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Automotive Risk Intelligence

Benchmarking Study of Level 2+ Assisted Driving Systems

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1. Introduction

Driver assistance systems have been developing in vehicles increasingly quickly in the last decade. Level 2 (L2) assisted driving systems use adaptive cruise control (ACC) and continuous lane centring to support a driver when travelling in fully marked lanes, such as on highways. As these systems have become more widely available, their functionality has also increased. Many manufacturers now offer features such as hands-free driving and lane change assist on selected roads. Such systems with increased complexity are referred to as Level 2+ (L2+) assisted driving systems. More precisely, these systems are now referred to as Driver Control Assistance Systems (DCAS) according to UNECE Regulations. This term will be used throughout the report to describe both hands-on and hands-off L2 systems.

The aim of this project is to assess the DCAS fitted to five vehicles from different manufacturers currently available in the US market. Two experienced test engineers will drive the vehicles to understand the positives and negatives of each system. The features will be scored subjectively by both test drivers, enabling a direct comparison between vehicles. The project aims to highlight the best DCAS based on both performance and consumer acceptance.

2. Methods

2.1 Assessment Criteria

A robust and reliable DCAS should strike a balance between effective vehicle assistance and an engaging driver experience. A scoring framework was devised with appropriate weightings for each system feature to ensure the vehicles were assessed consistently. A large emphasis was placed on the performance of the ACC and lane centring systems, though consideration was also given to how a consumer would interact with the vehicle. Table 1 below shows a breakdown of the assessment topics and their weighting within the scoring framework.

Assessment Topic	Weighting
Consumer Information	5 %
Speed Limit Information Function (SLIF)	10 %
Lane Support Systems (LSS)	27.5 %
Adaptive Cruise Control (ACC)	27.5 %
Driver Monitoring	15 %
Human Machine Interface (HMI)	15 %

Table 1: Assessment topics and associated scoring weightings.

The scoring framework has been devised with a primary focus on system safety, though consideration has been given to specific US societal driving behaviours and preferences. The framework provides a metric to quantify the performance of each system, while still highlighting the poignancy of user interaction and acceptance.

2.1.1 Consumer Information

One of the main risks associated with DCAS is overconfidence in the system's capabilities. Drivers' expectations of the level of assistance provided will be influenced by the information available to them before operating the system.

The owner's manual, vehicle infotainment system and any supplementary paperwork were examined for accuracy and clarity on the functionality, operation and limitations of the system. The online marketing material was also investigated for any misleading statements regarding level of assistance provided. Details of the specific scoring criteria are shown in table 2.

Test Subject	Scoring Criteria	Consumer Information Score
Online Marketing	Is the level of assistance clearly described? Is the system described as automated or self-driving?	20 %
Vehicle Handbook	Is it clear to a consumer that the system is only designed to assist? Is it clear that driver engagement is always required? Is the operation of the system described accurately? Are system limitations explained?	20 %
Infotainment System	Is the functionality and operation of the systems clearly described within the infotainment system menus?	20 %
Paper Quick Start Guide	Is there a supplementary paper quick start guide? Does the quick start guide provide clear information of the operation and limitations for the DCAS?	20 %
Video Guides	Are there any video quick start guides available, either through the infotainment system or online? Is the operation and limitations of the system clear?	20 %

Table 2: Consumer information test subjects, scoring criteria and weighting.

2.1.2 Speed Limit Information Function (SLIF)

Excessive speed is a leading factor in the cause and severity of many road accidents. The speed limit information function (SLIF) promotes safer driving by encouraging a driver to abide by the set speed limits. Many DCAS combine the ACC functions with the Speed Assist systems to provide a more intelligent speed control response. SLIF scoring criteria are shown in table 3 below.

Test Subject	Scoring Criteria	SLIF Score
Accuracy	Is the correct speed limit for each road displayed to the driver?	20 %
Warnings	Is a visual / audible / haptic warning produced when the speed limit is exceeded?	20 %
iACC Capability	Is the ACC set speed adjusted automatically in line with the SLIF?	20 %
Temporary Speed Limits	Does the system recognise temporary speed limit signs? For example, around roadworks zones.	20 %
Road Features	Does the system adjust the vehicle's speed appropriately for upcoming road features, such as off-ramps or bends?	20 %

Table 3: SLIF test subjects, scoring criteria and weighting.

2.1.3 Lane Support Systems (LSS)

The steering assistance system must support a driver to keep the vehicle in lane, on both straight roads and around bends. While it is important to provide accurate and precise vehicle positioning within a marked lane, this should not come at the expense of a collaborative driving experience. A safe and confidence-inspiring system will allow a driver to override the assistance without cancelling the steering support. Table 4 below shows the scoring criteria for LSS assessments.

Test Subject	Scoring Criteria	LSS Score
Usability	Is the system easy to switch on and off? Is operation of the system intuitive?	5 %
Continuous Lane Centring	How well does the system stay centrally in the lane markings? Is the system stable and reliable for long durations? Does the system exhibit any lane biasing when passing larger vehicles?	20 %
Hands-free Driving	Does the system offer hands-free driving on certain highways?	15 %
S-Bend	How well does the lane centring navigate consecutive, opposing bends?	10 %
Driver Input Response	Is the lane centring steering support collaborative? Is the driver able to easily override the system?	20 %
Lane Change Assist	Does the system perform automatic lane change manoeuvres? Are these initiated by the driver or automatically by the system? How well does it perform this manoeuvre?	15 %
Intentional Overtake	Does the vehicle apply emergency steering when the turn signal is applied and a vehicle is present in the blind spot?	10 %
Blind Spot Monitoring	Is the vehicle fitted with warning indicators for other vehicles present in the blind spot?	5 %

Table 4: LSS test subjects, scoring criteria and weighting.

2.1.4 Adaptive Cruise Control (ACC)

The ACC system controls the vehicle's speed to maintain a safe following distance behind other road vehicles. The system performance was assessed against nine separate scoring criteria, as shown in table 5 below.

Test Subject	Scoring Criteria	ACC Score
Usability	Is the system easy to switch on and off? Is operation of the system intuitive?	5 %
Distance Control	Is a consistent following distance maintained behind other vehicles?	10 %
Stationary Traffic	Does the vehicle decelerate comfortably for stationary traffic? What is the maximum speed that the system can be effective?	15 %
Slower Moving Traffic	Does the vehicle decelerate comfortably for slower moving traffic?	15 %
Decelerating Traffic	When following a vehicle that begins to brake, does the system maintain a safe distance between vehicles?	15 %

Field of View on Curved Roads	Does the system recognise slower moving traffic in the same lane around a curved road?	10 %
Automatic Resumption	Does the ACC system automatically resume after stand-still? Is a driver input required to reactivate the ACC system?	10 %
Traffic Cut-In	When a vehicle cuts in front of the test vehicle, does the system sensibly adjust to a safe following distance?	10 %
Traffic Cut-Out	When following a vehicle that moves into another lane, does the system react appropriately for stationary traffic ahead?	10 %

Table 5: ACC test subjects, scoring criteria and weighting.

2.1.5 Driver Monitoring

Some DCAS allow hands-free driving along certain roads by monitoring the driver to ensure they are remaining engaged with the driving task. The assessment of driver monitoring systems investigated the warnings that were produce when a driver is deemed distracted. The system robustness was examined by testing a variety of gaze locations and glance types, as well as adding occlusions to a driver's face. The full scoring criteria for driver monitoring systems is listed in table 6 below.

Test Subject	Scoring Criteria	Driver Monitoring Score
Unresponsive Driver	Does the system recognise an unresponsive driver? Does the system react to safely reduce the vehicle's speed?	20 %
Long Distractions	Does the system recognise a driver as distracted when they are not looking at the forward road view for a continuous period? Are the warnings appropriate?	20 %
Short Distractions	Does the system recognise a driver as distracted when they repeatedly look away from the forward road view? Are the warnings appropriate?	20 %
Phone Use Detection	Does the system recognise a driver that is using their mobile phone? Are the warnings appropriate?	20 %
Robustness to Occlusions	Does the system still reliably recognise a distracted driver when wearing occlusions such as sunglasses or hats?	20 %

Table 6: Driver monitoring test subjects, scoring criteria and weighting.

2.1.6 Human Machine Interface (HMI)

The HMI assessment looked at the information provided to the driver to convey the current level of assistance. This is expected to be largely visual information, but audible and haptic warnings may be used to convey a change in level of system assistance. Information should contain sufficient detail to fully inform drivers but should not be overcrowded or difficult to understand. Precise scoring criteria for HMI assessment can be seen in table 7 below.

Test Subject	Scoring Criteria	HMI Score
Visibility	Is the dashboard display clear and easy to understand? Are system status indicators always visible to a driver?	20 %
Auble Warnings	Does the system allow configurable audible warnings for system warnings / notifications?	10 %

Haptic Feedback	Does the system provide any haptic feedback to the driver?	20 %
Configurability	Is there a choice of driving information displayed in the instrument cluster?	10 %
Heads-Up Display	Is there a heads-up display fitted to the vehicle? Is all information in the heads-up display clear?	20 %
Change of Status Information	Does the system provide clear audible / visual information when the level of assistance provided by the DCAS changes? This will be scored in three categories: system unavailable, system cancelled, and system resumed.	20 %

Table 7:HMI test subjects, scoring criteria and weighting.

2.2 Test Vehicles

Five vehicles were tested from a range of vehicle manufacturers, listed below. The vehicles, shown in figure 1, were selected to provide a fair representation of the DCAS currently available on the market.

- Tesla Model S Plaid
- Ford F-150 Lightning
- BMW i7
- Jeep Grand Cherokee
- Cadillac Escalade

Figure 1: The test vehicles on display at Michigan Technical Resource Park. From left to right: Ford F-150 Lightning, BMW i7, Jeep Grand Cherokee, Tesla Model S, Cadillac Escalade.

2.3 Test Route

A repeatable test route was mapped out to ensure that each vehicle was tested on the same roads. The route was designed as loop between Michigan Technical Resource Park, approximately 15 miles North-West of Toledo, and Indianapolis, shown in figure 2. The route was comprised of mainly Interstate highways (I475, I469, I69, I70, I75) but it also included 80 miles of driving on the U.S. Route 24 in Ohio and Indiana. Each vehicle was additionally driven along approximately 10% of the test route again at night, to evaluate any differences in DCAS performance in low-light conditions.

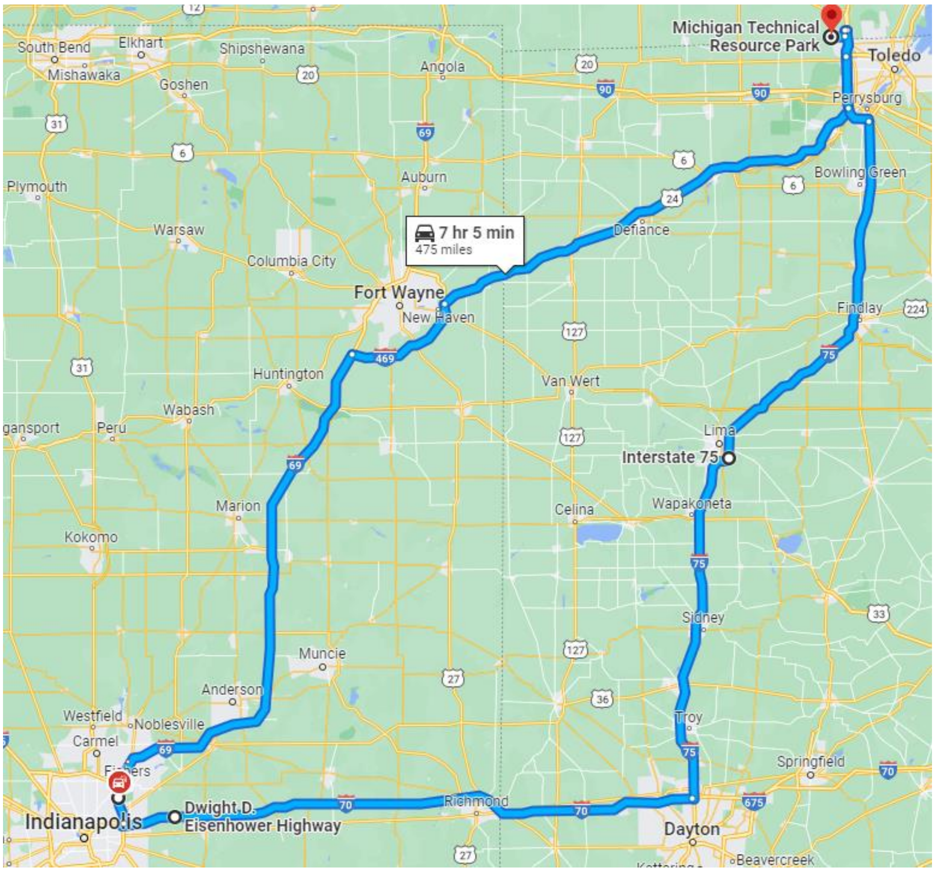

Figure 2: The test route loop between Toledo and Indianapolis.

2.4 Proving Ground Testing

Certain tests could not be performed on-road due to the risk of collision and were instead carried out on the oval circuit at Michigan Technical Resource Park. The testing would quantify the LSS performance and determine the operating limits of the ACC system for each vehicle. The emergency response in the event of a driver becoming unresponsive was also considered.

The target vehicle used for the ACC testing was the 4activeC2 (Model 2 v7.1 GVT) soft car target, shown in figure 3 below. It is made from radar suppressing foam that can be safely impacted and wrapped in skins to give the visual appearance of a Ford Fiesta and a radar cross-section that mirrors a real vehicle.


Figure 3: Front and rear views of the 4activeC2 car target.

3. Results

3.1 Case Study

A brief overview of the test vehicles is presented in table 8 below.

	Tesla Model S Plaid	Ford F-150 Lightning	BMW i7	Jeep Grand Cherokee	Cadillac Escalade
Powertrain	Electric	Electric	Electric	V6 Gasoline	V8 Gasoline
System Name	Auto-Pilot (Beta)	Blue-Cruise	Assisted Driving Plus	Active Driving Assist	Super Cruise
Road View Camera	✓	✓	✓	✓	✓
Forward Facing Radar	✗	✓	✓	✓	✓
Driver Monitoring Camera	Wide angle cabin camera	Infrared Cameras	Infrared Cameras	Infrared Cameras	Infrared Cameras
Hands Free Driving	✗	✓	✓	✓	✓
Lane Change Assist	✓	✗	✓	✓	✓

Table 8: Fitted DCAS equipment and features for each test vehicle.

DCAS were fully supported for all vehicles on the Interstate highways along the test route. However hands-free driving support was limited on sections of the U.S. Route 24 for the Jeep, Ford and BMW, due to the presence of regular intersections along this road. This had no effect on the scoring for these vehicles, as it remained clear to a driver that the system was not able to be engaged to its fully capabilities.

The test criteria in this assessment were independently and subjectively scored out of 5 by two experienced DCAS test drivers. Once all vehicles had been tested, the scoring was peer reviewed and averaged to give a final percentage score, producing a discrete ranking of vehicle DCAS. The results tables have been broken down into each assessment topic for ease of comparison.

3.2 Assessment Topic Scoring

3.2.1 Consumer Information Scores

Test Subject	Weighting	Tesla	Ford	BMW	Jeep	Cadillac
Online Marketing	20%	4	3	3	4	5
Vehicle Handbook	20%	3	5	4	5	5
Infotainment System	20%	3	5	4	2	3
Paper Quick Start Guide	20%	0	4	0	5	5
Video Guides	20%	3	2	2	2	1
Section Sub-total		52.00%	76.00%	52.00%	72.00%	76.00%

Table 9: Scoresheet for consumer information assessment.

3.2.2 SLIF Scores

Test Subject	Weighting	Tesla	Ford	BMW	Jeep	Cadillac
Accuracy	20%	4	4	5	5	5
Warnings	20%	5	4	5	5	3
iACC Capability	20%	3	4	0	0	0
Temporary Speed Limits	20%	4	4	4	4	0
Road Features	20%	5	3	4	0	3
Section Sub-total		84.00%	76.00%	72.00%	56.00%	44.00%

Table 10: Scoresheet for SLIF assessment.

3.2.3 LSS Scores

Test Subject	Weighting	Tesla	Ford	BMW	Jeep	Cadillac
Operation & Usability	5%	3	5	4	5	4
Continuous Lane Centring	20%	5	2	4	4	3
Hands-free Driving	15%	0	5	5	5	5
S-Bend	10%	5	3	4	4	3
Driver Input Response	20%	1	5	3	4	4
Lane Change Assist	15%	3	0	4	5	2
Intentional Overtake	10%	4	5	4	4	4
Blind Spot Monitoring	5%	3	5	5	5	5
Section Sub-total		57.00%	69.00%	80.00%	88.00%	72.00%

Table 11: Scoresheet for Lane Support System assessment.

3.2.4 ACC Scores

Test Subject	Weighting	Tesla	Ford	BMW	Jeep	Cadillac
Operation & Usability	5%	3	4	4	5	3
Distance Control	10%	5	4	5	4	3
Stationary Traffic Braking	15%	5	3	3	1	4
Slower Moving Traffic Braking	15%	5	3	4	3	3
Decelerating Traffic Braking	15%	5	3	3	3	3
FoV on Curved Roads	10%	5	5	5	5	5
Auto-Resume	10%	4	5	5	4	3
Cut-in	10%	4	3	5	4	4
Cut-out	10%	5	4	4	2	5
Section Sub-total		94.00%	73.00%	82.00%	64.00%	73.00%

Table 12: Scoresheet for Adaptive Cruise Control assessment.

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3.2.5 Driver Monitoring Scores

Test Subject	Weighting	Tesla	Ford	BMW	Jeep	Cadillac
Unresponsive Driver	20%	4	3	5	2	2
Long Distractions	20%	0	5	5	4	4
Short Distractions	20%	0	0	0	4	0
Phone Use Detection	20%	3	0	0	1	0
Robustness to Occlusions	20%	4	5	5	5	5
Section Sub-total		44.00%	52.00%	60.00%	64.00%	44.00%

Table 13: Scoresheet for driver monitoring assessment.

3.2.6 HMI Scores

Test Subject	Weighting	Tesla	Ford	BMW	Jeep	Cadillac
Visibility / Location	20%	3	5	4	4	3
Audible Warnings	10%	4	4	4	4	3
Haptic Feedback	20%	3	3	3	5	4
Configurability	10%	0	5	5	5	3
Additional Visual Information	20%	0	0	5	4	4
System Unavailable	20%	5	2	3	4	1
System Cancelled		5	3	4	5	2
System Resumed		4	5	4	3	4
Section Sub-total		50.67%	63.33%	80.67%	86.00%	65.33%

Table 14: Scoresheet for HMI assessment.

3.3 Final Gradings

Assessment Criteria	Weighting	BMW	Jeep	Ford	Tesla	Cadillac
Consumer Information	5%	52%	72%	76%	52%	76%
SLIF	10%	72%	56%	72%	84%	44%
LSS	27.5%	80%	88%	69%	57%	72%
ACC	27.5%	82%	64%	73%	94%	73%
Driver Monitoring	15%	60%	64%	52%	44%	44%
HMI	15%	81%	86%	66%	51%	65%
Grand Total		**75.5%**	**73.5%**	**67.8%**	**66.7%**	**64.5%**
Ranking		**1st**	**2nd**	**3rd**	**4th**	**5th**

Table 15: Final score with section weightings applied. Vehicles ordered according to overall ranking.

4. Discussion

From table 15, the vehicle with the best DCAS was found to be the BMW i7, with an overall score of 75.1%. The Jeep Grand Cherokee was a well-balanced system earning 2nd place, offering very good steering support and an engaging driving experience. The Ford F-150 Lightning was ranked in 3rd place, while the Tesla Model S and Cadillac Escalade were awarded 4th and 5th place respectively.

While the scoring framework provided a mechanism to directly benchmark each vehicle against, it should be noted that the numerical results can only quantify the specific test criteria. Test drivers' overall impressions on usability will be discussed in the following sections.

4.1 Comparision of Assessment Topics

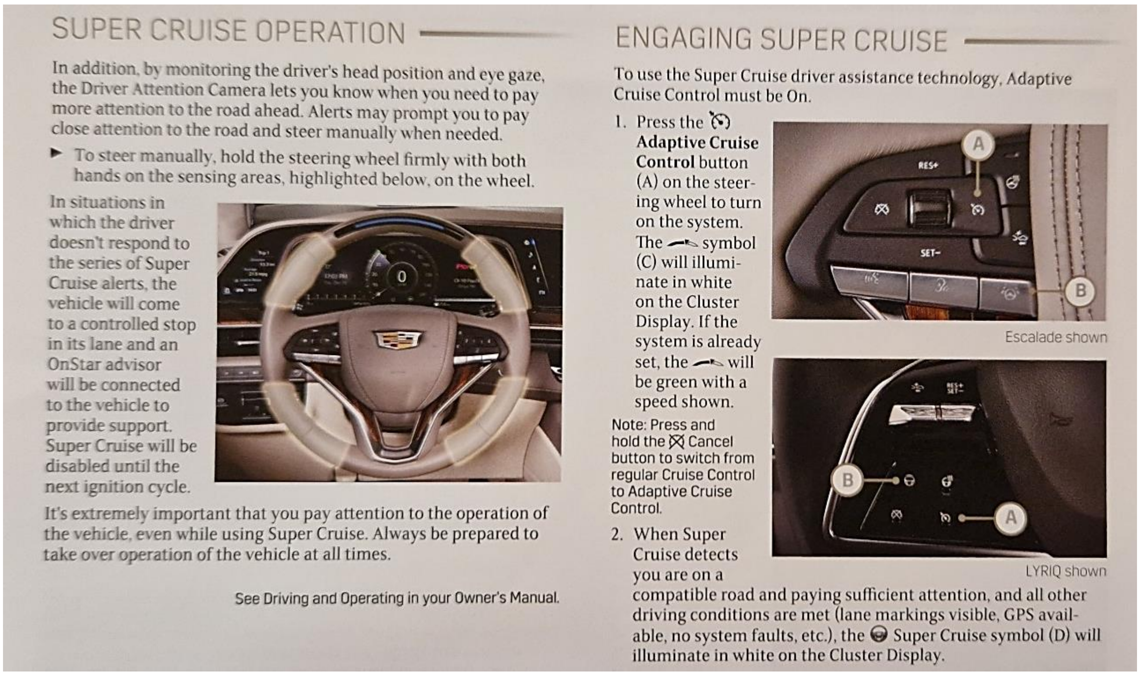
4.1.1 Consumer Information

The Ford, Cadillac and Jeep all scored well in the consumer information assessment, thanks to at least some information being available for all scoring criteria. A paper quick start guide supplied with these vehicles was a welcome addition, as they detailed the system operation in a clear and concise manner. Examples of this information from the Cadillac's guide are shown in figures 4 and 5.

Figure 4: Steering wheel features from the quick start guide for the Cadillac Escalade.

Another extremely helpful source of information for consumers is the in-vehicle infotainment system. The Ford F-150 was the best system in this regard, as every driver assistance feature had a brief explanation of scope include in the vehicle settings that was very simple to comprehend, as showcased in figure 6.

Quick start information on system operation and responsibilities can also be conveyed to drivers by video. However, the scoring for this criterion reflects the poor accessibility of these guides for all manufacturers. Some video guides were available online, either through the manufacturer's website or via websites such as YouTube, but it would be preferable for consumers to be able to access these videos directly through the infotainment system also.



SUPER CRUISE OPERATION

In addition, by monitoring the driver's head position and eye gaze, the Driver Attention Camera lets you know when you need to pay more attention to the road ahead. Alerts may prompt you to pay close attention to the road and steer manually when needed.

- To steer manually, hold the steering wheel firmly with both hands on the sensing areas, highlighted below, on the wheel.

In situations in which the driver doesn't respond to the series of Super Cruise alerts, the vehicle will come to a controlled stop in its lane and an OnStar advisor will be connected to the vehicle to provide support. Super Cruise will be disabled until the next ignition cycle.

It's extremely important that you pay attention to the operation of the vehicle, even while using Super Cruise. Always be prepared to take over operation of the vehicle at all times.

See Driving and Operating in your Owner's Manual.

ENGAGING SUPER CRUISE

To use the Super Cruise driver assistance technology, Adaptive Cruise Control must be On.

1. Press the **Adaptive Cruise Control** button (A) on the steering wheel to turn on the system. The symbol (C) will illuminate in white on the Cluster Display. If the system is already set, the will be green with a speed shown.

Note: Press and hold the Cancel button to switch from regular Cruise Control to Adaptive Cruise Control.

Escalade shown

LYRIQ shown

2. When Super Cruise detects you are on a compatible road and paying sufficient attention, and all other driving conditions are met (lane markings visible, GPS available, no system faults, etc.), the Super Cruise symbol (D) will illuminate in white on the Cluster Display.

Figure 5: DCAS operation instructions from the Cadillac's quick start guide.

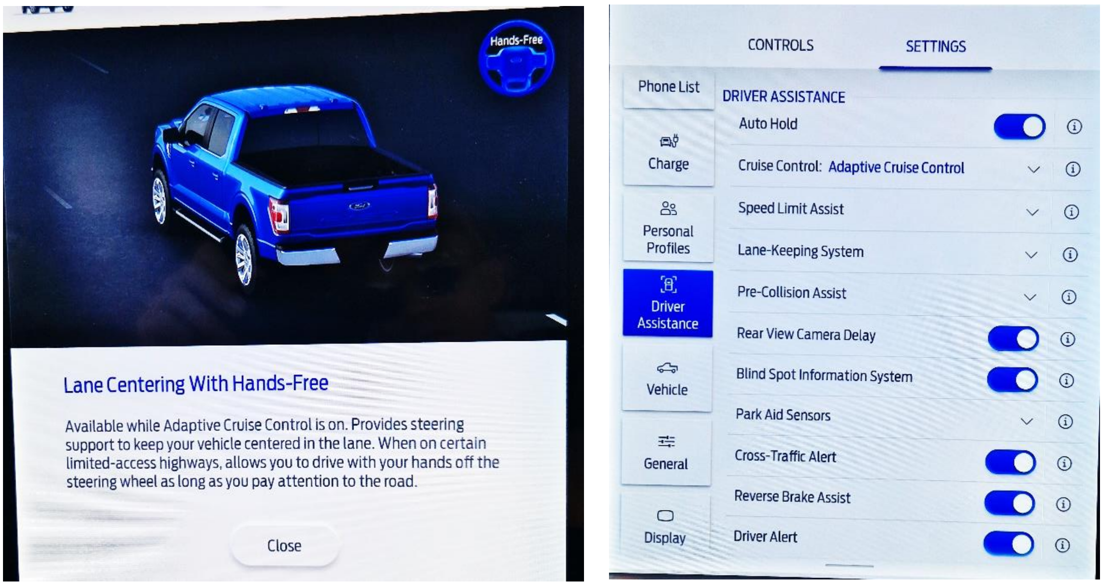


Figure 6: In-Vehicle infotainment guides for the Ford F-150 Lightning.

4.1.2 SLIF

The basic features of the SLIF system are the detection of speed limits and warning a driver when speeding. In these criteria, all five vehicles were very similar in their performance, which is likely due to the widespread availability of map data. Both test drivers appreciated that speeding warnings could be configured as either a visual icon or an audible chime for 4 out of 5 vehicles, with only the Cadillac not offering drivers a choice. The Cadillac was also the only vehicle that was entirely unable to detect temporary speed limits, as found in Work Zone areas, suggesting that their system relies heavily on known map data rather than using a forward facing camera to confirm the current speed limit. Notably however, all four vehicles capable of detecting temporary speed limits could only recognise printed signs. Variable speed limit signs that use LEDs proved troublesome for all test vehicles to recognise, due to a difference in the frame rate of vehicle cameras and the LED refresh rate, as shown in figure 7. The BMW's reaction after this type of sign is seen in figure 8.

Figure 7: Flashing LEDs are used on some temporary speed limit signs. The difficulties caused by LED refresh rate can be seen in the right image.

Figure 8: BMW i7 dashboard display showing the incorrect speed limit after passing a temporary LED sign.

The best SLIF scores were set apart by their ability to intelligently link the ACC system reaction with the current road. The Ford and Cadillac made attempts to slow down below the speed limit when navigating tight turns, such as on highway merging ramps, though not sufficiently to make a driver or passengers feel comfortable. While the BMW would slow down to an appropriate speed for road features, the Tesla proved to be the most capable in this regard by beginning a gentle deceleration well in advance of any manoeuvres.

Intelligent Adaptive Cruise Control (iACC) was only available on the Ford and the Tesla, though functionality could be improved for both. The ACC set speed was automatically adjusted to the speed limit detected by the SLIF system, which is no doubt more effective at reducing cases of speeding than a warning alone. However, this caused concern for the test drivers as the vehicle becomes a much larger risk to other drivers if any speed limits are detected incorrectly.

A safer approach would be to instead offer the new speed limit to a driver and await their confirmation via a single button push before adjusting the current vehicle speed. Furthermore, iACC systems should ideally identify and react to upcoming speed limit changes before passing the speed limit sign, as indicated in NHTSA and EuroNCAP Assisted Driving test protocols. Both the Ford and Tesla would only adjust their set speed after passing into the new speed limit.

4.1.3 LSS

The LSS scores in table 11 show the Jeep as the best performer overall by a significant margin, due to a combination of its robust lane centering and the collaborative feeling from the steering wheel. The lowest ranked system was the Tesla, which was stifled by its uncooperative steering and lack of hands-free driving.

In terms of usability, both test drivers agreed that the Ford and Jeep systems were simple to operate, while the steering wheel buttons to engage the LSS on the Tesla were remarkably unclear. This was also the case for the blind spot information conveyed to the driver; The Tesla did not provide a simple warning icon in the wing mirror to indicate the presence of other vehicles and instead opts to continuously inform drivers via the animated dashboard display. An example of this warning icon from the Ford is shown in figure 9 below.

Figure 9: Blind spot warning icon activating in the Ford F-150 Lightning.

Regarding continuous lane centering, there was a clear divide between systems that gave the test drivers confidence in the vehicle's ability and systems that irritated or worried drivers. The BMW and Jeep were very capable of maintaining a central position within a lane on both straight and curved sections of road, though the Tesla was the standout winner in this regard. The Ford and Cadillac scored poorly in these criteria as the vehicle would often weave noticably left and right within the lane, forcing the drivers to take control and steady the assistance system. A driver had to be particularly attentive to use these two systems on busy highways, resulting in a more stressful driving experience than would be had without the DCAS activated. None of the test vehicles showed any degredation in performance of continuous lane centering at night, though camera vision was understandably limited due to glare when driving towards direct sunlight at dusk.

The steering support systems in the Tesla, Jeep and BMW could detect large vehicles, such as semi-trucks and other commercial vehicles. They reacted by adjusting their position within the lane when passing these larger vehicles to give more lateral space. This feature was greatly welcomed by the test drivers, as it mimiced a common human behaviour and instilled confidence in the DCAS to recognise a variety of conditions encountered on roads. Such a feature is often referred to as lane biasing, and has been rewarded in the continuous lane centering score for each vehicle.

Lane change assist was fitted with varying functionality to four of the test vehicles but was unavailable on the Ford F-150 Lightning. Both the Tesla and Cadillac offered completely automatic lane changes, meaning no driver inputs were required to initiate the manoeuvre. Although there is an argument for convenience, the test drivers had to regularly override the system to prevent unnecessary lane changes, becoming more of a hindrance than help. The manoeuvre was very smooth and controlled in the Tesla, merging gently with the neighbouring lane to avoid excessive lateral accelerations that would be uncomfortable for passengers. The Cadillac was less smooth with its steering inputs and on most occasions would stray well beyond the lane center before correcting its trajectory in the new lane. This made the drivers feel nervous and, as a result, automatic lane changes in busy traffic conditions were supported manually by the driver.

In both the BMW and Jeep, the lane change assist feature was triggered manually by a driver by pressing the turn signal indicator in the desired direction. Both systems provided clear information throughout the manoeuvre, seen in figure 10, and instilled a level of confidence in the drivers by only starting to move over when there was a sufficient gap. The accuracy of the lane change was comparable between both systems but the Jeep scored highest in this criteria because the change in trajectory was so gradual and smooth. In contrast, the BMW performed each lane change quickly and assertively. Despite the system being clearly capable, test drivers found this manoeuvre less relaxing compared to other vehicles.

Figure 10: Dashboard display in the Jeep Grand Cherokee during a lane change assist manoeuvre.

4.1.4 ACC

Scoring an impressive 94%, the Adaptive Cruise Control in the Tesla was exceptionally good and was only let down by the usability of the system. Conversely, the worst performing vehicle in terms of ACC performance was the Jeep at 64%. The BMW scored a respectable 82% here, while the Ford and Cadillac both scored 73%.

Despite lacking a forward facing radar to determine distances to objects ahead of the vehicle, the Tesla outclassed the other test vehicles with respect to speed and distance control. It was the only vehicle capable of slowing down from 75mph for a stationary target using the ACC system alone. The reaction to other road traffic was always much earlier and more gentle compared to the other test vehicles, and as such, the drivers very quickly gained confidence in the systems abilities. The downside of a camera-only DCAS system, such as in the Tesla, is that ACC performance was limited in strong direct sunlight. The system does however warn a driver and disable the assistance as soon as the vision deteriorates. Operation of the system was simple but lacked intuitiveness; A driver must press the right-hand scroll wheel, as seen in figure 11, once to engage the ACC system and the set speed can then be adjusted by scrolling with this same button.

Figure 11: Tesla steering yoke and DCAS controls.

In second place for ACC performance, the BMW was not as reliable as the Tesla at detecting and decelerating for significantly slower moving traffic. It could only avoid a collision with a stationary target vehicle under ACC up to 55mph, though the system did provide audible and visual warnings when tested at higher speeds. These warnings were sufficiently early and urgent for a driver to recognise the immediate risk and intervene to avoid the collision themselves. The BMW excelled at maintaining a consistent following distance to other vehicles as well as navigating stop-start traffic smoothly, using the driver monitoring cameras to confirm that drivers eyes were on-road before pulling away from standstill. Although the steering wheel buttons, shown in figure 12, were more intuitive than the tesla, the test drivers occasionally found these buttons more awkward to press.

Figure 12: BMW i7 steering wheel and DCAS control buttons.

The identical scores for the Ford and Cadillac ACC systems accurately reflect their similarities in performance. Both vehicles were able to decelerate adequately to avoid collisions at normal highway driving speeds, though system reactions did not inspire confidence in the test drivers as braking often began much later than if a human was controlling the vehicle's speed. When following another vehicle, the distance was maintained slightly more consistently by the Ford, though this may be attributed to the electric drivetrain in the F-150 Lightning.

Figure 13: Jeep Grand Cherokee steering wheel and DCAS control buttons.

The Jeep showed a similar level of performance to the Ford and Cadillac in terms of its ACC response on road. The system was very user friendly as steering wheel buttons were very clear, as shown in figure 13, and both test drivers were quick to understand how the system is operated. However, the system was let down in tests carried out on the proving ground as the Active Driving Assist (ADA) was not available on this unspecified road. Even at 35mph, the ACC system showed no reaction to a stationary vehicle in the same lane of travel. When performing cut-out tests, the Jeep failed to recognise the revealed stationary target and quickly began to accelerate up to the ACC set speed. Whilst these characteristics were not observed as drastically on-road, the lack of ACC assistance when ADA is not available was concerning. The ACC system should be able to effectively support a driver on a variety of road types, not just highways.

The ACC behaviour of each vehicle at night directly mimicked the performance seen in daytime sunlight. While lighting conditions could not be replicated when driving the test route each day, the Tesla, BMW and Cadillac were driven at dusk and briefly encountered direct, low-angled sun which severely affected the camera vision. Only the Tesla informed the driver that ACC support was cancelled, though questions remain about the effectiveness of the ACC systems in the BMW and Cadillac without camera information, since it was unsafe to test the ACC performance in these conditions.

4.1.5 Driver Monitoring

With section total scores ranging from 44-64%, the results of the driver monitoring assessment presented in table 13 indicate there is still room for improvement across all vehicles. The Jeep Grand Cherokee was found to be the best all-round driver monitoring system from the tested vehicles, while the Tesla and Cadillac shared last place. It should be noted that the Tesla does not directly monitor drivers, despite having a cabin camera fitted, hence the non-scoring results for long and short distractions. All other vehicles used infrared cameras around the steering wheel and/or dashboard to monitor driver behaviour.

Long distractions were robustly detected by these systems for gaze locations all around the vehicle, though the Jeep and Cadillac took approximately twice as long to warn an inattentive driver when compared to the Ford and BMW systems. The Jeep was the only test vehicle that could recognise a driver making repeated glances away from the forward road view, though a specific warning for the detection of mobile phone use was limited. None of the systems evaluated suffered any loss in reliability when drivers wore highly reflective sunglasses, hats or other face coverings; Facial hair did not affect the robustness of any systems either.

Figure 14: Driver acting as distracted in the Jeep Grand Cherokee.

Figure 15: Visual information in the Cadillac Escalade when a distracted driver is detected.

System intervention when a driver is deemed unresponsive was difficult to score fairly for all vehicles since the assessment could only be performed on a proving ground for safety reasons. Most of the DCAS were geofenced to only work on specific roads but would still allow hands-on steering assistance in fully marked lanes. The Jeep and Cadillac did not offer this functionality and therefore provided no additional support to an unresponsive driver.

When tested, the Ford provided escalating audible and visual warnings to the driver before gently decelerating to crawling speed while maintaining steering assistance. The Tesla took this a step further by turning the hazard lights on and coming to a complete stop, although it took almost 40 seconds to produce any kind of warning. In contrast, the BMW produced prompt warnings for a disengaged driver. It applied brake jerks with the intention of shaking the driver awake before slowing to a complete stop and applied the hazard warning lights.

Stopping vehicles in lane on highways presents a different safety issue. A more sophisticated response could be implemented that looks to navigate the car safely to the nearest breakdown lane / shoulder, though this may only be possible on sections of road that are approved by manufacturers for use of the hands-free DCAS.

4.1.6 HMI

The HMI assessment revealed a striking variation between the test vehicles. The scores ranged from 51-86%, highlighting the different approach that has been implemented by each manufacturer. The Jeep narrowly outranked the BMW, with the Ford, Cadillac and Tesla taking the 3rd, 4th and 5th spots respectively.

The Jeep's dashboard could be configured to many different displays for driving information. The driver assistance display was basic, but the plain black background made it easy to interpret the DCAS status at all times. Conversely, the Tesla's display was too sparse, and icons were too small for a driver to easily understand the level of assistance being provided. The Cadillac also used small icons to indicate the current assistance level, but the display lacked clarity as it was too cluttered with other driving information. The Ford's display was the clearest overall, providing plenty of information and leaving the driver in no doubt regarding the status of the DCAS, as seen in figure 16 below.

Figure 16: The dashboard display in the Ford F-150 Lightning when Blue-Cruise is engaged.

Haptic feedback was used in some way by all test vehicles to provide more engaging warnings to the driver. The Tesla, Ford and BMW had a configurable option to produce haptic feedback through steering wheel vibrations, while the Cadillac and Jeep opted to use seat vibrations instead. This was a preferable form of haptic feedback given that drivers may not have their hands on the steering wheel. The downside to the Cadillac's HMI is that warnings could only be either audible or haptic; there was no option to have both forms of feedback, unlike the Jeep.

Additional visual information around DCAS status came in the form of a heads-up display, though the Tesla and Ford did not have this fitted. The heads-up displays in the Cadillac and Jeep provided the same information shown in their dashboards but could have been clearer if the icons and text were larger. The BMW scored best in this criterion and a comparative example of the heads-up display information is shown in figure 17 below.

The HMI notifications about changes in the level of assistance were assessed on the proving ground by blocking / unblocking the radar and camera used for the ACC and LSS aspects of the system respectively. The Tesla scored well in these assessments due to the lack of a radar as part of their DCAS. The Tesla produced a warning between 5-30 seconds after covering, stating "Front camera visibility is reduced" and that system performance was limited.

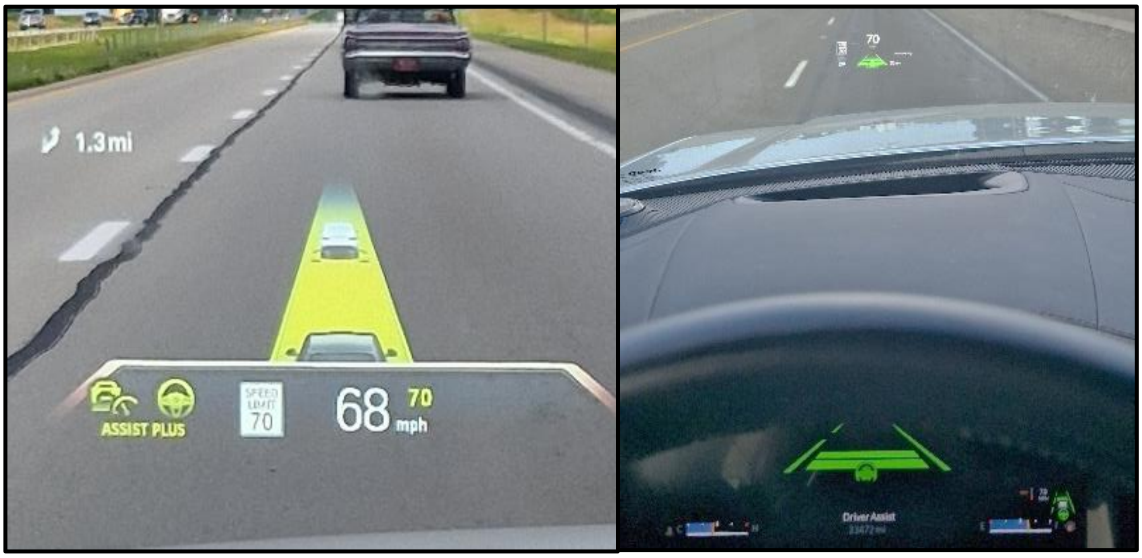


Figure 17: Heads-up display in the BMW i7 (left) compared to the Jeep Grand Cherokee (right).

The Ford and Cadillac showed basic warnings when the cameras were blocked, both at the start of a new journey and while the vehicle was in motion, but failed to indicate any degradation in system support when the radar was blocked. The Ford produced an orange warning lamp in the instrument cluster along with warning text, while the Cadillac only varied the colour of the lines that indicated the presence of lane markings, hence why the Ford scored better with respect to system unavailable / cancelled in comparison.

The Jeep produced very clear visual and audible warnings when covering the radar approximately 30 seconds after attempting to engage the ACC system. The warning text read “Active Driving / AEB / ACC unavailable. Wipe front sensors” which left a driver with no doubt about the system status. The same warnings were not produced when blocking the front camera, as the system needed to be engaged first, which was not possible for the Jeep on the proving ground. However, the lane markings displayed on the instrument cluster remained greyed out, indicating that the system was not available.

The BMW produced robust warnings within 30 seconds of system activation when both the camera and radar were blocked from vehicle start-up and when the systems were in use. Notably however, the BMW took approximately 2 minutes after engaging the system to produce a warning message when the vehicle had already been in motion with the sensors unblocked. The text warning of “Driver assistance limited” was considered sufficient, though the cause of this is not immediately as clear to a driver when compared to the Jeep’s response. Details of the fault were stored in the main infotainment display which a driver would have to manually navigate to.

4.2 Usability Grading

Each vehicle has been given an overall subjective usability score between 1 and 10 based on test drivers' impressions of the system. This score aims to represent how easy the systems were to use and the quality of driver experience when DCAS is engaged. While this score alone should be used with care, it helps to evaluate overall performance when considered in conjunction with the assessment percentage score.

4.2.1 Tesla Model S Plaid

The Model S is fitted with an exceptionally capable DCAS that can outperform the other test vehicles in almost all steering and ACC functions. The system is very good at remaining centred within lane markings and will adjust this position when overtaking larger vehicles such as semi-trailer trucks to give extra space. The test drivers felt very comfortable that the Model S could process what traffic is doing much further ahead and react in a safe and controlled manner.

Although the DCAS is very capable, the downfall of the Model S stems from the usability and assertiveness of the vehicle. Automatic lane changes without any driver initiation made users frustrated and nervous. The continuous steering assistance was particularly uncollaborative, requiring the most torque to override and therefore causing snappy steering actions when the assistance system cancels.

Usability score – 5

4.2.2 Ford F-150 Lightning

The Ford F-150's Blue-Cruise was the easiest DCAS to understand and use without prior knowledge of operation. The steering assistance is in tune with the driver and makes it abundantly clear that it is only there to assist, and that the driver must always remain in control. This is evident in how the system feels for a driver interacting with it; The transition between the system being off and on is seamless, which encourages the driver to use it more often. The system feels like a convenient addition as opposed to an assist that forces a driver to compromise their own way of driving.

The ACC system is sufficiently capable at sensing and reacting to other vehicles on the road ahead, though the speed control would be improved if throttle and brake inputs were smoother and more predictive. The lane centering system however caused some concerns for the test drivers, as snaking effects regularly moved the Ford close to other vehicles in the adjacent lane. This phenomenon seemed to worsen when the system had been active for long durations and made users want to take back control of the steering wheel.

Usability score – 7

4.2.3 BMW i7

The BMW i7's Assisted Driving Plus system was both engaging and intuitive to use. The dashboard and heads up display always provided clear information that was not distracting to drivers. Operation of the system was relatively simple, with both drivers finding the assistance easy to activate after their first use.

The LSS system was collaborative in terms of driver inputs, though the lane change assist manoeuvre was the most assertive out of all vehicles tested. The ACC system was both reliable and appropriate with its response to other vehicles. Despite not being the highest performer regarding ACC, the stable and safe following distance coupled with smooth control of vehicle speed made the BMW's ACC system the most pleasant to use.

Usability score – 8

4.2.4 Jeep Grand Cherokee

Despite a lesser performing ACC system, both test drivers found the Active Driving Assist system fitted to the Jeep Grand Cherokee the most usable DCAS. The information conveyed to the driver initially appeared basic, but with further use, the test drivers quickly began to appreciate the unambiguous dashboard display. The system was also very easy to operate as the steering wheel buttons felt straightforward and familiar.

The LSS system was assured and reliable throughout the test drive, reinforced by the timely warnings when the system was aware it would soon disengage based on the road conditions. The clear separation between when the vehicle could and could not support hands-free driving was also held in high regard. Test drivers felt that the ADA system was not trying to be unnecessarily complex either. This is showcased by the lane change assist feature, which only performed the manoeuvre upon the driver's request.

Usability score – 9

4.2.5 Cadillac Escalade

The SuperCruise system in the Cadillac Escalade has been available in the US market for longer than any of the other DCAS tested. Operation of the controls was undemanding, and the ACC system appeared reliable both on-road and at the proving ground. However, the lack of clarity in the dashboard and heads-up displays left the test drivers unsure of the overall capability. Moreover, the continuous lane centering ranged from bothersome at the best of times to distressingly unstable at the worst. Test drivers chose to manually disengage the SuperCruise system more than any other vehicle, which is a concern given its widespread availability on the US road network.

Usability score – 6

5. Conclusion

This benchmarking study finds the BMW i7 to have the best performing DCAS fitted, though the Jeep Grand Cherokee deserves credit for the overall usability of their system. The Tesla Model S is a very capable system, but a lack of driver collaboration and engagement harms the overall user experience. Each vehicle performed well in different assessment criteria, though it is clear that no one system is perfect yet.

Hands-off driving was available in 4 out of 5 of the test vehicles which is facilitated by the driver monitoring systems. This study finds that all manufacturers tested still have some way to go to improve the robustness of their driver monitoring. It is the opinion of Thatcham Research that more advanced driver monitoring features will be crucial to the safe adoption of DCAS technologies in the future.

6. Abbreviations

ACC – Adaptive Cruise Control

LSS – Lane Support System

DCAS – Driver Control Assistance System

L2 – Level 2 Assisted Driving

HMI – Human Machine Interface

iACC – Intelligent Adaptive Cruise Control

SLIF – Speed Limit Information Function