engineers
UN ECE	United Nations Economic Commission for Europe
VIN	Vehicle Identification Number

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Definitions

Dynamic Driving Task (DDT): The tactical functions (object and event detection and response) and operational functions (longitudinal and lateral motion control) which form part of driving the vehicle. Strategic tasks, such as deciding the destination, are not included.

Automated Driving System (ADS): The hardware and software that are collectively capable of performing the entire DDT on a sustained basis. In this context sustained means that the DDT will be performed by the ADS not just for one external driving event that requires the input of the driver but continuously across multiple such events. The ADS may be capable of complete automation in all on-road circumstances that a human could drive; it may have one automated driving feature within a specified operational design domain; or it may have several different automated driving features each restricted to different operational design domains.

Automated Driving System Entity (ADSE): The legal entity responsible for the ADS. This could be the manufacturer, registered operator of the vehicle or another entity.

Operational Design Domain (ODD): Set of Static and Dynamic operating conditions under which a given ADS is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.

Automated Driving (AD): Occurs when the Automated Driving System takes full responsibility for the DDT from the human driver, who then becomes a User-in-Charge. The User-in-Charge must be available for safe transition of control between the ADS and the driver but is not required to maintain their own safety or that of other road users, while the ADS is in charge.

Automated Vehicle: Any vehicle capable of Automated Driving.

Driving Domain: A high level set of four categories of ODD, representing the classes of driving situation the ADS is intended to function: Parking, City, Inter Urban or Highway.

User-in-Charge: A proposed definition for use in future regulation (Law Commission, 2018). When the ADS is engaged, the User-in-Charge is the person who should be fit and ready to respond to an intervention request, whether planned or unplanned. A User-in-Charge will always be qualified and fit to drive the vehicle and will likely retain obligations in respect of, for example, vehicle roadworthiness and insurance.

Relevant System Failure (RFS): A malfunction in any vehicle system that prevents the ADS from reliably performing the DDT on a sustained basis, according to design intention. This includes mechanical failures that stop the ADS from working as normal, such as a broken track rod end, or a tyre puncture. These mechanical failures may not be detected by the ADS.

Minimum Risk Condition (MRC)/Minimum Risk Manoeuvre (MRM): See Safe Harbour below.

Safe Harbour: A vehicle location or condition to which an ADS or User-in-Charge may bring a vehicle to minimise the risk of a crash when a given trip cannot or should not be completed. This term has been used to communicate the 'minimum risk condition (MRC)' defined by (SAE, 2018) more simply and can be considered equivalent. Thus, a minimum risk manoeuvre (MRM) is the driving manoeuvre that the vehicle must execute to take it from the current driving condition to reach safe harbour.

DDT Fallback: The response by the User-in-Charge to either take over the dynamic driving task or to achieve a minimal risk condition after a relevant system failure occurs, or upon exiting the operational design domain. Also, the response by an ADS to achieve minimal risk condition given the same circumstances.

Failure Mitigation Strategy (FMS): Where a vehicle suffers a relevant system failure and cannot achieve a defined minimum risk condition, the ADS may have an additional failure mitigation strategy designed to bring the vehicle to a controlled stop wherever the vehicle happens to be, if the User-in-Charge also fails to perform the DDT fallback sufficiently quickly.

ADS-Initiated Intervention Request: Notification by an ADS to the User-in-Charge indicating that they should promptly perform the DDT fallback, which may require the User-in-Charge to resume manual operation of the vehicle (i.e. becoming a driver again) or achieving a minimal risk condition if the vehicle is not drivable.

Offer and Confirm: A process where the ADS makes the driver aware that an automated mode is available for use. The driver then confirms that they wish to accept the offer and becomes a User-in-Charge by activating the system using the defined procedure.

Request and Confirm: A process by which either the ADS or the User-in-Charge makes a request for control to pass to the User-in-Charge, of which the User-in-Charge must confirm acceptance and through which the ADS must provide support before the handover is completed.

User-in-Charge-Initiated Handover Request: An input from the User-in-Charge to inform the ADS that the User-in-Charge wishes to resume the role of driver.

Secondary Tasks: Distracting tasks that a User-in-Charge might undertake within the vehicle that do not form part of the DDT. These tasks go beyond the use of systems that are accepted today for manual/assisted driving. Also known as secondary activities.

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Foreword

Automated driving will bring huge changes and opportunities to motorised transportation and will deliver significant benefits in terms of road safety and reduction in collisions and road casualties.

Autonomous vehicles capable of whisking us silently door to door may still be some time away. Tomorrow's reality will be today's cars fitted with Automated Driving technology that will in certain situations enable the user to safely email and watch TV whilst the car takes over the role of driving. However, this first generation of automation will need to restrict these non-driving tasks to use via in-vehicle systems.

In the event that the user doesn't take back control, it is vital that these systems are able to keep the vehicle's user, its passengers and all other road users safe, and this will require the vehicle to take the most appropriate action to reach Safe Harbour.

Whilst these developments are effectively an extension of today's Assisted technology, it does represent a huge change from the insurers point of view because the liability for any accident caused will shift from the driver to the car. And since these changes are relatively subtle there is the real risk that drivers misunderstand their obligations and system limitations, meaning that the in-vehicle displays must make these absolutely clear.

It is therefore vital that vehicle manufacturers design these systems to be safe and that the international regulations that govern functionalities are strict enough to prevent ill thought through technology coming to market as makers race to be first.

This document is the culmination of two years' work of the members of Automated Driving Insurers Group and sets out the Insurers' view on how these systems should function to ensure they do indeed deliver the anticipated societal and crash reduction benefits expected of them.

David Williams
AXA Insurance
Chairman of the Automated Driving Insurers Group

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Executive Summary

Arguably motorised transportation has had the biggest societal impact over the last 100 years. However, as we enter the next automotive paradigm, we will see that engagement fundamentally change as technology delivers almost endless possibilities in terms of making journeys simpler, easier and most importantly safer.

This report is dedicated to defining the safe adoption of automated driving functions in an increasingly complex mobility landscape. Thatcham Research is helping connect the insurance and automotive industries to achieve the consumer and wider societal benefits that the journey towards safe automation will bring.

Automated driving gives the vehicle user the opportunity to undertake secondary tasks not related to driving for at least part of their journey. This is seen as one of the major expected benefits of automation and is, therefore, a powerful economic incentive for consumers and manufacturers. The design of these systems are governed by international regulators who are defining new rules to control the functionality of these technologies.

Twelve criteria detailing the UK Insurers' requirements for the safe introduction of automated driving on the highway are presented in detail in this paper.

Automated driving systems must not lead to confusion, either through system naming or through their use. When the vehicle is in control, the driver becomes the User-in-Charge and must be made aware of this either through an illuminated steering wheel or the instrument panel.

It will only be possible to start automated driving when a combination of dynamic and static conditions are met. Static conditions, such as road type, are predictable whereas dynamic conditions, such as weather or traffic, can change causing the conditions required for automated driving to quickly change.

Initial automated driving systems available in the next two years are expected to have more dynamic conditions meaning that automation will come to an end at short notice when those conditions break down. These systems need to keep the user ready to take back control and so must limit secondary tasks to those available or connected to the infotainment system. User monitoring must ensure that the user only uses devices connected in this way. When the ADS needs to hand over control to the user at short notice, it will still have to support the user until they are safely engaged again in the DDT.

By 2025 we expect to see more advanced systems with the capability to drive in all situations on the highway. Handovers will be planned allowing the system time to bring the user back to driving. This allows the user to have more freedom to do other activities, using their travel time more productively.

Although automated driving in the right contextual conditions is expected to be much safer than manual driving, some accidents will still occur in the increasingly complex mobility landscape. Insurers must be provided with enough data when a collision happens to establish whether the ADS or the human driver was in control. If the ADS was in control, then the human would be a User-in-Charge and able to claim for any injuries sustained.

This document will be extended over the next year to include the other driving domains of Parking, City and Inter Urban.

Jonathan Hewett
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CONTEXT

This document represents the views of the Automated Driving Insurers Group, under the auspices of Thatcham Research and the ABI, in identifying the key requirements of motor insurers regarding automated driving functionality.

It builds on previous documents (ABI, 2018), and includes detailed technical and functional requirements for safe automated driving systems, providing a framework for regulatory definitions. Initially, this is for the Highway (UK motorway) driving domain.

The paper is intended to support international regulators in defining automated driving systems; national regulators in determining their specific requirements for such systems; and vehicle manufacturers in designing safe systems.

It presents a detailed set of requirements which are necessary for safe automation from the insurers' perspective. Previous insurer definitions have been reviewed and updated, recognising technical and regulatory progress and - where possible - increasing harmonisation of terminology with the latest relevant documents from other authorities.

This document should be considered as the insurance industry's core guidelines for the introduction of safe automated vehicles. Requirements will follow for other Operational Design Domain categories, including Parking, City and Inter Urban conditions.

Defining Automated Driving

Automated Driving is when the Automated Driving System (ADS) takes full responsibility for the driving task from the human driver, who then becomes a User-in-Charge and may engage in secondary tasks. The User-in-Charge must be available for safe transition of control between the ADS and the driver but is not required to maintain their own safety or that of other road users, while the ADS is in charge.

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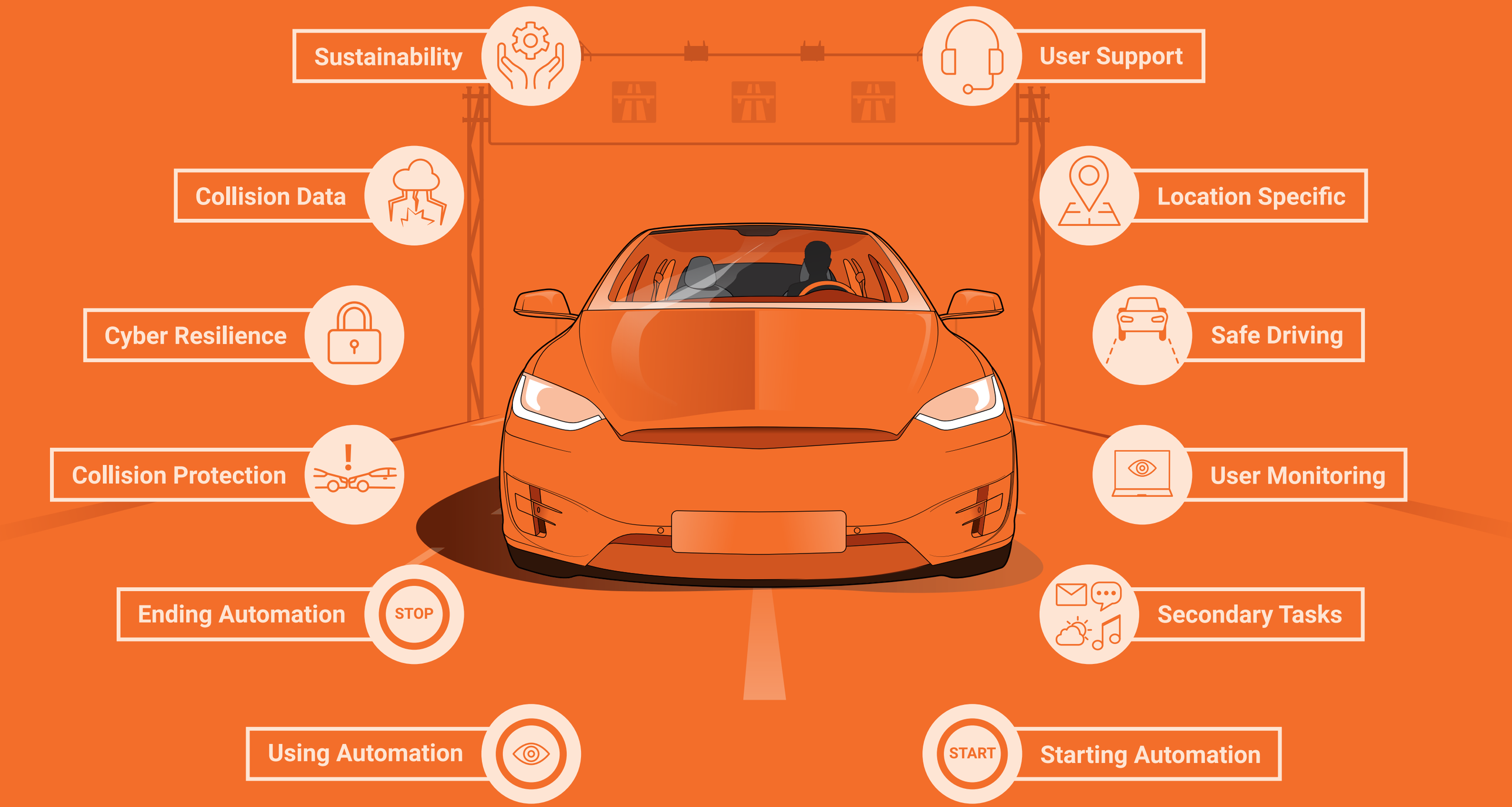

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INTRODUCTION

This document builds upon previous definitions and research to provide a more detailed definition of safe Automated Driving Systems (ADS) with specific reference to their use in a highway environment. In this context, highway has been defined as a high-speed road with a divided carriageway and restricted access for certain vulnerable road users or vehicle types.

Purpose and Audience: The document identifies the key requirements of motor insurers regarding automated driving functionality and represents the views of the members of the Automated Driving Insurers Group under the auspices of Thatcham Research and the ABI. It is intended to support international regulators in defining ADS; national regulators in determining their specific requirements for ADS; and to support vehicle manufacturers in designing safe ADS.

Automated Driving (AD) is when the ADS takes full responsibility for the dynamic driving task from the human driver, who then becomes a User-in-Charge and may engage in secondary tasks. The User-in-Charge must be available for the safe transition of control between the ADS and the driver but is not required to maintain their own safety, or that of other road users, while the ADS is in charge. Automated Driving is part of a framework of systems with different roles and responsibilities (Avery, 2019) as illustrated in Figure 1, below.

Assisted	**1.** Driver retains responsibility and shares control with the vehicle **2.** Vehicle and driver share Object and Event Detection and Response (OEDR) **3.** Driver may not perform secondary tasks over and above those permitted in normal driving
Automated	**1.** Vehicle has full responsibility for control in an ODD defined by the VM **2.** Vehicle performs OEDR **3.** Driver may perform certain other secondary non-driving tasks **4.** Driver needs to be available for transition of control – but not to maintain safety
Autonomous	**1.** Vehicle has full responsibility for control in an ODD defined by the VM **2.** Vehicle performs OEDR **3.** Driver is effectively a passenger **4.** Driver has no ability to control apart from a mode change

Figure 1: Differentiating the levels of automation

For each type of system, the document sets out four driving domains (or ODD categories) where automated driving might be applied and 12 defining principles describing the key requirements that Automated Driving Systems in each driving domain must meet. Depending on the implementation and capability of the ADS, it is anticipated that some SAE Level 3 systems might be able to meet the criteria for AD, but the majority will be classified as assisted with the expectation that their drivers will not be allowed to undertake secondary tasks as they ultimately remain responsible for the dynamic driving task.

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Background

(SAE, 2018) defined 6 levels of automation from 0 (not automated at all) to 5 (full automation on all roads a human driver could navigate). Although designed to define technical functionality these levels are now widely used by vehicle manufacturers, regulators and the media and, as such, have become the most common definition of automation. The extent to which a human driver is required, and the role that they are expected to fulfil changes substantially across SAE Levels 2, 3 and 4, as shown in Figure 2, below.

Studies have shown that the public do not properly understand these different system capabilities and their roles and obligations as drivers. For example, (Euro NCAP, 2018) found that 7 in 10 drivers believed that they can purchase a car today that can drive itself. (Teoh, 2019) found that even the name of systems was important. Almost half of drivers thought it was safe to remove their hands from the wheel of a system named autopilot compared to just over 20% for one named traffic jam assist. Six percent thought it would be ok to take a nap with an autopilot system compared to 3% for other names. When drivers do understand, research e.g. (Merat, et al., 2014) has shown that humans are not good at performing the supervisory and fallback roles expected of them at SAE Levels 2 and 3 respectively. As such, the use of the SAE Levels to define automation provides insufficient clarity.

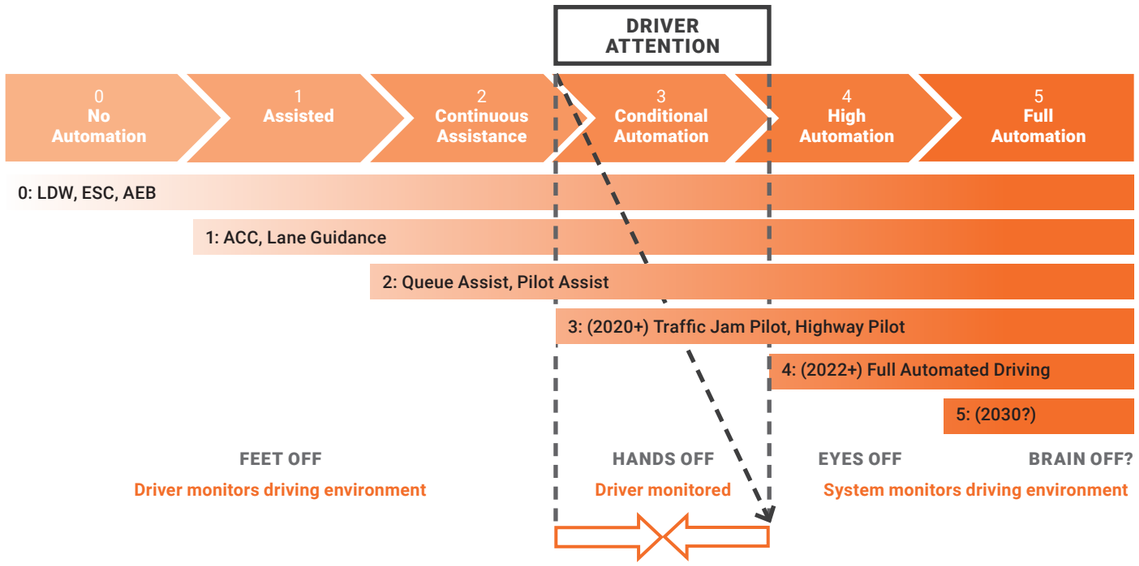

Figure 2: Illustration of the SAE levels of automation

In 2018, the ABI and Thatcham Research produced a report seeking to clarify the difference between systems to avoid confusion when describing vehicles that can 'drive themselves'. That document proposed this binary classification of systems:

Assisted Driving refers to systems that provide **Continuous Assistance** to the driver, meaning technologies that combine speed control and steering assistance working together. The driver is ultimately in charge of and must remain actively engaged in the dynamic driving task (although not necessarily have hands on the wheel) and constantly monitor the road environment. Vehicles with these systems, can be regarded as having a comfort feature that offers safety benefits and are generally equivalent to SAE Level 2.

Automated Vehicles are those with **Automated Driving Systems** that enable the vehicle to take full control of speed and direction and allow the user to engage in other tasks not related to the control of the vehicle. When automation is limited to specific areas, these vehicles are equivalent to SAE Level 4. A vehicle capable of full door to door automation would be regarded as SAE Level 5.

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Regulatory perspective

International Regulations on the approval of new vehicles will define the functional requirements for different Automated Driving Systems and will permit their sale in all countries that are parties to those agreements. These will define the construction of vehicles. However, how drivers use the vehicles is a matter for national legislation and individual countries will need to review and amend their own legislation in order to control, for example, the extent to which drivers can undertake secondary tasks or to establish requirements for mandatory insurance cover and the assessment of liability.

UK: The Automated & Electric Vehicle Act, (AEVA) states that "Automated vehicles are those that have the capability of driving themselves without human oversight or intervention for some, or all, of a journey. In an automated vehicle the driver can, in at least some circumstances or situations, hand all control and responsibility to the vehicle and effectively become a passenger, using it in automated mode." It defines how automated vehicles will be identified and insured.

The Road Traffic Act 1988 and the Construction & Use Regulations 1986 define driver responsibilities at the wheel and will need amendments to permit automated driving.

Most regions that have taken action on Automated Driving Systems for example (NHTSA, 2017) (NTC, 2018) have based definitions on the principle that the vehicle is only automated when the driver is free to safely undertake tasks unrelated to the operation of the vehicle (known as secondary tasks).

However, regulators and insurers face very important decisions based on this definition: Laws will need to be changed to allow the driver to undertake secondary tasks. To make these decisions, criteria must be available to precisely identify those vehicles that qualify as safely automated and those that don't.

Definitions of automation relying only on the extent to which the driver is required for the dynamic driving task shift the responsibility for creating a more detailed technical definition to the regulators responsible for in-use regulations which control what drivers can do, or to the manufacturers.

The SAE definitions clearly state that they impose no requirements on systems, nor do they make any judgement in terms of system performance or safety. The levels only reflect the design intent for the ADS feature and are assigned subjectively based on the manufacturer's knowledge of the system's design, development and testing.

In jurisdictions where regulations are based on mandatory self-certification (e.g. USA), this formally allows regulators and, by extension, insurers to defer the detailed decision as to whether a specific system is automated to the manufacturer, who is in the position of greatest knowledge. However, in jurisdictions that require pre-market approval (e.g. Europe), the regulatory authority must determine whether a vehicle should be approved for sale or not. The decision would usually be implemented by independently certifying that test results, calculations or audits of design documentation demonstrate that detailed and objective technical criteria have been met.

This document is intended to encompass the two regulatory approaches and aims to:

- Review and update the previous insurer definitions, acknowledging technical and regulatory progress
- Where possible, increase harmonisation of terminology with the latest relevant documents e.g. (SAE, 2018) (Law Commission, 2018) (NTC, 2018) (NHTSA, 2017), Safety First for Automated Driving 2019 https://www.daimler.com/documents/innovation/other/safety-first-for-automated-driving.pdf
- Further develop the framework of requirements to provide more detailed technical and functional definitions of safe ADS to provide a framework for regulatory definitions

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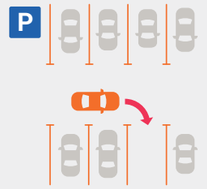
DRIVING DOMAINS

It is recognised that a wide variety of ADS are being proposed with different and, in some cases, very specific Operational Design Domains (ODDs). The detailed technical content that is applicable to any specific ADS will be heavily dependent on the ODD. However, it is not practical to create a separate regulation for every variation of ODD. Therefore, broad categories of ODDs, which are defined as Driving Domains, have been created to support the definition framework. Thus, it is envisaged that key high-level criteria will be applicable in each driving domain, but detailed technical requirements derived from each of the criteria may be different in each driving domain. This allows the regulatory approach to start with simpler driving domains and to remain flexible enough to work for a wide variety of ADS with more limited ODD within that category. It also allows for simplified communication to consumers. Four driving domains are defined below.

Detailed ODDs can be characterised as having a combination of Static and Dynamic conditions. These are important in that the static boundaries such as road type are fixed and predictable when entering or leaving the ODD. Dynamic conditions such as traffic speed and weather can cause the ODD to break down quickly or with little warning.

Driving Domain Definitions



Parking

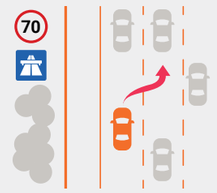
Operation at low speed (< 10 km/h) within designated parking facilities.

City (Urban)

Operation on divided or undivided carriageways in densely built up areas with speed limits of ≤ 60 km/h. Including operation in areas with no restriction on the access of other road user types (pedestrians, cyclists, large vehicles, powered two wheelers etc) and across a wide variety of junction designs and complex, unusual traffic conditions.

Inter Urban

Operation on divided or undivided carriageways in rural or lightly built up areas with speed limits of ≤ 130 km/h. Including operation in areas with no restriction on the access of other road user types (pedestrians, cyclists, large vehicles, powered two wheelers etc) and across a wide variety of junction designs and complex unusual traffic conditions and may be characterised by less consistent road marking and signage.



Highway

Operation on divided highways (with each direction of travel physically separated by a central barrier) that do not grant access to pedestrians, cyclists and very slow-moving vehicles. Effectively Motorways in the UK.

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KEY CHALLENGES WITH INITIAL AUTOMATED DRIVING SYSTEMS

In many aspects of regulating the safety of automated driving systems, stakeholders are in agreement of the outcomes that need to be achieved, and it is only the very complex technical detail of how to achieve them that needs resolution. However, there are some fundamental underlying issues where there is significant divergence between industry and other stakeholders as to what outcomes should be permitted. These are more controversial.

Some of the key concerns of insurers centre on the role of the driver and their interaction with the automation provided by their vehicle, whether assisted or automated:

- **User Understanding** – Does the user know what role they are expected to fulfil and fully understand its implications?
- **User Ability** – How easy or difficult is it for the user to fulfil their role, even where it is fully understood?
- **User Abuse** – How likely is it that users know what role they should fulfil but deliberately try to abuse the system?

Evidence has shown that these are legitimate concerns:

- Surveys suggest that many drivers over-estimate the abilities of current systems (Euro NCAP, 2018) (Teoh, 2019)
- A range of evidence from automation in other industries (Kyriadis, et al., 2017) suggests humans are poor supervisors of automation and (Wiggerich, 2019) showed examples of drivers appearing attentive but failing to perform emergency avoidance situations under assisted driving
- Users engaged in secondary tasks during automated driving can take as long as 45 seconds to regain proper situational awareness and control of driving after automation ends (Merat, et al., 2014)

The response of the human driver can be very important in the following situations:

- **False Negatives** – The system fails to detect and respond to a situation that it should e.g. a potential collision situation
- **False Positives** – The system takes some distinct action in a situation where it should not make any change e.g. the system adds a substantial steering input when the lane continues straight ahead, perhaps a consequence of false detection of a curved lane marking
- **End of Automation** – When the system reaches the end of its operational design domain, can no longer safely execute the DDT and requires the User-in-Charge to resume the role of driver

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The number of collisions that can be expected as a result of any of these factors will simply be the product of the level of risk that they pose and the exposure to the risk. The number of collisions can be mitigated by controls intended to reduce the frequency with which relevant situations occur or by controls intended to reduce the level of risk.

Assisted driving systems require the driver to retain responsibility for safe driving and to supervise any part of the dynamic driving task that the system is automating. The reason that the human has this role is because the manufacturer does not yet believe the system is competent enough to deal with all circumstances it will encounter within the ODD. As such, the frequency of both false negatives and false positives could be relatively high and the inclusion of the driver as a fall back is intended to mitigate the level of risk to limit the overall number of collisions. Early evidence suggests that false negatives are the main safety concern in assisted driving with at least three publicly identified fatal collisions where the system failed to detect a readily identifiable hazard such that it did not warn the driver (or warned too late) and the driver also failed to detect the hazard because they were engaged in secondary tasks.

Simple risk mitigations are intended to reduce the risk by ensuring the driver remains attentive, for example by sensors detecting that the driver is making steering inputs. Where inattentiveness is detected at any stage (i.e. not awaiting a critical moment when driver input is required), then the system may end the assistance. This might minimise the level of risk posed from false actions of the assisted system, but it increases the frequency of 'end of automation events'.

For automated driving, there are important differences. In automated driving, the user should be free to undertake secondary tasks and so will not be actively monitoring the DDT or supervising the system. In either a false positive or a false negative situation, the ADS believes (mistakenly) that it is taking the right action. So it will not warn the user in any way that they need to take over the dynamic driving task. Where the user is allowed to be inattentive and the system takes no action to warn the user, the level of collision risk is extremely high and there is little if any means of controlling that risk. Thus, all risk mitigation efforts must be focussed on minimising the frequency with which such situations occur.

In most jurisdictions, the vehicle manufacturer may become liable for collisions occurring during automated driving. The financial risk of this will provide strong incentive for manufacturers to produce high quality systems. Regulations should formalise a minimum standard that manufacturers should go to in this design process, although the technical details of how that should be achieved are still evolving.

In the UK, the Automated & Electric Vehicle Act ensures that where collisions caused by a vehicle operated by an ADS occur, claims will be made against an insurer in the first place. For these events, the User-in-Charge will also be entitled to compensation for any injuries sustained meaning that each collision has the potential for an additional personal injury claimant. However, insurers will have a right to pursue recovery against the ADSE, where their system was in control at the time of the collision or where there was fault or failure in the ADS that resulted in the collision. For liability disputes to be fairly and speedily resolved, data must be equally and equitably accessible to both manufacturer and insurer to establish whether driver or vehicle was in control at the time.

The remaining concern is what happens when the system reaches the end of its ODD, either by static, predictable conditions (e.g. leaving the highway at your pre-planned destination) or by dynamic uncertain conditions where the ODD has 'broken down' (e.g. sudden change in weather or traffic situation). In many current examples of assisted driving, the predictable exit does not apply because activation is not restricted by geography. However, ODD breakdowns do occur as a result of weather and, if the basic 'hands on wheel' sensing detects an 'inattentive' driver then, existing systems will typically either:

- Deactivate, immediately causing the vehicle to revert to full manual control
- Bring the vehicle to a progressive controlled stop in a straight line

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Inattention is the largest contributor to serious collisions, representing a contribution of up to 54% of fatal collisions in the UK.[1]

[1] DfT Transport Statistics table RAS50001 for 2017 comprising driver failed to look properly (26%), impaired by alcohol 9%, impaired by drugs 7%, impaired by fatigue 4%, driver using mobile phone (2%), distraction in or outside vehicle (6%). Note that some accidents may be contributed to by more than one of these causes such that summing them presents an over estimate of the total contribution by 'inattention'

If an ADS system was simply deactivated because a driver was inattentive or too slow to respond to an ADS-initiated handover when the end of automation was reached, or because inattention was detected then an inattentive driver is left at the wheel of a fast-moving motor vehicle. Inattention is the largest contributor to serious collisions, representing a contribution of up to 54% of fatal collisions in the UK . Adding to road fatalities is not acceptable. Similarly, stopping in a live traffic lane on the highway presents a clear risk of a serious collision from the rear as well as introducing a new hazard to the other vehicles in the same lane. In general, this will only currently occur in relatively rare cases of breakdown where drivers are unable to pull over to the side, where drivers fall asleep in traffic jams and then the traffic clears, or where an accident occurs and a vehicle is stranded in lane. Collisions with such vehicles can and do occur but the low exposure to risk ensures the total numbers remain relatively small.

The first proposals for systems automated in the highway domain (Audi, 2017) and the associated draft legislation for automated lane keeping systems (UN ECE, 2019) also base the required minimal risk condition on a progressive stop in lane. Insurers' main concern with these proposals is that they are both aimed at an ODD centred on 'traffic jam' type situations where traffic is moving at relatively low speed (≤60 km/h) on highways with a speed limit of up to 130 km/h. Traffic is transient and congested speeds of 50 km/h could change to busy but more freely flowing traffic of 80, 90 or 100 km/h or more in a much shorter time than the 45 seconds that some human factors research thinks is necessary to safely bring a driver back into the loop. This will potentially have a significant impact on road safety.

Stops in live traffic lanes that currently occur in line with the frequency of catastrophic vehicle failures (one event in hundreds of thousands of vehicle kms) could potentially now occur several times in one single congested journey. The level of risk would be unacceptably high if the ADS could not continue to operate correctly in the absence of surrounding traffic, for example. This has the potential to greatly increase the number of high-speed collisions with stationary vehicles. However, the risk may be less if speed was the main restriction and, in the absence of surrounding traffic, the ADS could continue to operate safely at its maximum speed even though surrounding traffic was travelling much faster.

There are several ways in which these risks could be mitigated:

- Reducing frequency by keeping the user in the loop
- Reducing frequency by using aggressive and effective means to quickly bring the driver back into the loop
- Reducing the frequency and/or level of risk by restricting permissible ODDs to avoid systems carrying the worst of the risks
- Reducing the level of risk by the use of safer minimal risk conditions

In spite of these mitigating actions, insurers consider that there is still an increased risk which is unacceptable for safe automation and so systems that can only stop in lane should not be classified as automated.

This document proposes controlling this risk through measures intended to ensure that where a breakdown of the ODD may happen, the user is kept in the loop as much as possible. It also proposes controlling the level of risk when the situation occurs, by requiring a more sophisticated minimal risk manoeuvre wherever possible.

In line with the principles of performance or outcome-based regulation, insurers are open to consideration of any solution that can be shown to control the risks as well as, or better than, the current proposal.

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AUTOMATED DRIVING DEFINITION

Challenges for UK Motor Insurers

The new challenges that Automated Driving Systems may bring to motor insurers can be summarised as follows:

- Motor insurers will become liable for accidents caused by an Automated Vehicle whilst it is operating in an Automated Mode, i.e. it has an ADS engaged and is driving itself

- Under the definition of a User-in-Charge, when the ADS is activated, they will be a 3rd party to vehicle control and they will be entitled to compensation for injury if an accident is caused by their own vehicle's ADS. This potentially introduces an additional claimant in each such case

- Since the driver will only be entitled to make a claim under such a system when the vehicle is operating in an Automated Mode, identifying whether the human or the ADS was driving is critical and therefore it will be vital that their insurer has immediate access to sufficient data from the vehicle to determine whether an ADS was engaged at the time of the incident

Manually driven, Assisted and Automated Vehicles are expected to share roads that are not likely to change substantially for some considerable time. A mixed and evolving fleet will represent an ongoing risk to insurers for an equivalent period of time.

We expect these challenges to be seen by insurers in other jurisdictions.

Motor Insurer Response to the Challenges

Motor insurers have four main requirements for Automated Driving:

- **Clarity of Definition** – A set of criteria to define Automated Vehicles and to differentiate them from Assisted Vehicles, as well as providing a high-level framework for technical and functional regulation of Automated Driving Systems

- **Clarity of Operational Design Domain** – Clearly defined, controlled and understood

- **Clarity of Function (Automated)** – Dynamic record of vehicles capable of Automation

- **Clarity of Liability (Automated)** – Accident data must be immediately available on a neutral and equitable basis to both the insurer and manufacturer to establish who was driving in an Automated Vehicle accident

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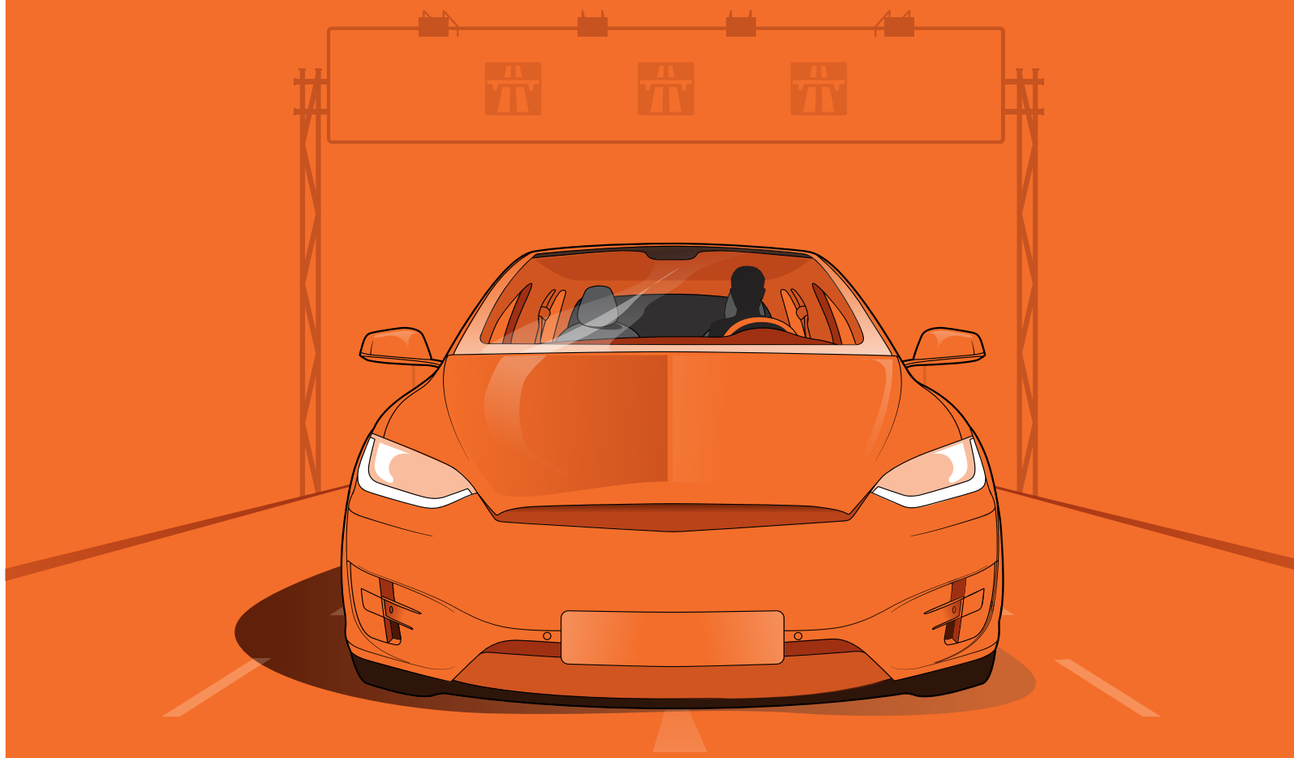
Defining Automated Vehicles

It is crucial that there is a clear definition of what constitutes an Automated Vehicle so that:

- Insurers can classify and provide insurance cover for these vehicles appropriately
- Regulators can control the safety performance of vehicles and can amend legislation around the ability of drivers to undertake secondary tasks with precision and confidence
- Drivers and enforcement authorities understand the role of the driver in any given circumstance

Key criteria for safe automated driving are proposed based on evolving the consumer-centric definitions in (ABI, 2018):



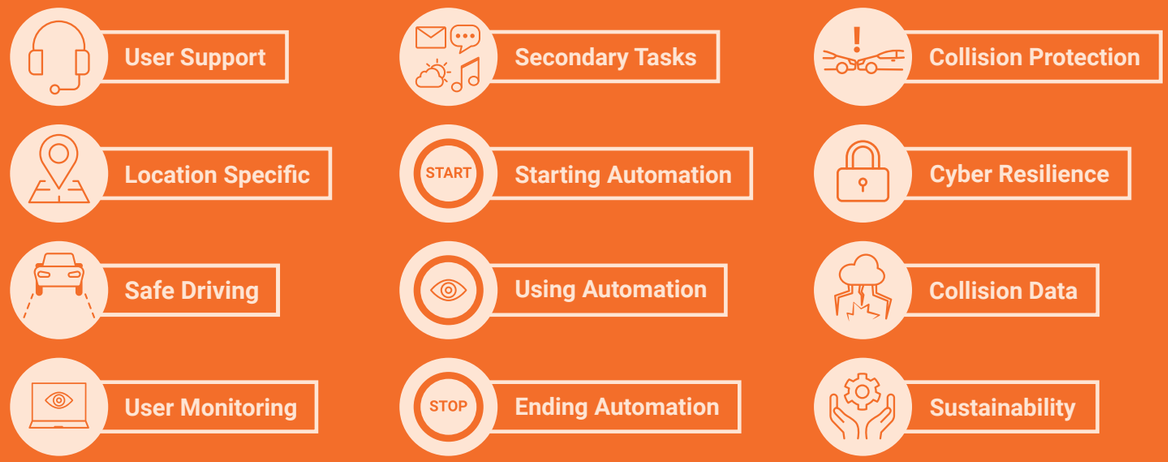


Figure 3: Twelve key criteria defining safe Automated Driving

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1. User Support: Information, Naming & User Obligations

Manufacturers must eliminate consumer confusion. System naming, information in adverts and manuals must all be appropriate for the driver role. Automated Driving will be differentiated from assisted driving systems by clearly different user interfaces. Vehicles must ensure and validate that drivers understand the system functionality and their roles and obligations in Automated Driving before automation can start. The system must be inherently simple and intuitive to understand that the need for training is minimised. This must be supported with clear and detailed information, at the dynamic VIN level, for insurers and regulators.

2. Location Specific: Operational Design Domain (ODD)

Defined in detail by the manufacturer as the static and dynamic conditions necessary to enable the ADS and constantly monitored by the ADS to ensure that Automated Driving is only available while ODD conditions hold. The ODD must be capable of accurately identifying when conditions are met and predicting when they will end. System ODDs shall be published by the manufacturer.

3. Safe Driving: Automated Driving System (ADS) Capabilities & Behaviour

The ADS must be reliably capable of all driving tasks within the ODD, interact predictably with other road users, and obey road traffic laws. Where software updates change the characteristics or capability of an ADS they shall be subject to regulatory approval for subsequent new vehicle sales. The same standards must also be applied to software updates applied to vehicles already in the market place. A robust 'safe system' design process, comprehensively tested and validated, must be followed.

4. User Monitoring

Active user monitoring is essential and must not rely on 'hands on wheel' detection alone. The system will monitor the user attentiveness state from when they activate the system to the point when they are fully engaged with the DDT once more. User attentiveness will be used by the ADS to determine the best strategy for managing safe handover.

5. Secondary Tasks

Distracting secondary tasks, such as using a mobile phone, when driving are currently prohibited by law. This will need to be amended. Where an unplanned handover from automation is expected, secondary tasks must be limited to those available through the vehicle infotainment system to ensure that the user be reengaged with the DDT at short notice. Where only planned handovers are expected, additional secondary tasks may be permitted.

6. Starting Automation

Automated Driving shall only be possible when the ODD conditions are met, self-diagnostics confirm system health and the driver is in a fit state. It will be initiated through a clear 'offer and confirm' process.

7. Using Automation

Whilst the User-in-Charge will be able to undertake appropriate secondary tasks while the ADS is in control, user monitoring must manage the user attentiveness to ensure that they are ready for handover at the appropriate time.

8. Ending Automation

The operation of the ADS may be ended in various ways.

- **Planned handover** – For example, when a static ODD condition such as a highway exit is approached. This will result in the ADS initiating a managed handover of control giving the driver sufficient time to reengage with the DDT
- **Unplanned handover** – For example, when the dynamic ODD condition such as weather quickly changes. This will result in the ADS initiating a warning process to engage the driver with the DDT immediately
- **User-in-Charge initiated handover** – Follows a multipath Request and Confirm process to resume the DDT
- **A system failure** – ADS initiates a warning process to engage the driver with the DDT immediately. The system must maintain the capability to perform an MRM

All handovers of responsibility for the driving task shall use the clear 'Request and Confirm' process. The system must monitor the driver and provide support until they are fully re-engaged in the DDT.

The ADS shall achieve safe harbour if the User-in-Charge, or the ADS, fails in their role. The exact minimum risk condition that will constitute safe harbour will vary according to the circumstances. Stop in lane will not be an acceptable default safe harbour.

9. Collision Protection: Collision Avoidance & Protection

The vehicle must be equipped with emergency collision avoidance technology that can react to all foreseeable critical situations in the driving domain. Emergency collision protection technology must engage when ADS is operating. Vehicles will also require state-of-the-art passive safety protection.

10. Cyber Resilience

ADS must be designed, developed and maintained to minimise the vulnerabilities and the consequences of cyber intrusion. The ADS, and any over-the-air updates, must minimise cyber security risks in both technologies and organisations, requiring certified compliance with ISO 21434.

11. Collision Data

Vehicle manufacturers must make a limited data set available to insurers, without charge, confirming whether the ADS or the human driver was in control leading up to a collision. The data recording must be triggered in all collision and emergency system intervention situations.

12. Sustainability

The emergency collision avoidance systems must be tolerant of sensor degradation and maintain full functional performance for at least 10 years. Their software system must have full functional support for 10 years. Systems must be designed to be self-healing for minor damage and display tell tales if a fault is detected. Periodic technical Inspection must be updated to validate safe emergency collision avoidance system function.

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Ending Automation Safely

There are four processes which will be used to exit automation. Whilst the detailed requirements cover these, this section is intended to build understanding.

Focussing on planned and unplanned handovers, the ADS must manage the safe transition of control to the driver in scenarios which are dynamic. This means that the ADS may have limited time to re-engage the user as driver so it is important for the user to be supported as they re-engage with the DDT.

Planned Handover
Responsive Driver

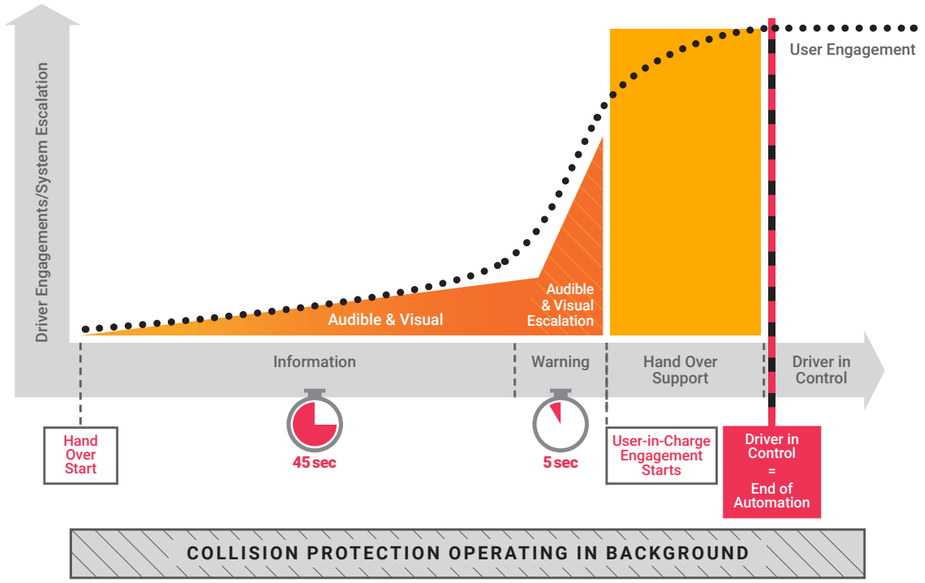

Figure 4: Planned handover example – responsive user

In the case of a planned handover when a static, predictable ODD end condition is approached, such as end of highway. The ADS initiates a planned handover of control informing the user with sufficient time. The responsive user (Figure 4) shows the user engaging during the information countdown.

Research suggests drivers typically need 12-15 seconds to take back control (Kuehn, et al., 2017). This contrasts to research by (Merat, et al., 2014) where it took up to around 45 seconds for the driver's control to fully stabilise. In combination, this research supports an allowance of 15s for the driver to physically take back control and the continued provision of post-handover support to the driver.

Handovers will follow an information, warning and intervention (IWI) approach.

After the warning starts, the user starts engaging with the system. Although the user is now steering, with their feet on the pedals and eyes on road, the ADS will continue to monitor and support the user until they have fully re-engaged with the DDT. At this point automation ends and the driver is in control again.

Unplanned Handover
Responsive Driver

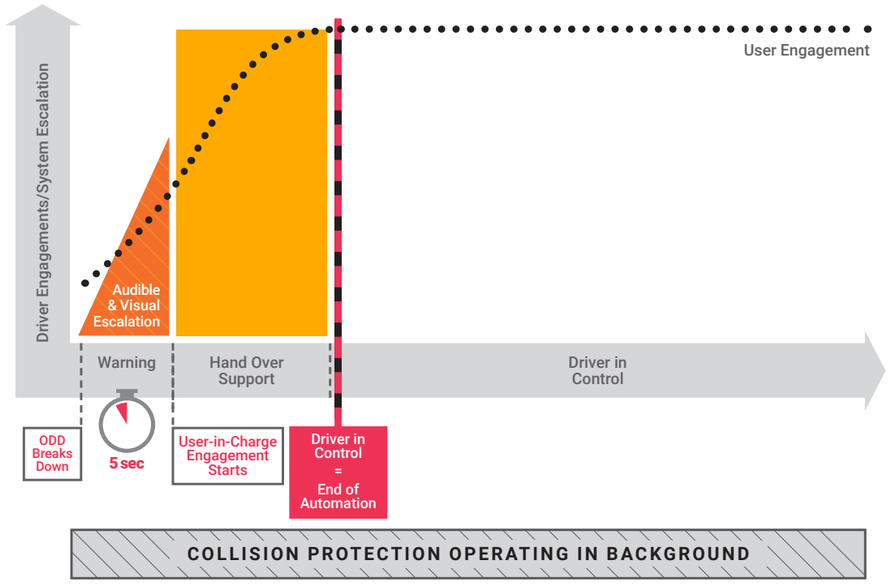

Figure 5: Unplanned handover example – responsive user

In the unplanned handover where a dynamic ODD condition such as traffic dissipating occurs, the ODD breaks down dynamically and the system must start with a user warning to re-engage the User-in-Charge immediately. The responsive user (Figure 5) needs significantly more support after starting to re-engage to ensure they become fully re-engaged in the DDT. The ADS provides support to the user until they are fully engaged. At this point the user becomes the driver and automation ends.

As with all these examples, the collision protection features provide background support throughout.

These two examples have considered engaged users who take back control before the need for the system to intervene. The following examples consider what happens when the User-in-Charge does not re-engage.

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Planned Handover
Unresponsive Driver

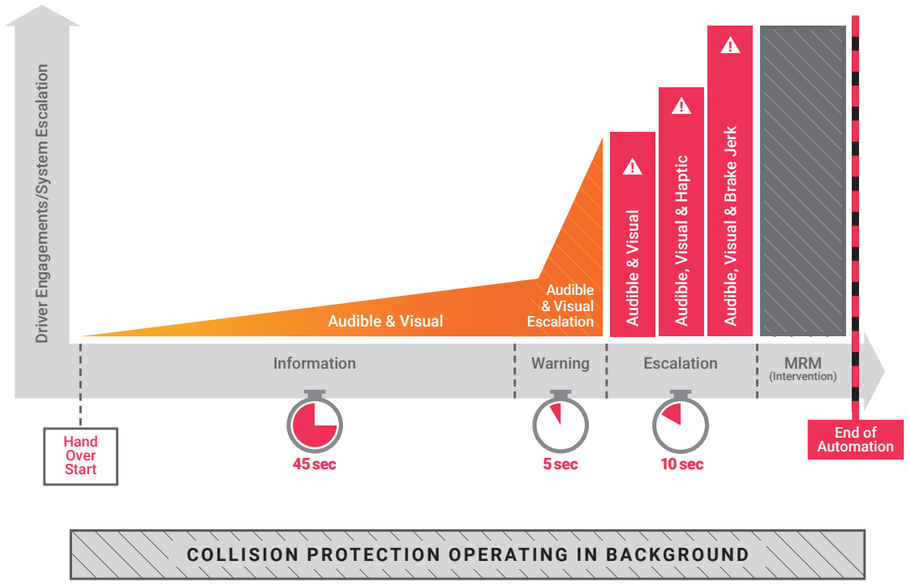

Figure 6: Planned handover example – unresponsive user

Figure 6 shows the timeline for a planned handover where the user does not re-engage with the DDT. Once again the system proceeds through an information countdown followed by an escalating series of warnings becoming increasingly intrusive to the user over 15s. If they do not take control at this stage then the ADS will intervene and carry out a MRM. Automation will end once the vehicle has reached safe harbour.

Unplanned Handover
Unresponsive Driver

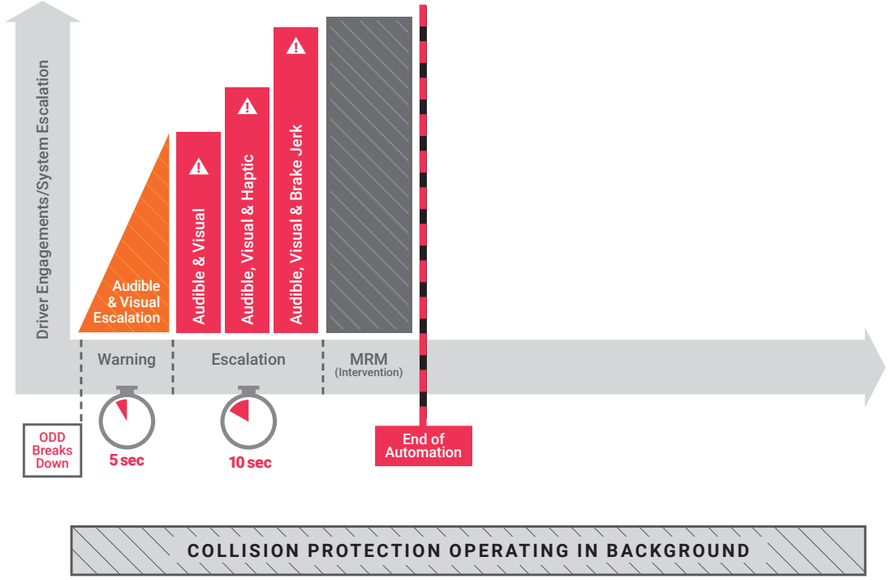

Figure 7: Unplanned handover example – unresponsive user

The final example (Figure 7) demonstrates the similar process for an unresponsive user but with an unplanned handover. The user will again have 15s from start of warning to the MRM intervention being initiated by the ADS.

In the event of a system failure, it may be possible for the system to follow an unplanned handover process, with a short transition of control back to the driver. However, a severe system failure may mean that control must be handed back immediately because automated functions, such as the ability to carry out a MRM, are no longer operational – this is expected to be rare.

A User-in-Charge initiated handover must follow a multipath Request and Confirm process to ensure that false take back of control does not occur. The system will still need to provide monitoring and support to the user in this scenario as they re-engage with the DDT and become the driver again.

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The driver will be re-engaged when they exhibit a sufficient level of situational awareness combined with driving process control. Situational awareness can be defined as the ability to scan the environment and sense danger, challenges and opportunities while maintaining the ability to conduct normal activities. Situational awareness is the subject of much human factors research and certain measures such as measuring anticipation (the ability to read situations and act earlier) have been used in driving research. Process control is simply the normalisation of steering, acceleration and braking functions as the driver retakes control. Thresholds will need to be set for these criteria with support from ongoing human factors research.

The example stepped warnings provided are:

- **Audible and Visual** – Clear alert sounds and illuminated steering wheel starts flashing
- **Audible, Visual and Haptic** – Alert increases in volume and pitch, steering wheel flashes increase frequency, haptic feedback through seat or reversible retractor
- **Audible, Visual and Brake Jerk** – Alert increases again in volume and pitch, steering wheel flashes increase frequency, haptic feedback through brake jerks

For initial systems, unplanned handovers are expected to be the main cause of the ODD ending. Typical causes for these handovers would include:

- Roadworks with reduced lanes
- Heavy rain and other adverse weather
- Missing road markings
- Entering a tunnel

As technology and systems advance, these unplanned handover scenarios are expected to be within the ADS capability meaning that the user can engage in a full range of secondary tasks.

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ASSESSING AND VERIFYING THE PERFORMANCE OF AUTOMATED VEHICLES

Assuring minimum standards of performance through type approval regulation has traditionally involved the definition of a sufficient number of tests and limit values to ensure that, in typical real world situations, the feature performs to the standard. For traditional safety features such as the crashworthiness of vehicles, a small number of test conditions are defined that are considered representative of real world collision types. It is accepted that not all variations of crash type are tested but that the goal of setting a minimum standard across the industry is achieved and this has proven effective at helping to drive down the number of road casualties.

As technology has evolved and become more complex, this model of regulation has had to adapt. For example, Autonomous Emergency Braking systems (AEB) are known to suffer false positive activations but the conditions in which this might occur are rare and highly variable. The regulation of these systems contains a single, very simplistic, test of false activation that, in isolation, represents a very low minimum standard of performance. However, a standard set of requirements to control the safe design of complex electronic control systems was developed and implemented in a variety of different regulations where complex electronic control might be a feature. This is based on an audit of the design process using principles of system safety and functional safety.

The development of ADS represents a step change in complexity of software and electronic systems compared with systems such as AEB. Currently no vehicles are on the road that can meet the definition of an automated vehicle proposed in this document. The traditional approach will not be sufficient for this level of complexity and the lack of experience with real technology at this level makes it difficult to be prescriptive without the risk of serious adverse unintended consequences, either directly on safety or indirectly through inhibiting innovation and development in the field.

A new approach is needed which must be able to economically test a significant number of expected driving scenarios as well as more extreme scenarios. Most testing will need to be in a virtual environment with validation from on road and track testing. The testing framework will establish both the consistency of vehicle behaviour between the real and virtual scenarios as well the overall safety of the system.

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For these reasons, the insurance industry supports a hybrid approach involving three main elements:

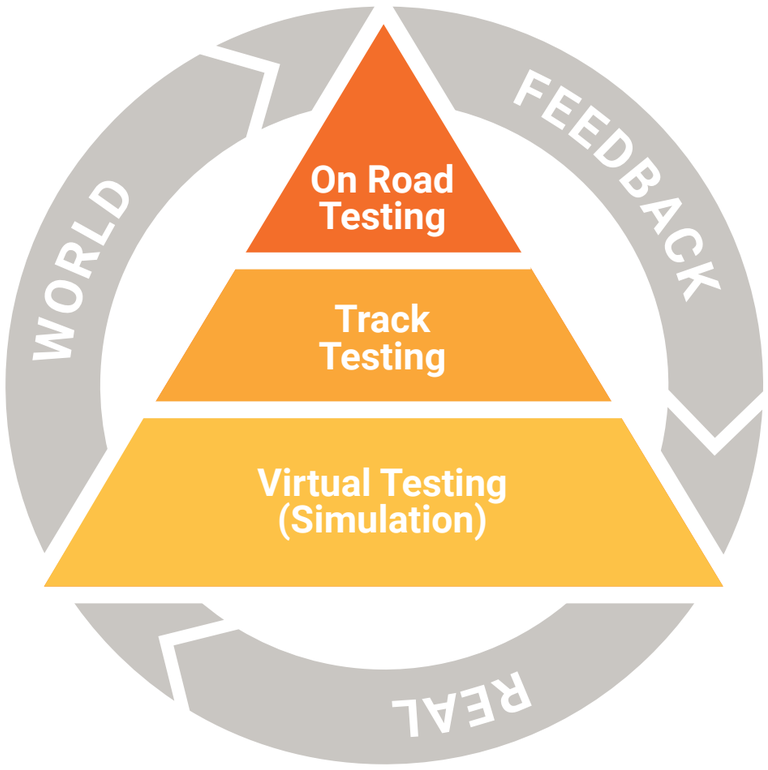

Figure 8: Proposed four part test and assessment cycle

Virtual Testing (Simulation)

The manufacturer shall assess the functionality of the ADS through simulation in a virtual environment to test the perception and decision parts of the ADS in a wide range of typical critical and non-critical driving situations representing a large proportion of all situations the ADS will experience in its ODD in real service. The assessment must cover normal, continuous, driving, emergency situations, exiting the ODD and system failures with and without appropriate driver responses. The manufacturer's evidence of testing and design processes must be audited utilising a standard set of scenarios, such as the MUSICC database currently being developed. This, in turn, should include examples of each of the 338 crash type scenarios identified in insurance industry research (BAST & GDV, 2003) where they are applicable to the ODD.

Track Testing

A random selection of the simulated driving scenarios should be recreated on the test track to physically check basic perception and manoeuvring capabilities, emergency/collision avoidance capabilities and complex edge case scenarios. In each case the result must be both that acceptable performance was achieved on the test track and that the result was in line with the equivalent simulation. Test results must demonstrate consistency between the simulated and track tests. There will be some variation in the outcomes and a degree of tolerance must allow for this to reflect differences in specific conditions.

On Road Testing

This will subject the vehicle to a wide range of scenarios during a sustained period of driving on the road. This will add an element of the random nature of public road testing to the simulation and track testing and evidence should be collected to prove that all requirements were met during the drive. Ideally this testing should be conducted in an environment with a digital twin so that the real world driving experience can support the validation of the simulation results. The scenarios encountered in this test will remain a small sample of the total that might be encountered in normal driving but, if structured in a similar way, could be considered analogous to the driving test for human drivers.

Real World Feedback

Real world feedback, for instance from insurers, would be used to refine and augment the test and assessment process to improve future safety and functionality.

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FUNCTIONAL REQUIREMENTS IN THE HIGHWAY DRIVING DOMAIN

User Support: Information, Naming and User Obligations

This section provides more detailed specifications defining automation in a way which could be translated into regulatory requirements. Currently, this has been completed for the Highway driving domain. It will be expanded to include other driving domains over time.

For each of the 12 criteria, technical requirements are presented with a proposed test approach; reasoning for the requirements is covered in the justification section; and a box is included for UK specific examples where appropriate.

Technical requirements

Naming

System naming must clearly describe the functionality available both in terms of capability and ODD. Naming shall not mislead consumers on the capability of the systems on the vehicle. Any feature capable of sustained operation of lateral and longitudinal control of the vehicle that cannot meet the requirements of this document shall be designated as an Assisted Driving feature.

Where features of an ADS meet the requirements, then manufacturers are free to use 'automated' and variants of this in combination with 'driving' in the naming ensuring that the ODD is made clear.

Information and HMI

The vehicle is likely to be equipped with more than one discrete driving automation system. Information about each of these must be supplied and include, as a minimum, whether they are assisted or automated; the driving domain they operate in; details of the ODD conditions; and the role expected of the driver (in accordance with local vehicle usage laws). This must be provided in user manuals but also in digital databases, linked to specific vehicles at VIN level.

In-vehicle information must clearly display the current driver status in the DDT and the ADS functionality driving the vehicle (where multiple ODDs may provide different functionality). The user displays for automated driving must be clearly differentiated from the assistance and manual functions. A good example of this is steering wheel illumination which can be used to indicate automation available; automated driving engaged; and visual handover warnings.

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User Obligations

Systems must be designed to be simple and intuitive to understand such that training requirements are minimised, as with other core systems such as steering.

The on-board systems shall ensure that each vehicle user understands their obligations under each automated function before they can engage it. For an ADS, this must include how to start automation, the user's role when the ADS is driving, and the process for ending automation.

The ADS must only offer automation if the driver has acknowledged understanding of ADS operation, updates and their obligations when using the system.

The system must reflect any changes to the ADS capabilities from over-the-air (OTA) updates which require additional information to support user understanding.

Test and Assessment

This will be evaluated in the on-road assessment by reviewing information supplied and attempting to activate systems without having first acknowledged user understanding.

Justification

Naming

Research (Teoh, 2019) has clearly shown that the naming of a driving automation system has a strong effect on the driver's perception of its capability and their expected role. Many drivers misunderstand the role that they need to take and this will potentially be exacerbated with the introduction of more advanced systems with differing capabilities. It is essential that the driver has no confusion over the vehicle's functionality and the driver's responsibility.

Naming needs to reflect the system capability which is expected to be enhanced over time through OTA updates. While it is important for consumers to understand the capability of their system at point of purchase, limiting naming to describe specific ODDs or criteria may quickly become redundant.

In the UK, the Automated & Electric Vehicle Act requires the Secretary of State for Transport to create and maintain a list of automated vehicles. However, the Act does not yet define what information must be recorded on that list, whether or not it refers to capability within a model range, what is fitted to a specific vehicle, or how it should be recorded. UK insurers propose a dynamic, VIN-level database, linked to the DVLA vehicle registration database.

Information

Both vehicle users and insurers must know the capability of the specific vehicle being used/insured. Drivers need this to understand their role when systems are activated. Insurers need to understand the same capabilities to assess the risk associated with the vehicle and charge an appropriate premium. Initially most manufacturers will sell automated driving features as additional cost options rather than as part of the vehicle's standard fitment. To identify whether a specific vehicle is capable of being used for automated driving, insurers must be able to identify fitment of ADS at an individual vehicle level, not just at make/model level.

Once laws are changed to allow drivers to undertake secondary tasks when the ADS is driving, it will be necessary for law enforcement officers to validate the presence of the ADS. It will therefore be essential that individual vehicle records are stored in an automated vehicles database that can be updated to cater for future OTA software updates and changes to subscriptions to the ADS functionality. OTA updates may enhance the functionality in the vehicle systems and introduce new or enhanced automated driving features (a software update could also be used to remove or reduce functionality or modes). Recording these changes against the VIN will ensure all interested parties (such as drivers, insurers; rental or leasing companies; fleet operators or enforcement agencies) can be made aware if there is a change to the automation status of the vehicle.

The system HMI needs to change during automated driving to reinforce the change in role for the user. The displays for the User-in-Charge, when an ADS is activated, must look significantly different when compared with the driver displays for an assisted driving system or manual driving to provide strong visual cues to vehicle users of their role in the DDT. The example of steering wheel illumination is already seen in vehicles and provides an opportunity to standardise colours and indicators across all vehicles.

User Obligations

Classroom style training of drivers is likely to be expensive and impractical and its effectiveness in the context of automation is not known. The requirements propose a system design approach which makes the system simple and intuitive meaning that much of the practical training is through experience. However, it will be important to develop enforceable technical requirements that can ensure this standard of simplicity is actually achieved on all in-service vehicles.

It is essential that users have a very clear understanding of their changing roles and obligations as different types of automation are provided to them. Users also need to know how to start and stop the system so that they are fully aware of the handover processes.

Achieving and confirming understanding must be verifiable to ensure the driver is capable of using the system safely.

The freedom associated with manual driving comes with a significant number of obligations and responsibilities. In automated driving, many of those obligations will be taken on by the ADS but not all (such as vehicle roadworthiness, insurance and taking back control).

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Location Specific: Operational Design Domain (ODD)

Technical Requirements

The manufacturer of an ADS shall publish a detailed definition of the ODD in which the ADS will function safely. Road type is one of the main criteria that must be defined. Any ADS that operates in the 'Highway' driving domain shall be subject to the requirements in this document.

The ODD requirements shall be a combination of static (fixed, such as Highway) and dynamic features (changing, such as Traffic conditions).

As a minimum, manufacturers shall include specific information on whether or not there are any further restrictions in the ODD in terms of:

- Junctions
- Geography
- Speed range
- Road conditions
- Traffic conditions
- Environmental conditions.

In the UK, Highway shall be interpreted to mean a motorway as defined by the Motorway Traffic Regulations.

The ADS must be capable of accurately identifying when all conditions defining the ODD are met; accurately predicting the point at which those conditions are no longer met; and monitoring the environment to be ready to take action if the ODD starts to break down.

Test and Assessment

The manufacturer shall demonstrate through virtual testing how the ADS will identify that it is within the ODD, and how it will reliably predict when it will leave the ODD with sufficient notice to allow managed handback.

The type approval authority will check the results of the virtual testing during the on-road trial by placing the vehicle in a range of situations both outside, entering, within and exiting the ODD to assess whether the system reliably indicates its availability.

Justification

It is important that the design freedom of the vehicle industry and its ability to innovate new systems is not constrained by regulation. The manufacturer needs freedom to constrain the ODD to the capabilities of the ADS. This approach is not free from risk. It is possible that the introduction of similar systems with subtly different design domains will lead to consumer confusion. This could be as simple as time-of-day restrictions on systems. More complex ODDs also have the potential to lead to confusion meaning that drivers will rely on the vehicle to inform them, accurately, that the ODD conditions are met.

These ODDs need to be published and be freely available for consumers, insurers and regulators to enable open understanding of the different systems and where they can operate.

Vehicles will be introduced which have an ADS with more than one ODD and different functionality and technical requirements for each ODD. The vehicle must recognise the boundaries and apply the requirements for the current ODD. It is essential that the definition of the ODD is detailed, accurate and comprehensive.

Safe Driving: Automated Driving System (ADS) Capabilities & Behaviour

Technical requirements

General Capabilities

The ADS must be able to carry out the Dynamic Driving Task (DDT), safely perceiving, planning and executing all reasonably foreseeable driving situations that may be encountered, within the system's ODD such as merging into traffic, other vehicles changing lane and stopped vehicles (Thorn, et al., 2018). The ADS must interact in a predictable, safe and legal way with other road users such as drivers of non-automated vehicles and non-vehicular road users. To achieve this, the ADS must follow a robust design and validation process based on a systems-engineering approach with the goal of designing the ADS to be free of unreasonable safety risks.

Where a manufacturer updates the software installed on a type approved vehicle, variant or version which is a significant change in the capability or performance of the ADS, then it shall be treated as a new variant, or version, requiring new approval before vehicles featuring the new standard can be sold.

Further restrictions are essential to control software updates applied to vehicles already sold and in-service as part of 'in use' regulations. There must be a lifetime approval process for vehicles. Vehicle manufacturers (or Automated Driving System Entities) shall demonstrate to approval authorities that they have rigorous systems for ensuring that any software system update process is safe. This shall include, but not be limited to, ensuring strict version control, quality controls, continuous system testing and ensuring that all vehicles receive safety critical updates. Potentially dangerous situations such as updating while the vehicle is in motion must be prevented. Software design must allow roll back of software to an earlier, fully approved version if there are issues with the robustness of testing or performance of a software update.

The capability and behaviour of the ADS shall be defined in relation to three overall objectives:

- **Primary Objective** – To maximise safety
- **Secondary Objective** – To make progress and maintain free movement of traffic
- **Tertiary Objective** – Ease and simplicity for users

The primary objective shall always take precedence over the others.

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Perception & detection

The ADS shall be capable of perceiving, detecting and understanding all relevant objects that it will foreseeably encounter within the ODD. As a minimum, this shall include:

CATEGORY	SPECIFIC TO THE HIGHWAY DOMAIN	LOCATION/SPEED
Road Users	ADS must recognise all road users permitted in the domain or that could be reasonably expected to be there. This may include pedestrians alongside broken down vehicles and stray animals.	In running lanes or hard shoulder with other road user speeds from 0 to ODD limit or 130 km/h, whichever is lower. Detection shall be reliable when the ADS equipped vehicle is travelling at system maximum operational speed or 130 km/h, whichever is lower.
Traffic Signs	All highway signs, variable message signs, digital signs for managed highways (e.g. flashing amber warnings, red X for lane closure), temporary roadworks signs. If junctions are within the ODD, system must also recognise traffic lights. Emergency services signals (blue lights).	At nearside of road, on central reservation or overhead gantries to a height of up to [7m].
Road Markings	Lane separation markings, road edge markings, rumble strips, cats eyes. If junctions are within ODD, markings separating carriageway from slip road.	Surrounding running lanes, slip roads and hard shoulder.
Inanimate Objects	Large objects, debris or standing water liable to cause significant damage or vehicle directional instability if hit by the vehicle.	In running lanes or hard shoulder.

Table 1: Perception & detection requirements

Operational Behaviour

Behaviour characteristics may vary according to traffic conditions. Three basic definitions are applied:

- **Unconstrained Movement** – No other road users are within detection range of the ADS
- **Steady State Traffic** – Ego vehicle ADS is travelling in a flow of surrounding traffic travelling in compliance with law and guidance, accelerating at no more than 2 m/s2 in any direction
- **Transient Traffic** – The actions of surrounding traffic cause steady state conditions to be broken

The following key behaviours must be observed and if any conflict exists, behaviours higher up the list take priority over those lower down the list.

BEHAVIOUR	TRAFFIC CONDITION	CRITERIA
Legal speed	All	Must not travel faster than the applicable speed limit acknowledging the vehicle type and any temporary or variable limit.
Selection of speed/follow distance to ensure the ego vehicle can always stop in the distance it can see to be clear	Unconstrained	The distance the ADS can see to be clear will be the lower of: • The maximum distance at which the system can have reliably identified other road users/objects and accurately quantified its speed and trajectory • Line of sight as constrained by sensor field of view, road curvature and road slope (crest of hill or valley floor) The distance required for the vehicle to stop will be a function of vehicle speed, the time required to track a road user/object, recognise a collision risk and apply the brakes, and the brake build up time and maximum deceleration achievable considering the status of vehicle components and friction conditions (dry, wet, icy).
	Steady state	Calculated as for unconstrained but with the distance to the vehicle ahead as an additional sightline constraint. Safe Distance: The follow distance shall be whichever is greater, that determined by the calculation or that implied by compliance with the 2 second rule.
	Transient	Where the rules for steady state traffic have been broken, the ADS shall take immediate action to restore the limits implied in steady state driving. This may involve either braking or a lane change. If the ADS equipped vehicle is itself not at imminent risk of collision then, the restorative action shall not cause any other road user travelling at legal speeds to accelerate, decelerate or corner at more than [2m/s2] in order for them to avoid a collision, after allowing for a standardised human reaction time of [1.4] seconds.
Do not cross lane boundaries unless safe to do so	All	The ADS shall not cause the vehicle to cross a lane boundary if, to avoid a collision, it would cause any other road user travelling at legal speeds to accelerate, decelerate or corner at more than [2m/s2], after allowing for a standardised human reaction time of [1.4] seconds.
Safe steering or cornering	Unconstrained or steady state	The ADS shall not cause the vehicle to corner at a speed that would produce a lateral acceleration over [80%] of the maximum achievable by the vehicle, allowing for the prevailing tyre road friction at the time.
	Transient	The limitation above shall not apply in transient traffic conditions where the ADS determines that cornering at high lateral acceleration is the best way of avoiding a collision.
Courtesy	All	The ADS must be courteous to other road users, for example, giving way to vehicles indicating to move into the ADS lane where this is safe.
Make progress and maintain free flowing traffic	All	The ADS shall, without any delays or hesitations in excess of [0.5] seconds cause the vehicle to accelerate to the lower of: • The maximum speed at which the ADS determine it to be safe to operate automatically without contradicting any of the previous rules • The maximum speed set by the User-in-Charge

Table 2: Criteria for operational behaviour

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Test and Assessment

The manufacturer shall demonstrate through virtual testing how the ADS will comply with the relevant capabilities and behaviour for the Driving Domain in which it is operating. The simulation of performance in a wide range of driving scenarios shall be a key part of this assessment.

The driving scenarios to be simulated will depend on the exact definition of the ODD. Basic perception and manoeuvring tests, normal driving and edge case scenarios shall be included. Two methods for defining the minimum acceptable quantity and content of simulations are considered:

- A standard methodology for producing a minimum library of mandatory scenarios, based on the detailed definition of the ODD (not yet developed)

- Definition of a large, exhaustive matrix of scenarios to be analysed where the manufacturer deletes variables/ conditions that cannot occur within the ODD.

It shall be demonstrated that in each individual driving scenario, all technical requirements are met. The details of the simulation regime shall be determined based on the outcome of the range of current research projects considering this subject such as OmniCAV, COSMOS, VeriCAV, D-Risk, Sim4SafeCAV, Musicc, Headstart, Pegasus etc.

The type approval authority shall confirm compliance with a random selection of the above requirements, either during track or on-road testing. Technical requirements must be met in the physical tests, the results of which must fall within an acceptable tolerance of the result of the equivalent simulated test.

Justification

The primary consideration for all automated driving should be the safety of vehicle occupants and other road users. However, it is impossible to formally test every single driving situation that might occur on public roads around the world. A 'safe system' design approach is considered an essential requirement. Existing definitions of type and variant are based largely around macro level mechanical vehicle design. However, vehicles already exist with driving characteristics that can be changed substantially by software changes alone. Recognition of software versions is considered an essential requirement for pre-sale type approval, and also post-registration modification of vehicles and regulation of 'in-use' performance.

Perception and recognition

An ADS must be able to see and recognise all different road users it encounters and to identify objects that represent a hazard to the vehicle. Certain types of road user should not be present on highways. Insurers take the view that all road users should still be recognised because it is foreseeable that at least in rare, possibly illegal, circumstances, they may still be present.

Behaviour

The insurers' view is that the rules of driving (e.g. UK Highway Code, Driving Test, Geneva Convention), as related to safety, must be applied equally to both human drivers and ADS. It is not acceptable to 'bend' or break the laws and this should be applied equally to both. Humans learn to drive based on a relatively small number of key principles embedded within the rules and then apply those in the millions of subtly different driving scenarios they encounter in the real world. The safety requirements

for the ADS have been based on our interpretation of those principles and the most important safety related rules.

Driving rules and laws are typically set nationally to reflect different infrastructures and environments, as well as different customs and practices. Type approval of a vehicle is likely to be international. Different approaches to the requirements at type approval can, therefore, be considered:

- Define only fundamental behaviours at international level that can be accepted by all contracting parties as universal. Rely on national governments to impose laws that subject ADS to the same behavioural laws as human drivers (where relevant, e.g. excluding rules around eating while driving, etc.) and to ensure liability for contravening those rules lies with the ADS entity

- Create libraries of more comprehensive rules, for each contracting party to the regulation, to increase the extent of control exercised at type approval.

The latter would be a significant task, which may ultimately have benefits for technical harmonisation and reducing the burden on manufacturers to demonstrate compliance in each territory. Insurers have proposed a first set of draft requirements derived from UK rules and practice but considered to have the potential for universal application.

Compliance with the prevailing speed limit is considered essential. Extensive research, for example (Taylor, et al., 2001), proves the link between speed and the frequency and severity of collisions.

Being able to stop in the distance that can be seen to be clear is another fundamental rule that can be interpreted for different driving situations. Vehicles must slow down as they approach the crest of a hill or a tight bend; or if atmospheric conditions reduce the usable detection range of the sensing system. Compliance with the two-second rule helps ensure that automated vehicles drive in the same way as other legally compliant vehicles, despite their potential to safely follow more closely in certain circumstances. This requirement is strongly dependant on tyre road friction. If the vehicle cannot reliably estimate tyre road friction in real time, it may be necessary to identify generic factors to account for common conditions that could reasonably occur within the ODD (e.g. wet road, ice/frost etc).

Many existing road rules relate to road markings such as lane boundaries, give way lines and stop lines. These can be reasonably reduced to the instruction not to cross over such markings unless safe to do so. 'Safe' is not rigidly defined but drivers are usually taught not to pull out of a junction if it would cause an approaching vehicle to change path or speed. The proposed requirement for vehicles not to have to accelerate or decelerate in any direction by more than 2 m/s2 is a technical interpretation of that teaching. Requiring it only to apply to vehicles travelling at legal speeds acknowledges that it may not be possible to design an ADS to compensate for all the illegal behaviours of others. Those travelling illegally must accept that they are placing themselves and others at greater risk and may require harder braking to avoid collision.

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The requirements to be able to stop within the system perception distance may constrain cornering speeds but, for highway driving, bends with wide sightlines may still allow excessive lateral acceleration, which is why a specific limit was proposed. Again, this requires either measurement of available friction or generic factoring for defined conditions. In unplanned situations, where a swerve may be the best avoidance action, the limit on lateral acceleration is removed.

Driving courtesy has been included as a required behaviour. This reflects the need to consider other road users when driving to avoid unexpected accidents where a human driver would give way for example.

The safety of all road users is the primary consideration when defining the capabilities of the ADS. However, early development of automated vehicles has identified strict compliance with laws and hesitancy of vehicles as a contributor to a potentially higher than expected incidence of automated vehicles being struck in the rear by other vehicles. This same risk is highlighted by instructions in the UK driving test :

> "You should approach all hazards at a safe, controlled speed, without being over cautious or slowing or stopping other road users. You should always be ready to move away from junctions as soon as it is safe and correct to do so. Driving too slowly can frustrate other drivers which creates danger for yourself and others." [2]

It is therefore important for safety that automated vehicles make good progress. It is intended to be universally applicable, but factors other than those defined may affect whether it is safe or desirable to travel at the speed limit, so allowance has been made for this.

Test and Assessment

The fundamental approach of combining three separate elements into a new test and assessment approach is well accepted and insurers also accept this. The use of virtual testing in the validation, verification and regulation of ADS is in its infancy and a minimum standard is important. Appropriate simulations will depend on the specific ODD. The manufacturer must demonstrate that the system works both in normal conditions and in the more extreme edge cases. There are a huge array of potential scenarios to consider and many research projects across the world are studying this problem. The detailed definition of the virtual testing will need to be informed by these analyses.

In the interim, regulators looking to approve automated vehicles in their territory will need to balance the volume of local testing carried out against the potential risks of the ADS operating in its specified driving domain.

The fundamental approach discussed is proposed in relation to type approval.

[2] https://www.gov.uk/government/publications/driving-test-report-forms/driving-test-report-explained#maintain-progress

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User Monitoring

Technical Requirements

The vehicle shall be equipped with user monitoring systems capable of detecting whether the User-in-Charge is alert, monitoring the road, engaged in appropriate secondary tasks, or fully engaged in the DDT using technology installed in the vehicle and connected to the ADS. Functions may include monitoring the use of driving controls; the use of the infotainment system; and facial feature tracking to assess the direction of eye gaze or drowsiness. User monitoring shall not rely solely on 'hands on the wheel' detection.

User attentiveness status must be used by the system to determine the best strategy for managing handover to the driver in a safe manner.

The user state must be continuously monitored during Automated Driving. Following the start of user re-engagement, the system must continue to monitor the user until they are fully engaged with the DDT. The use of a combination of user situational awareness and driving process control is proposed but requires further human factor research.

Test and Assessment

The safe design of the system shall be demonstrated through simulation documentation. Validation that the system works as intended will be assessed on a closed test track with a human user simulating each main type of inattention expected to be detected and ensuring the vehicle takes the expected action.

Justification

User Monitoring is essential to safe automated driving. Any User-in-Charge must remain sufficiently engaged and alert to be able to fulfil their role as a driver when required. Requirements for this will change for each ADS. Where an ADS system may require the User-in-Charge to take back control at short notice to maintain system safety, the User-in-Charge must be sufficiently alert to resume the DDT in 15 seconds. Research suggests that users will find this difficult if they are not engaged in the DDT. As a result the user monitoring system will have to monitor the User-in-Charge after they take control to ensure support is provided until they are fully engaged in the DDT.

Experience with current assisted driving systems has strongly suggested that relying on 'hands on the wheel' detection alone is not sufficient to assess driver engagement. See for example, (Wiggerich, 2019). There are also a number of examples where drivers can bypass the 'hands on wheel' recognition making it unacceptable as a standalone monitor.

Currently, research on the effectiveness of alternative monitoring methods remains immature however the use of facial monitoring to assess attentiveness appears to be one of the better methods (Schwarz, et al., 2019).

Testing with an inattentive user should not be undertaken on public roads because, by definition, it is not considered a safe operational state.

User re-engagement presents a challenge because different users will re-engage at different rates. A suggested approach is to require a sufficient level of situational awareness combined with demonstrating driving process control.

Situational awareness can be defined as the ability to scan the environment and sense danger, challenges and opportunities while maintaining the ability to conduct normal activities. This is the subject of much human factors research while certain measures such as measuring levels of anticipation (the ability to read situations and act earlier) have been used in driving research.

Process control is the normalisation of eyes on road, steering, acceleration and braking functions as the driver retakes control. Thresholds will need to be set for these criteria with support from ongoing human factors research. The ADS will provide support until the human driving behaviours are sufficiently aligned.

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Secondary Tasks

Technical Requirements

Technical changes to permit the User-in-Charge to undertake secondary, non-driving, tasks whilst the ADS is engaged will be required in national vehicle usage legislation. This legislation will ideally introduce mechanisms to allow enforcement authorities to identify vehicles with an ADS in operation.

The nature of appropriate secondary tasks that can be undertaken must be constrained to the ODD conditions. If an ODD has dynamic conditions which lead to unplanned handovers then the only permissible tasks are those where the user interacts with the vehicle instrument panel and/or infotainment system. Sleeping shall not be permitted in these conditions.

Where the ODD only has static conditions, all standard ADS initiated handovers are predictable and user re-engagement is planned then the use of other devices such as books and mobile phones shall be permitted. In these conditions it may also be possible to permit the user to sleep, provided the ADS is able to engage them in sufficient time for a planned handover.

Test and Assessment

The safe design of the system shall be demonstrated through simulation documentation. Validation that the system works as intended will be assessed on a closed test track with a human user simulating a specified selection of secondary tasks.

Justification

The ability for a driver to effectively become a passenger and undertake tasks not related to driving, at least for part of a trip, is one of the major expected benefits of automated driving and is, therefore, a powerful economic incentive for consumers and manufacturers.

For any ADS capable of operating in all reasonably foreseeable conditions on a given road type, or in a defined geographic location, the driver should be legally permitted to undertake non-driving tasks. The ADS will use a managed approach where a planned handover needs to occur.

Where an unplanned handover can be expected, the driver will not be allowed to sleep or undertake secondary tasks which are not delivered through the infotainment system. This scenario requires the driver to take back control in a short period of time which will not combine well with drivers who are sufficiently disengaged.

Since most of the car parc will not be allowed to undertake secondary tasks for the foreseeable future, consideration needs to be given to how to avoid the ADS being incorrectly stopped by enforcement officers. This supports the need for a database of ADS enabled vehicles directly accessible in the same way as the Motor Insurers Database in the UK. In the short term, only systems that include dynamic parameters in the ODD are likely to be available. During that time, all automated vehicles on the road will, therefore, be restricted to vehicle-based secondary tasks only. In future, when more advanced systems become available that may even permit sleeping, the database of ADS enabled vehicles will need to be upgraded to allow separate identification of the different classes of automation.

Starting Automation

Technical Requirements

The ADS shall continuously monitor the vehicle status to assess whether the ODD conditions are met and sufficient information is available to safely operate the vehicle (e.g. planned destination, weather en route). The system must be free of relevant diagnostic errors.

User monitoring must confirm that the driver is in a fit state (for example that they are not drowsy at outset).

The vehicle shall only offer the driver the option to activate the ADS when all the conditions required for safe automated driving are met. The system shall only be activated with a clear Offer and Confirm process. The ADS shall not be activated until the driver confirms that they wish to start automated driving. It shall not be possible for the driver to accidentally activate automated driving.

After starting the ADS, the user shall be reminded by an audible or visual message of their role during the period when the ADS is operating the vehicle and the point where they will be expected to take back control. The status of the ADS shall always be prominently displayed.

Test and Assessment

Compliance with these requirements shall be demonstrated during a public road test during at least three activations of the ADS in different locations or driving circumstances.

Justification

The ADS is designed for a specific ODD so it must not be possible to activate it beyond this to ensure safe function of the system.

The driver's changing role in the DDT is crucial and can easily lead to confusion, so clear indicators from the vehicle must show what is required in the form of displays and audible prompts.

The driver must to be in a fit state to engage the system since a fatigued driver is far more likely to fall asleep when they become a User-in-Charge in an ADS where they may be required to take back control at short notice. Ideally the system should alert the driver to their fatigue and encourage rest stops.

The Offer and Confirm process is a clear way to establish transfer of driving responsibility. The risk of a driver unintentionally activating the ADS must be minimised and manufacturers will need to consider the best methods to achieve this.

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Using Automation

Technical requirements

Appropriate secondary tasks are permitted while the ADS is in control. User monitoring must evaluate and manage the user state to ensure they are ready for handover at the appropriate time.

If an unplanned handover can be expected, the system must apply an information, warning and intervention (IWI) approach to ensure that the User-In-Charge's attentiveness is maintained at a level that allows the ADS to hand back control to the driver within 15 seconds.

User monitoring must be capable of identifying and warning users who are engaging in prohibited secondary tasks. Where an unplanned handover can be expected, the only secondary tasks will be through the infotainment system. Users must be given an escalating warning if undertaking other tasks. This must lead to initiating the end of automation if the user continues the task.

The system must continuously indicate the ADS status.

Test and Assessment

Where secondary tasks are restricted only to activities linked to the vehicle, the ability of the vehicle to detect and prevent other activities shall be assessed as part of the track testing.

User state monitoring and management will be assessed by virtual testing and track testing.

Justification

The level of user disengagement that is permitted will depend on the need to hand control back to the user at short notice. Where unplanned handovers are possible, the user state must be managed to ensure the user maintains at least a minimum threshold of attentiveness to prevent the user becoming drowsy.

User drowsiness potentially introduces significant risks to the ADS. If a user falls asleep they will require much more time to be brought back into the loop – in the case of an unplanned handover this will be unacceptable. It is important that the ADS manages driver behaviour where an unplanned handover is likely. The information, warning, intervention (IWI) approach means that drivers can undertake secondary tasks to remain alert and will be more ready to take back control when needed. This will depend on effective driver monitoring systems and HMI feedback processes.

Where an unplanned handover is expected, the level of user distraction allowed will be far more limited. This is to enable the user to reengage with the DDT faster. If the user chooses to engage in prohibited secondary tasks, the system must be capable of identifying and addressing this behaviour since it reduces the safety of the ADS when handover is required.

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Functional Requirements in the Highway Driving Domain

In the UK, changes will be required in the Road Traffic Act 1988, Construction & Use Regulations 1986 and the Highway Code. A designation of whether an unplanned end to automation is possible should be included in the 'Secretary of State's list' of automated vehicles.

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Ending Automation

Technical Requirements

The operation of the ADS may be ended in several different ways:

A planned handover where the static conditions for the ODD end allowing the system to manage handback in a comfortable manner.

An unplanned handover where the dynamic conditions for the ODD end requiring immediate user response.

A User-in-Charge initiated handover, with the user taking back control at any point during automated operation.

A system failure, the ADS must be designed so that no single component failure shall prevent it executing a minimum risk manoeuvre. The ADS must also include self-checks for sensor function, the plausibility of signals received, and system integrity, and warn drivers of malfunctions. Non-ADS failure risks shall also be minimised, for example, by the use of run flat tyres.

The handover of control to the user must comprise an information, warning, intervention (IWI) approach. Handover times must reflect the dynamic situation and the user state. In all cases, after the user starts re-engaging, the system must continue to monitor and provide support until the user is fully engaged in the DDT and automation can end.

The user shall start re-engaging with the combination of hands on steering wheel, feet on pedals and eyes watching the road ahead.

If the ADS carries out a MRM, it must be capable of safely changing lanes to reach safe harbour.

Planned handover

A planned handover IWI process shall be:

- **Information** – Countdown providing audio and visual stimuli (45 seconds)
- **Warning** – Escalating audible, visual and haptic (including brake jerk) stimuli (15 seconds)
- **Intervention** – Minimum risk manoeuvre

If the user fails to start re-engaging control after the warnings, the vehicle shall initiate the intervention of a minimum risk manoeuvre. The user may start re-engaging at any stage in this process.

The planned handover must provide sufficient time within the ODD to fully engage the user in the DDT after the IWI process.

Unplanned ODD handover

The immediacy of an unplanned ODD exit means the IWI shall start with a warning. The process shall start when the ODD breaks down:

- **Warning** – Escalating audible, visual and haptic (including brake jerk) stimuli (15s)
- **Intervention** – Minimum risk manoeuvre

If the user fails to take back control after the warnings, the vehicle shall initiate a minimum risk manoeuvre. The user may start re-engaging at any stage in this process.

Once the user starts re-engaging, the system shall monitor the user and provide support until they are fully re-engaged in the DDT. At this stage automation will end.

User-In-Charge initiated handover

This must follow a multipath process to ensure the user does not start re-engaging in error. The system must monitor the user to ensure they have re-engaged with the DDT before ending automation.

System failure

Where a system failure limits the system capability then the unplanned handover process must be followed.

Where a system failure occurs such that the system is unable to complete any minimum risk manoeuvre then an immediate hand back to the driver must occur.

Minimum risk manoeuvres

The minimal risk condition shall vary according to the prevailing circumstances in terms of ADS condition, ability of the User-in-Charge to resume control and any prevailing road, environment or traffic conditions that define the ODD. The minimum risk condition shall never be to simply deactivate the ADS while moving, nor to stop a moving vehicle in a live traffic lane. Whenever the vehicle implements a minimum risk manoeuvre it shall activate direction indicators if a lane change is required and then activate the hazard warning lights once no more lane changes are required and the vehicle is slowing to a stop such that it could be considered an obstruction. The following scenarios define acceptable standards of minimal risk manoeuvre:

- **Standard highway section with hard shoulder** – The ego vehicle shall indicate to change lane and move over to the hard shoulder and come to a controlled, stable stop
- **Highway junction** – If the ego vehicle is not in the nearside lane, it shall indicate and move to the nearside lane. If passing the exit, it may move onto the slip road and park on a hard shoulder present there. Alternatively, it may move past the mouth of the junction and pull over to the hard shoulder positioned after the junction
- **No hard shoulder, emergency refuge area or exit junction available within [2.5 km]** – Where not already in lane 1, the ego vehicle shall indicate and manoeuvre into lane 1 then activate a restricted speed mode at 30 km/h that allows the ADS to remain in control of the vehicle. It shall then proceed to the nearest emergency refuge area or junction, exit the live lane and come to a stop. The ADS must continue to comply with all safety requirements outlined under ADS capabilities, during the distance travelled in restricted speed mode
- **No hard shoulder and no exit or emergency refuge area available within [2.5 km]** – The vehicle shall indicate and move to lane 1 and then slowly come to a stop as far as possible off the carriageway to the nearside of lane 1 and automatically notify emergency services via the eCall system or equivalent
- Heavy slow-moving traffic with a weather related breakdown of ODD may require a stop in lane with hazard indicators on

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STOP

Highway safe harbour will comprise hard shoulders on highway and slip road; refuge areas; or, in the absence of these, the far nearside of lane 1. In an emergency, stop in lane may be made but it must not be an acceptable system default for safe harbour.

Manufacturers shall design for any other foreseeable scenarios within the specific ODD of the ADS. Manufacturers may also apply different minimum risk strategies in the scenarios defined above. However, in each case, they must demonstrate, using the principles of virtual testing how the implemented approach offers at least an equivalent level of safety.

In the event of a vehicle failure, the vehicle may implement a failure mitigation strategy instead of the minimal risk manoeuvre. The failure mitigation strategy shall never be to deactivate the ADS in a moving vehicle without clear confirmation from the User-in-Charge that they are ready to resume the dynamic driving task. As a minimum, the failure mitigation strategy should activate the hazard warning lamps and decelerate the vehicle to a controlled stop with at least the minimum level of deceleration required to act as a haptic warning to the human user, within the pre-failure travel lane, while maintaining directional stability. The manufacturer may implement different failure mitigation strategies at their discretion but must demonstrate using virtual testing that these will offer at least an equivalent level of safety to the minimum action defined.

Human Machine Interface

Where the ADS system or its sensors are unserviceable through faultiness or accident damage the system must clearly indicate to the user that the system is non-functional, via a permanent failure indicator clearly identifiable by the user. The indicator must remain illuminated whenever the vehicle is live until system repair is undertaken.

All handovers of responsibility for the dynamic driving task shall follow either the applicable Offer and Confirm or Request and Confirm process described. The HMI used must be clear and unambiguous and communications from the vehicle to the driver should follow standardised principles with respect to the urgency and criticality of warnings, such as those discussed in (UN ECE, 2011), adapted if and where necessary to account for users that have become 'out of the loop' during automation. Similarly, ISO standards exist to define standard dashboard 'tell tale' designs and colours. These shall be expanded to allow for standardised elements of the HMI used in ending automation.

Where leaving the ODD of an ADS allows the option to switch directly to an assisted driving situation, the look and feel of the vehicle displays must change substantially and drivers will be informed of their change in role.

All changes of user role in the operation of the vehicle shall use the applicable clear Offer and Confirm or Request and Confirm process.

STOP

Test and Assessment

Assessment of scenarios requiring a planned or unplanned handover shall be assessed as part of the virtual testing. Selected scenarios shall be validated during track testing and further assessment will be undertaken during the on-road trial including User-In-Charge initiated handovers.

Minimum risk manoeuvre and failure mitigation strategies: virtual testing with selected situations validated with track testing. Scenarios for simulation should be a subset of those defined involving ODD exit in the 'ADS capabilities' section but with the addition of a lack of user response. In addition to this, simulations shall be run with a wide variety of system failures.

Justification

The end of vehicle automation is critical for safety. A User-in-Charge will need time to re-engage having appropriate driving control and situational awareness prior to resuming driving. Some current research e.g. (Merat, et al., 2014) suggests it can take as much as 45 seconds for the user's behaviour to normalise. Additional time may be required for a minimum risk manoeuvre if the user has not properly responded during this time. However, a Study of Level 3 System takeback times indicate that 12 to 15 seconds is sufficient (Kuehn, et al., 2017) though the driver will need support to fully re-engage with the DDT.

Road and environmental conditions are dynamic. It is important to recognise that setting fixed times for transferring control risks introduces new hazards for the user where they need to take control quickly. A flexible approach is needed. It is also essential that the user is given support from taking back control to being fully normalised in the DDT.

User-in-Charge initiated handovers must follow a multipath Request and Confirm process to avoid human error ceasing automation unintentionally: handing back control to a user who is unready or handing back control during a critical driving situation.

Automated operation of the vehicle can also be ended because of system failures. This includes failures of the ADS but also failures of other vehicle systems that render it unsafe for the ADS to continue operating the vehicle. In this situation the appropriate response will depend on the severity of the failure and the residual capability remaining. Although such failures should be very rare, it may not be possible in all circumstances to provide 15 seconds' notice. Where possible the ADS should achieve a minimum risk condition. This may not always be possible and an immediate handover may be necessary.

When an ADS exits its ODD, the vehicle may be able to offer an assisted driving function as an alternative. For example, an automated 'traffic jam pilot' may exit its ODD when the traffic speed increases such that it exceeds the limit. At that point, it may be able to offer a 'highway assist' function for higher speeds that requires driver supervision. The ADS system must, therefore, confirm that the user is fit to resume the role required before making such a handover.

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Minimum Risk Manoeuvres

Stopping in a live lane on a high-speed Highway carries very significant collision risks. An ADS not operating in all traffic situations and capable of human driving will require at least one handover of control back to the user in any trip that they choose to activate automation. Unless the risk of the user failing to respond to the intervention request can be made tiny, then the frequency with which a minimal risk condition is required will be much greater than the frequency of situations covered by the terms 'emergency' and 'breakdown' in the current Highway Code for human drivers. Thus, stop in lane it is not considered an acceptable option for the minimum risk condition for ADS operating on highways.

The scenarios presented for the minimum risk condition are thought to represent the majority of road configurations on the highway and the proposed distance of 2.5km is based on the assumption that in sections of managed motorways in the UK, emergency refuge areas can be up to 1.5 miles apart. The actions to be taken in each case are interpretations of the basic instructions to human drivers to get off the road if possible and to warn other traffic.

The scenarios presented are not the only ones that vehicles might encounter on the Highway network and a range of more complex edge cases may be possible. The actions proposed are simplistic and do not necessarily account for all eventualities (traffic, weather etc) that could occur in those scenarios. Designers of ADS therefore need the freedom to adapt the requirements to the full range of circumstances that could be encountered, and the regulations should not excessively constrain their ability to be innovative. This is the rationale behind specifying scenarios and definitive requirements but allowing manufacturers to deviate from them, providing they can demonstrate that their solution provides an equivalent level of safety. This equivalence must be demonstrated with the rigour required for the full safety concept to be demonstrated by virtual testing.

The level of minimum risk manoeuvre required will need significant system capability to achieve and it will not always be possible in the event of system failure. While an ADS must be designed with sufficient redundancy so that a single failure should not degrade performance by enough to prevent a minimum risk manoeuvre, it is possible that more than one failure could occur at a similar time, a failure could occur at the same time as exiting the ODD; or a significant mechanical failure could occur outside of the ADS but which adversely affects the operation of the ADS. These very rare situations would be consistent with the description of 'emergencies' in the Highway Code that would permit a driver to stop in lane. In these situations, the ADS should be permitted to implement a failure mitigation strategy instead of a minimum risk manoeuvre. This should include the option to simply stop the vehicle, activate the hazard warning lights and automatically notify emergency services via the eCall system or equivalent.

The UK Highway Code provides instructions for drivers on the Motorway:

If your vehicle develops a problem, leave the Motorway at the next exit or pull into a service area. If you cannot do so, you should pull on to the hard shoulder and stop as far to the left as possible, with your wheels turned to the left.

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Collision Protection

Technical Requirements

The ADS shall be designed to ensure that it reacts to foreseeable critical situations that could occur. As a minimum, systems operating in the Highway Domain must be capable of the following emergency avoidance and mitigations actions:

Stationary Vehicle Ahead – The ADS must be capable of avoiding collision with a stationary vehicle ahead, in the same lane of travel, up to the maximum speed at which the ADS will operate the vehicle. The ADS may opt to change lane to avoid collision but, if so, it must demonstrate that it is capable of assessing whether it is safe to do so. If the assessment shows that it is not safe to do so, avoidance via braking to a stop must be achievable

Obscured Stationary Vehicle Ahead – When a stationary vehicle ahead is obscured from view by another vehicle (obscuration vehicle) between the ego vehicle and the stationary vehicle and the obscuration vehicle changes lane to avoid collision without prior braking then the ego vehicle shall be capable of avoiding the collision

Pedestrian on Highway – From the maximum travel speed that the ADS will operate at, the ADS will avoid collisions with an unobscured adult pedestrian crossing from an adjacent lane at a speed of 8 km/h

Other vehicle moving out of lane into collision with the side of the ego vehicle – The ADS must attempt to avoid the collision with the encroaching vehicle by adjusting path and/or speed acknowledging other traffic in the immediate vicinity and its path

Emergency avoidance capabilities must default on for both automated and manual driving. If the manufacturer considers it unsafe to apply this requirement, then evidence to support the position shall be provided as part of virtual testing. Reduced performance is permitted if achieving the performance required when the ADS is active implies intervention at a stage that might be considered premature by a human driver (time to collision >2s). The evidence behind such reductions shall be presented.

The inclusion of an Automated Driving feature within the Highway ODD category shall not excuse the vehicle from compliance with any other regulation governing the collision avoidance, occupant protection or partner protection performance of the vehicle.

The vehicle must be fitted with passive safety systems that provide state of the art levels of protection equivalent to the latest evolving Euro NCAP five star safety ratings.

Test and Assessment

Emergency Avoidance and Mitigation: Draft test procedures for Assisted Driving collision protection have been formulated by Euro NCAP for grading systems. These will form the basis of future evaluations for Automated Driving emergency functionality.

Justification

The requirements proposed under ‘Safe Driving’ will not only significantly reduce the chances of an emergency situation occurring but will also cover how the ADS should respond in such situations. Although many of the ‘Safe Driving’ scenarios are not easily testable and will rely on simulations, the emergency situations are independently testable. Explicitly requiring and testing these capabilities may increase public confidence that the systems are safe.

By their nature, some emergency situations are caused or contributed to by the actions of other road users. It will be extremely difficult for ADS to avoid these situations completely. However, the same situations may also be extremely difficult for human drivers to avoid. Thus, the benchmark will be a nominal human ability to avoid or mitigate a collision in these situations. This should be based upon standardised reaction time and typical braking and steering behaviours in emergencies. The minimum standards of performance of the automated vehicle shall be set at a faster response than the human performance in the same situations.

Vehicles with ADS in the Highway driving domain will still be manually driven for a proportion of the driving time. Automated Driving will only occur on the safest road type if its road safety potential in the Highway domain is comparatively limited. The perceived value in being able to undertake secondary tasks, rather than improved safety, will justify the cost of the sophisticated hardware and software required and drive consumer demand. However, the sophisticated hardware and software can then be used to provide much more effective collision avoidance ADAS during manual driving on highways but also on many other roads. Identifying and testing these capabilities explicitly and requiring those functions to be active in manual driving is, therefore, likely to bring much greater road safety benefit than automated driving on the highway alone.

While the overall probability of a vehicle equipped with an ADS in the Highway driving domain being involved in a collision is expected to be lower than that for a vehicle with no ADS, any vehicle capable of manual driving will still carry the same collision risks when manually driven. Thus, all the same safety provisions must apply.

The vehicles will continue to be vulnerable to impacts from other vehicles and so vehicle manufacturers must not compromise on passive safety systems reducing occupant protection in the event of a collision.

These systems combine to provide a safety layer underpinning the ADS performance of the DDT.

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Cyber Resilience

Technical requirements

The vehicle systems, of which the ADS is one element, must be designed, developed and maintained over the lifetime of the vehicle to minimise the vulnerabilities and the consequences of cyber intrusion.

They must meet UN ECE WP.29 regulations on cyber security and over-the-air software updates. As part of type approval, vehicle manufacturers, sub-brands, supply chains and vehicles must meet the ISO/SAE 21434 Automotive Cyber Security standard. This standard is due to be published in 2020.

Test and Assessment

The first insurer requirement on cyber security will be certified, audited evidence of compliance with the ISO/SAE 21434 standard. As connectivity of vehicles and infrastructure proliferates, an additional, more dynamic and demanding layer of assessment may be developed, compliance with which is likely to be required by the insurance industry, particularly with respect to automated vehicles.

Justification

Cyber intrusion to (or hacking of) ADS presents a significant potential for harm on the roads. This perceived threat is one of the greatest barriers to public acceptance of automated vehicles. Therefore, it is vital that vehicles are effectively protected from cyber-attack in all its forms, and that consumers and insurers have a sufficient level of assurance of the cyber security of vehicles.

The automotive industry clearly recognises the threat of cyber-attack, both as a risk of loss and also in terms of the potential reputational damage it would inflict. The industry is taking steps accordingly, notably through the development of the comprehensive ISO/SAE 21434 standard. This standard is due to be published in 2020, and encompasses the agreed principles of cyber security, including corporate responsibilities and organisational functions, as well as design and implementation of the systems within an individual vehicle. It will cover all of the principles of automotive cyber security that have been published by many organisations globally, and have been derived from the principles developed in the wider cyber security landscape. It is accepted that, along with the UN ECE WP.29 regulations, the standard will provide sufficient assurance that an effective approach to cyber security has been taken.

Since the standard covers requirements which cover the design, development and support of a connected vehicle, including the complex supply chains that support the automotive industry, the insurance industry requires clear evidence of a neutral audit of compliance to the standard over and above a simple reassurance that the standard is being applied. It is recognised that the current nascent regulations and standards may not be sufficient to provide assurance of the cyber security risk of vehicles and manufacturers. This means that an additional, more dynamic and demanding layer of assessment is likely to be required by the insurance industry as understanding of the technology develops.

The criticality of cyber security to the adoption of CAVs, and its accompanying societal benefits, is such that the requirements of the insurance industry will continually reflect industry best practice and will therefore extend beyond the regulations and standards once enhanced best practices are developed and published.

Collision Data

Technical requirements

In the event of a collision, insurers must have access to sufficient data to establish whether the ADS or the driver was in control leading up to the incident. This is a limited dataset which shall confirm whether the driver or ADS was in control of the vehicle and not the data required to assess the distribution of liability between different vehicles involved in the collision. This limitation is made on the condition that the proposed EU legislation to mandate Event Data Recorders (EDR) requires sufficient information to allow insurers and vehicle manufacturers an equal ability to assess the distribution of liability between different vehicles in a collision involving at least one automated vehicle.

The limited data request is:

- GPS-event time stamp
- Activation status of each automated driving feature
- Driver acceptance between automated/manual mode time stamp
- Record of driver intervention of steering, braking, accelerator or gear-shift
- Driver seat occupancy
- User engagement commenced
- Has Minimum Risk Manoeuvre (MRM) been triggered
- System status (linked to fault code)

In the case of a fault that leads to system inoperability, the system must store a date stamp of when inoperability occurs.

The trigger criteria for the data has not been specified at this stage. To establish liability for insurance claims, all collision and emergency system intervention events must trigger a data transmission.

The specific data may need to vary in other jurisdictions. It is anticipated that within each jurisdiction a central repository in the form of a neutral server for the shared accident data will be required to ensure efficient management of the claims processes.

When a collision occurs, the action the ADS can take shall be limited by the extent of vehicle and/or system damage sustained. If sufficient functionality is retained, the system shall achieve the minimum risk condition or, as a minimum, implement the failure mitigation strategy. The ADS shall activate an automatic emergency call system (known colloquially as eCall) specified in accordance with UN ECE R144.

This data shall be made available to the road safety research community. The administrator of the neutral server should be required to make an anonymised version of the database available for research purposes with sufficient reference detail to be able to link it to national collision databases.

Test and Assessment

The diagnostics specification and post-collision data provision shall be assessed as part of the virtual testing element.

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Justification

Where an automated vehicle is accepted as being in control during a collision, the user will become a passenger in terms of liability and has the right to compensation for their injuries.

To enable the new rights given to users in the Automated and Electric Vehicles Act, UK insurers have requested this as a minimum level of information to establish whether the car was in automated mode and, thus, whether the 'driver' was actually a User-in-Charge and be entitled to make a compensation claim for any injuries they may have incurred.

While manufacturers will argue that the format for collecting and providing data be standardised internationally, it is important that international regulations are designed in such a way that the legal rights of vehicle users and passengers in domestic legislation are always met.

To avoid ambiguity, it is essential that the required data is recorded in every collision, not just when the ADS is active. This will ensure that collisions that occur immediately after handovers are identified and described accurately and that there can be no misinterpretation of rare incidents where a data transmission failure occurs.

In the UK, insurers will have a right to recover the cost of claims from the motor manufacturer or ADS provider where there was a fault or failure in the ADS that caused the collision. To enable insurers to deal with such recoveries, it is therefore essential that the law provides for a level playing field such that both sides have access to the same data in near real time in the event of any dispute of the facts.

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Sustainability

Technical requirements

The emergency collision avoidance systems shall be tolerant of ageing of the vehicle and shall be designed to maintain the same functional performance over a life of at least 10 years. Sensors shall be self-aligning and shall not require extensive calibration procedures to maintain performance over the vehicle's lifespan.

Software systems must be supported to ensure that full functional performance of the emergency collision avoidance systems is available for at least 10 years.

Sensors shall be positioned to be protected in minor low speed collisions and, if damage to the sensors is sustained or functionality is lost due to any type of sensor failure, a clear tell-tale warning light shall notify the driver, along with an appropriate narrative message. This tell-tale must be similar in form to an airbag or a check-engine warning.

Where collisions have minimal physical impact on the emergency collision avoidance systems or their related sensors, the systems shall be able to self-heal to maintain optimal functionality. If this cannot be achieved, then the permanent tell-tale warning indicates to the owner that further investigation by a trained technician is required.

Where self-healing fails, vehicle manufacturers must support this with clear guidance as to when (scenarios) and how (repair methods) repair of the emergency collision avoidance systems and their associated components must be undertaken. This information must be readily available to the wider repair community and a system of post repair certification must be introduced. The requirement for specialised tooling and equipment to undertake these repairs shall be minimised, repair and servicing must be supported by comprehensive diagnostics through a suitable secure interface, providing clear details and a log of the presence and status of ADS and associated sensors, using harmonised terminology where possible. Provision of supporting equipment, replacement parts, up-to-date software and wider support for the repair of ADS-equipped vehicles must be available at a reasonable cost and for the lifetime of the vehicle.

Changes to the Periodic Technical Inspection (PTI) shall be introduced to ensure ongoing validation that the emergency collision avoidance systems are functioning safely.

Test and Assessment

System degradation can be simulated with virtual testing by stress testing the sensor input data coupled with ongoing benchmarking in PTI testing.

Self-healing can be validated with low-speed impact testing.

The repair requirements and provision of support will be evaluated in the documentation review, by reviewing the information available and the manufacturer's on-going support strategy.

Justification

To ensure vehicles remain safe, they must have adequate diagnostics to identify to the driver when their emergency collision avoidance systems' capability is compromised.

For consumer acceptance, vehicles must be designed so that minor collisions should not cause expensive damage to the ADS and systems should be straightforward to repair after a more significant collision. Diagnostics need to support safe repair and certification of the safety of repairs should be possible.

Creating a meaningful test at a level sufficiently simplified and standardised for use at PTI would be an enormous challenge. However, if type approval requires systems to incorporate sufficient self-diagnostics meaning that emergency collision avoidance systems will not be available whenever an electronic fault is detected, then performance checks on the emergency collision avoidance systems' behaviour may not be needed at PTI. PTI can, therefore, focus on simpler checks of the diagnostic functions and the mechanical systems that the emergency collision avoidance systems also rely on, where failures may not be detected by the self-diagnoses. However, considerable additional research into the best way of maintaining emergency collision avoidance system performance over time will be required.

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