

AN ASSESSEMENT APPROACH TO ASSISTED DRIVING SYSTEMS

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ABSTRACT

An increasing number of vehicles on the global market provide Assisted Driving technology, also referred to as SAE Level 2 partial automation, providing the opportunity for increased driver and road safety. It is the next step towards automated vehicles. To ensure its safety benefits consumers need to be aware and informed about the capabilities of these systems. With these systems being at the cutting edge of modern vehicle technology only limited vehicles currently have these systems fitted, although they are slowly being installed into lower priced mass-produced vehicles, and therefore few consumers have experience or know of the capability of these systems.

This paper investigates a way of assessing the driver support capabilities and HMI of vehicles with Assisted Driving systems to provide information of how the systems cope in different everyday scenarios which they may encounter. This paper outlines the development process of these assessments through both desk-based literature considerations and on track testing methods. Ten different vehicles were put through the assessment process to prove out the test method and offer information on the abilities of various systems. The vehicles are all produced by different manufacturers and range from cheaper less capable to higher end advanced systems with the purpose of showing that within Assisted Driving systems there is vast difference in the performance outcome in both everyday driving and safety critical situations. The assessment of the systems will allow for a basis which will be expanded on for greater in-depth evaluation into the overall safety of the systems and ultimately the assessment of automated vehicles.

The assessment protocol has been developed in agreement with Euro NCAP for the evaluation of ten production vehicles available to buy late 2018, looking into developing the protocol for future testing and grading of new vehicles to be released with Assisted Driving technology.

INTRODUCTION

Latest advances in Advanced Driver Assistance System (ADAS) technology implemented on modern vehicles has seen the introduction of Assisted Driving technology, also referred to as SAE Level 2 partial automation. Assisted Driving provides braking and acceleration control in combination with a steering support function that assists with keeping the vehicle in the driving lane. To achieve this systems use a combination of radar, lidar and camera sensors fitted variously at the front, rear, sides, corners and windscreen of the vehicle to monitor the driving environment and immediate traffic. These functions allow for simultaneous longitudinal and lateral control support, facilitating potentially reduced driver workload and an associated road safety benefit.

Currently no defined assessment protocols exist for Assisted Driving systems and systems developed to date have evolved with notable differences between the technical solutions implemented by various vehicle manufacturers. This has caused differing functionality, performance and Human Machine Interaction (HMI) designs for vehicles fitted with Assisted Driving systems, with the potential to confuse drivers. If a vehicle equipped with Assisted Driving technology is used correctly and the driver works in collaboration with the system, then there is the potential for improved vehicle and road safety. However, if the consumer is uninformed regarding the capability of the system that their vehicle is equipped with then those safety benefits maybe lost in over reliance on the system by the driver, or the driver not having the confidence in using the system and never activating it.

Assisted Driving system functionality that is anticipated to be of benefit to road safety given the effects in regular driving include:

- 1) Headway maintenance: Adaptive Cruise Control (ACC) operates to maintain speed or a set headway to traffic ahead, the shortest setting of which is typically greater than maintained by drivers in regular driving.
- 2) Lane guidance: helps maintain the vehicle within the lane, reducing the possibility of drifting into oncoming or overtaking traffic or running off the road.
- 3) Reduced driver workload: assistance with controlling the vehicle has the potential to reduce driver fatigue through supporting the actions required.

For safe and effective Assisted Driving there is the need to strike a balance regarding the level of assistance provided to deliver a perceivable benefit whilst ensuring the driver remains engaged with the driving task, and not relying on driver monitoring systems to force the driver to pay attention. Studies show that if the system effectively performs fully effective Object and Event Detection and Response (OEDR) drivers can develop over-trust in its capability and fall out-of-the-loop^[3]. As a result, if the vehicle enters a situation the system is unable to manage, and the driver is not attentive to identify the developing situation, there is an increased risk of collision. This also works in the opposite way in that if the system is not very capable the driver is less likely to use the system and not gain the additional safety benefits. **Error! Reference source not found.** represents this 'irony of automation' in graphical form.

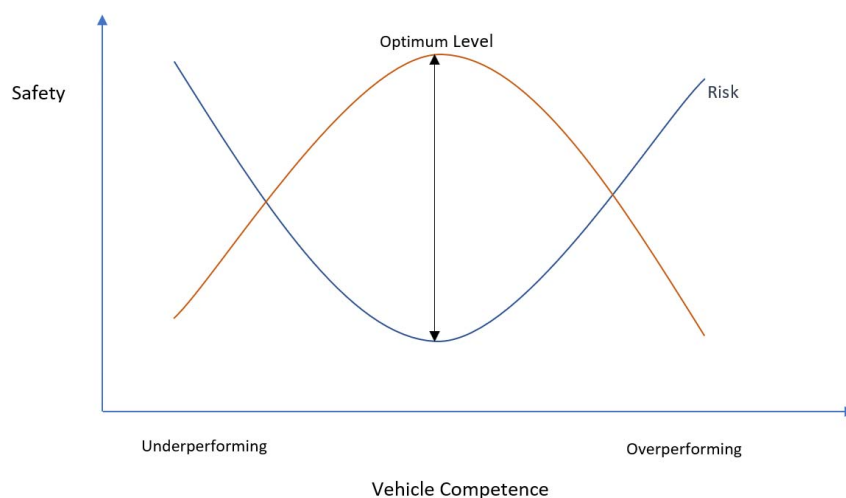


Figure 1. Assisted Driving – safety against vehicle competency

AIM

The aim of this research is to develop an assessment protocol for evaluating Assisted Driving technology that provides a means of considering the system naming and associated literature and testing the system for safety in an objective and repeatable format. It will provide the consumer with information describing the system capability, performance and limitations in typical real world driving scenarios and emergency situations, helping the consumer to understand the system and use it effectively and responsibly to the benefit of road safety. Ultimately the assessment protocol will develop into a consumer grading scheme for Assisted Driving safety.

METHOD

In the absence of any proposals or formalised procedures for assessing Assisted Driving systems the ‘Assisted and Automated Driving Technical Assessment1’^[1] was used as a basis to create initial assessment criteria. Within the literature the criteria for Assisted Driving is outlined under ten headings of:

- 1) Naming
- 2) Law abiding
- 3) Design domain
- 4) Status
- 5) Capability
- 6) Driver monitoring
- 7) Safe stop
- 8) Crash intervention
- 9) Back-up systems
- 10) Accident data

For developing the assessment, the criteria were regrouped because of the nature of their complementary content to desk-based literature review and track-based testing.

Literature Review

The literature associated with a vehicle’s Assisted Driving system, such as online promotional material, operational tutorials and the vehicle handbook etc. can influence a driver’s anticipation of the capabilities of the system, how it will perform and what their role and responsibilities are whilst using the system^[4]. Assessment commences by reviewing the literature accompanying the vehicle describing the system to gather information on the functionality, performance, limitations and driver responsibility. The information therefore needs to be clear and accurate. The following is assessed:

- The naming of the system: it should not specify or suggest automation. The source material should not imply self-driving or automation.
- Capability and limitations: a description of how the driver can expect the system to function and any situations in which the system is limited or unable to perform.
- Operational environment: whether functions are generally available or limited to specified design domains e.g. highways.
- Initial operation: whether a quick start operational guide is provided to explain the system.

Track Testing

To assess the safety aspect of the Assisted Driving system it must be presented with typical the real-world driving situations that can be readily expected to be encountered on the public road. However, to ensure a safe environment and achieve repeatable testing this activity must be performed within the confines of a controlled test track. Vehicles are assessed in the following scenarios.

Longitudinal testing The current Euro NCAP AEB test protocol scenarios were used as a basis for testing the longitudinal capabilities of the ACC system replicating the case where a lead vehicle is directly ahead in lane on a straight section of road. Speeds were increased to those typically encountered on highways (130km/h) because this is the environment in which current systems are recommended for operation.

ACC Test Scenarios:
CCRs: 50 to 130km/h (10km/h increments)

CCRm: VUT 80 to 130km/h
Target 20km/h & 60km/h

CCRb @ -4m/s^2 : VUT 55km/h
Target 50km/h

In addition to these in-line traffic scenarios additional lane changing tests based on a typical highway manoeuvres were included. The first is where a slower moving vehicle cuts in ahead from an adjacent lane. A second is a vehicle in front changes lanes into an adjacent lane revealing a stationary vehicle ahead in lane. These two tests were named as cut-in & cut-out scenarios as shown in Figure 2 & Figure 3.

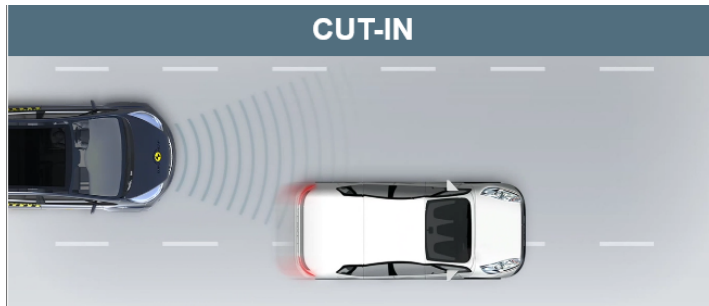


Figure 2. Cut-in test scenario

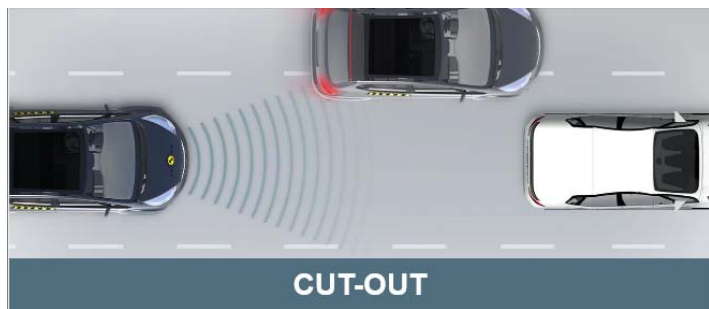


Figure 3. Cut-out test scenario

Cut-in @ TTC -1.5: VUT 50km/h
Target 10km/h
Cut-in @ TTC 0.5: VUT 130km/h
Target 80km/h

Cut-out @ TTC 2.0: VUT 70km/h
Target 50km/h
Cut-out @ TTC 2.0: VUT 90km/h
Target 80km/h

All tests are performed with the ACC set to the nearest following setting.

The test target specified for use is the Global Vehicle Target (GVT) impactable 3D car target according to ISO 19602 Part 1 (see Figure 4). This document specifies the properties of an omni-directional multipurpose vehicle target that will allow it to represent a passenger vehicle in terms of size, shape and sensor attributes for testing purposes.



Figure 4. Global Vehicle Target (GVT) according to ISO 19602 Part 1

Lateral testing Testing the lateral control of an Assisted Driving system involves testing the lane guidance system relative to a marked lane and the interactivity of the steering system in response to driver steering inputs.

The capability of the steering system is evaluated by driving along a straight section of lane markings that transition into a curve to the left immediately followed by a curve to the right, a so-called 's bend' (**Error! Reference source not found.**5). This configuration was selected because it investigated not only the ability of the system to steer into a curve, but also transition between curves in alternate directions as often encountered on the public road.

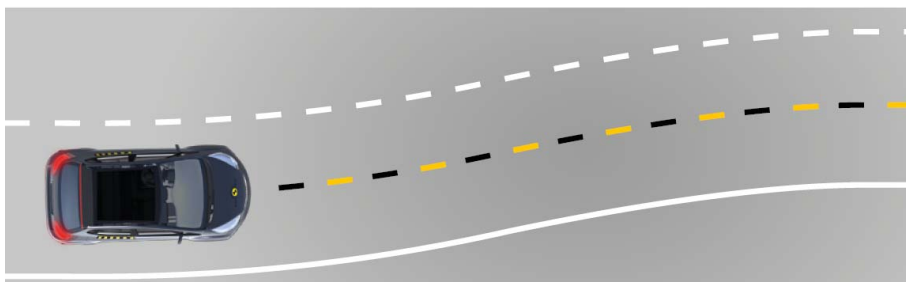


Figure 5. S-Bend test scenario

S-Bend dimensions:

- Left turn radius 900m at 6° angle
- Right turn radius 500m at 6° angle

The S-bend test is performed at increasing speeds from 40mph up to 75mph in 5mph increments.

The test is used to identify the overall level of assistance the vehicle provides driving through the layout. It is considered appropriate that an Assisted Driving system should support the steering through the curves acknowledging necessary directional changes but not necessarily perform complete guidance centering the vehicle in lane throughout the entire manoeuvre. Such authority would infer more automated-like control leaving little for the driver to contribute, potentially affecting perception of the system and ultimately their engagement with the driving

Assessing the driver interactivity with the steering system is performed by investigating the change steering effort required to alter the position of the vehicle within the lane sideways by 0.5m during normal manual driving compared to when the Assisted Driving system activated. The response of the Assisted Driving system to driver inputs is also monitored i.e. does the system shut down or will it tolerate driver inputs and continue to operate. An example of this manoeuvre is avoiding an object, such as a pot hole, within a lane, as shown in Figure 6 below.

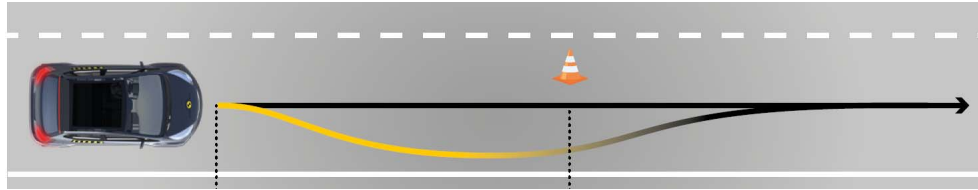


Figure 6. Driver interactivity test scenario

This test is performed with a driving robot following a defined path and investigating the steering torque required for each testing configuration. The baseline reference measurement is then compared with the Assisted Driving measurement to identify the change in steering torque profile throughout the manoeuvre.

Driver inactivity escalation By law Assisted Driving systems must incorporate a means of providing a timely audio-visual warning escalation and ultimately cease assistance in case continuous driver inactivity is detected. However what action to take when ceasing assistance if the driver fails to respond is not specified. Testing is undertaken to investigate the various strategies implemented.

TEST FLEET

A range of ten vehicles equipped with Assisted Driving systems from different manufacturer were assessed. These include:

- 1) Audi A6
- 2) BMW 5 Series
- 3) DS7 Crossback
- 4) Ford Focus
- 5) Hyundai NEXO
- 6) Mercedes-Benz C-Class
- 7) Nissan Leaf
- 8) Tesla Model S (v8.1 software)
- 9) Toyota Corolla
- 10) Volvo V60

RESULTS

Assessing a broad range of state-of-the-art production systems identified the breadth of Assisted Driving capability currently available on the market. A summary of the results of all ten vehicles tested was published in October 2018 on the Euro NCAP website ^[2]. A subset of key results identifying differences between the vehicles tested is presented.

Literature Review

The literature review of promotional material identified that the vehicle manufacturer Assisted Driving system naming conventions were split with five incorporating appropriate 'assist' terminology (Audi, BMW, Hyundai, Mercedes-Benz and Volvo), four using inappropriate 'pilot' terminology suggesting automation (DS, Ford, Nissan and Tesla), otherwise non-descript terms were used (Toyota). Only two cases of notably inappropriate promotional material were identified from Tesla and BMW, promoting full self-driving capability with respect to future developments and showing hands-off driving respectively.

All the vehicle handbooks included information advising that the Assisted Driving system was a driver support function and that the driver retained full responsibility for the safe driving of the vehicle. The majority identified that the Assisted Driving system was intended for use on highways and all listed various performance and operational limitations regarding the road and traffic situations.

Track Testing

Longitudinal control The Tesla Model S stands out by stopping for the stationary target in lane ahead deploying comfort braking by ACC system throughout the entire speed range tested up to 130km/h. Whereas, for example, in the same test the Audi A6 test avoids up to 70km/h using the ACC system, 70 to 100km/h

avoids using emergency intervention by AEB or FCW, and mitigates the collision speed between 100 to 130km/h.

Generally, the longitudinal control in all vehicles tested performed more effectively at higher speeds when approaching the slow-moving vehicle compared to when approaching the stationary vehicle. It is understood that is because of the confidence of identifying and classifying a moving vehicle compared to a static vehicle.

The highly dynamic cut-in and cut-out scenarios challenged all vehicles. In the cut-in scenario four vehicles issued a late collision warning that was insufficient to respond to for avoiding the collision. In the cut-out scenario one vehicle managed to avoid a collision by emergency intervention, six provided a late collision warning and three did not respond at all.

Lateral control The capability of the steering systems also showed demonstrable differences in performance driving through the ‘s-bend’. For example, Tesla Model S navigates the curves remaining centred in the lane throughout the entire manoeuvre at all speeds tested, whereas the Volvo V60 would steer in lane through the initial left turn and attempt to turn in the opposite direction to the right but start to drift out of lane in the transition to the right turn, especially at higher speeds. This is shown in Figure 7 & Figure 8 below.

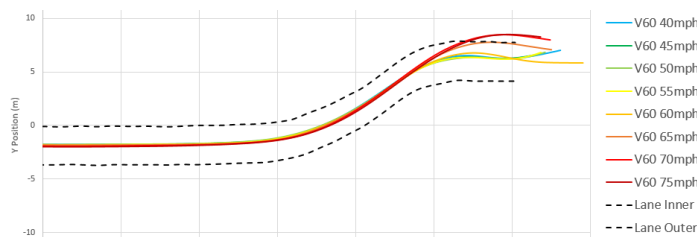


Figure 7. Volvo V60 S-Bend results

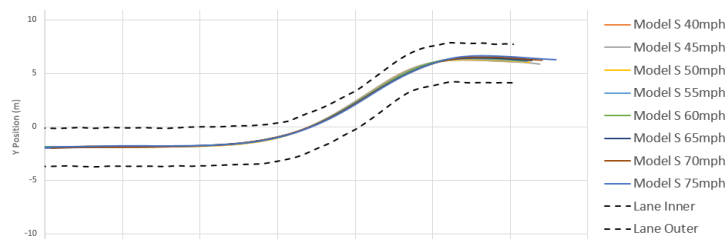


Figure 8. Tesla Model S S-Bend results

The Tesla Model S demonstrated a high degree of steering authority navigating the ‘s-bend’, and this is also identified in the steering interactivity test. The Tesla has the greatest peak proportional increase in steering torque of all ten test vehicles, as shown in Figure 9.

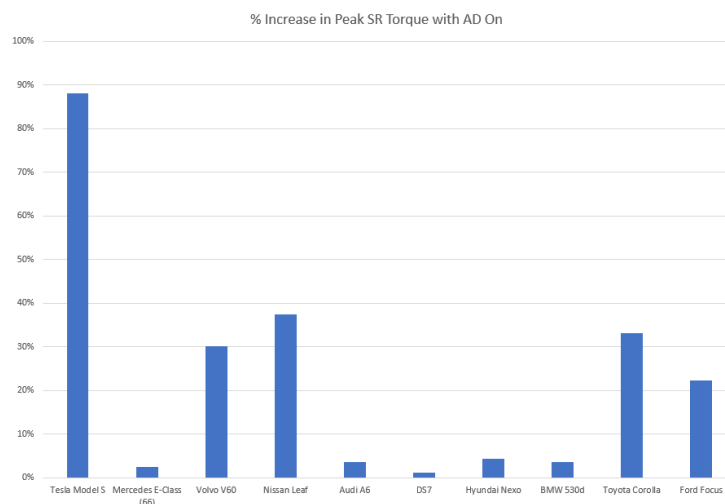


Figure 9. Percentage of steering torque increase during driver interactions test

With the Assisted Driving system active the peak steering torque required to alter the vehicle position within the lane almost doubled compared to that during normal driving. Comparatively the Mercedes, Audi, DS, Hyundai and BMW vehicles demonstrated only modest increases in peak steering torque of less than five per cent. Additionally, the Tesla was the only steering assistance system to completely disengage in response to the driver input with no further operation until the driver reactivates the system. All other systems either continued to provide lane guidance support throughout the manoeuvre or were suspended whilst the steering input was applied and then automatically resumed shortly after the vehicle returned to the centre of the lane.

Driver inactivity escalation Various solutions have been implemented in current production vehicles regarding the action taken if the driver fails to respond to an inactivity warning. This ranges from simply ceasing to provide steering support whilst maintaining ACC speed control, to maintaining steering support and bringing the vehicle to a controlled stop in lane, activating the hazard warning lights and initiating an emergency eCall.

The testing identified that five of the vehicles ceased to provide steering assistance and five came to a controlled stop in lane. Figure 10 is an example of the Nissan Leaf escalating the warnings before beginning a controlled stop after 30 seconds of driver inactivity.



Figure 10. Example of driver disengagement procedure on Nissan Leaf

LIMITATIONS

The tests presented are a first step in assessing Assisted Driving systems and as such are limited to a handful of simplistic, repeatable track tests. However, on the public road drivers, and therefore Assisted Driving systems, encounter a wide variety of road and traffic situations on every journey, not to mentioned changes in lighting and weather conditions etc. Therefore, to develop a meaningful grading scheme a wider range of assessment must be undertaken to inform drivers on the relative merits of the various systems. It would also serve to inform drivers on the limitations of systems thus reinforcing the requirement for them to always remain engaged and vigilant and be prepared to take full manual control of the vehicle. Some examples are discussed below.

Road Environment

Assisted Driving systems have demonstrated a level of competency at managing interactions with other traffic straight ahead in the assessments presented. It has been identified that in a similar traffic situation on a curve system performance can deteriorate substantially with apparently minor changes in the boundary conditions from the driving point of view. To assess this the CCRm & CCRs tests can be performed around the s-bend, at the same speeds, as show in Figure 11.

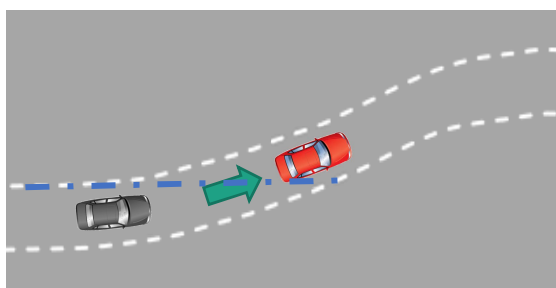


Figure 11. Target vehicle placed within a bend scenario

Vulnerable Road Users

Vulnerable Road Users (VRUs), such as pedestrians and cyclist, frequent roads in which Assisted Driving systems are available to use. The assessments presented are focussed towards highway driving using the GVT to represent other vehicular traffic, however VRUs may also be present if, for example, a traffic queue assist function was used in an urban area. The current AEB VRU test scenarios could be implemented for pedestrians crossing between stop-start queueing vehicles or for cyclists riding in line with the traffic to demonstrate performance or limitations.



Figure 12. Example of ACC longitudinal VRU test scenario

Weather and Lighting

The tests presented are all performed under good testing conditions to achieve repeatability, namely daylight, clear visibility, no precipitation falling etc. Real world experience has highlighted that Assisted Driving system performance can deteriorate in less optimal conditions such as darkness or poor weather conditions. Testing could be considered under these conditions to illustrate the effects to drivers.

Sensor Issues

The sensors used to enable Assisted Driving technology are necessarily positioned towards the perimeter of the vehicle structure to provide a clear view of the surroundings. However, this also makes them susceptible to fouling and damage. Exploratory testing has identified that whilst some systems advise of the need for maintenance almost immediately in case of a sensor blocking issue, others continue to apparently operate for extended periods of time without the driver being advised of a degradation in their functionality and system performance e.g. ACC reverting to normal cruise control.

CONCLUSIONS

Assisted Driving systems are already available in a wide range of vehicles and are rapidly being introduced into mass market affordable vehicles. The combination of lateral and longitudinal assistance, when used responsibly by the driver, could benefit road safety through improved headway, lane positioning and reduced driver fatigue through being supported with the driving task.

The literature review of promotional material identified that the vehicle manufacturer Assisted Driving system naming conventions were split between appropriate and inappropriate terms and only two cases of notably inappropriate promotional material were identified. All the vehicle handbooks included information advising that the Assisted Driving system was a driver support function and that the driver retained full responsibility for the safe driving of the vehicle.

The track tests developed for assessing Assisted Driving systems evaluating longitudinal control, lateral support and driver interactivity proved effective at identifying differences in functionality and performance between vehicles. However, it is acknowledged that the tests themselves are a simplistic representation of typical scenarios encountered in real world driving. A future grading scheme would require a broader range of scenarios to be considered to achieve a more representative grading and illustration of system functionality and limitations. Similarly, the testing was performed under a limited set of controlled conditions necessary to

achieve repeatability. Real-world driving conditions vary substantially, and a more representative assessment could be achieved by considering additional factors e.g. driving in darkness.

This initial assessment of ten production vehicles has identified that there is a range of functionality and performance differences between Assisted Driving systems. Some systems portray a high degree of driving competence in response to the lane geometry and interactions with other traffic whilst others offer more modest performance. For example, the Tesla Model S stood out in CCRs test by coming to a halt behind the stationary target at all speeds up to 130km/h using comfort braking only whereas all other vehicles tested either failed to acknowledge the stationary vehicle at higher speeds or only achieved collision mitigation by emergency response.

The Tesla was also the only vehicle to navigate the 's bend' curves remaining centred in the lane throughout the entire manoeuvre at all speeds tested, however it also demonstrated the highest proportional increase in peak steering effort in the driver interactivity tests and subsequently steering support was disengaged whereas all other systems continued to operate after returning to the central lane position. The highly dynamic cut-in and cut-out scenarios challenged all vehicles and little meaningful intervention was identified except for in one vehicle.

Various solutions have been implemented in current production vehicles regarding the action if the driver fails to respond to an inactivity warning ranging from simply ceasing to provide steering support whilst maintaining ACC speed control, to maintaining steering support and bringing the vehicle to a controlled stop in lane.

For safe and effective Assisted Driving there is the need to strike a balance regarding the level of assistance provided to deliver a perceivable benefit whilst ensuring the driver remains engaged with the driving task, and not relying on driver monitoring systems to force the driver to pay attention. The next step is to develop the testing and an associated grading scheme to enable the evaluation of system performance and drive best practice to achieve the road safety benefits associated with Assisted Driving technology maintaining headway, improving lane guidance and reducing driver workload and associated fatigue.

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