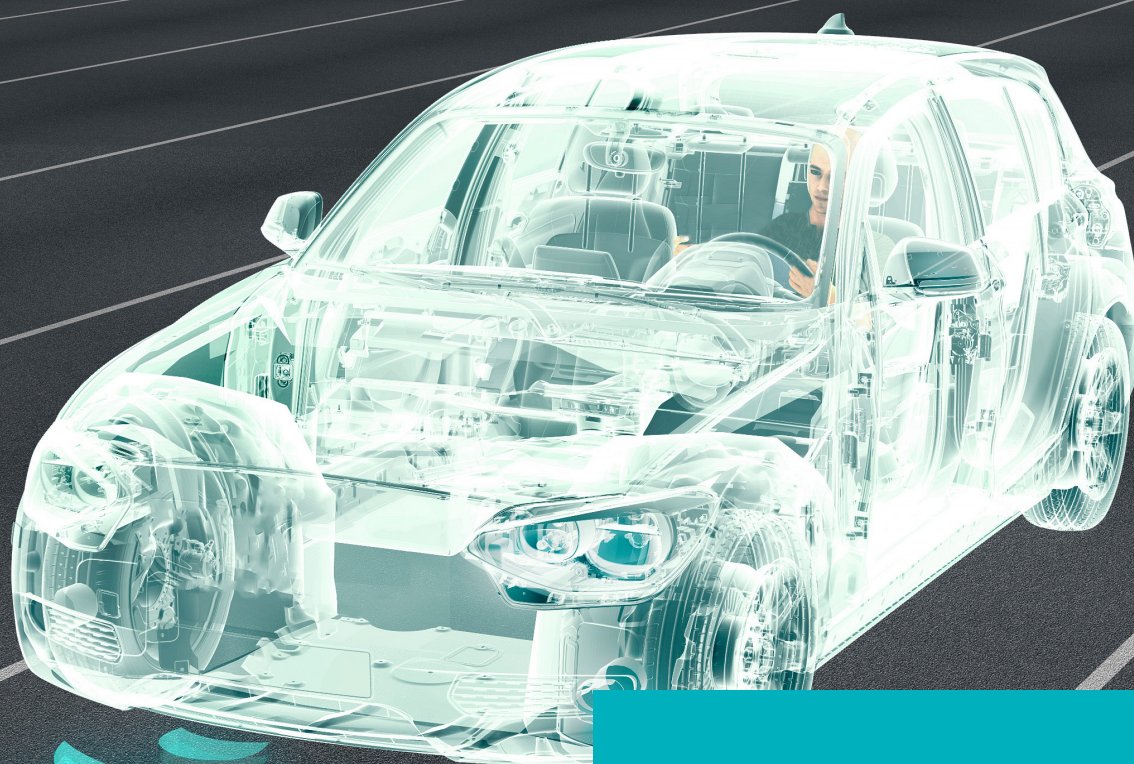
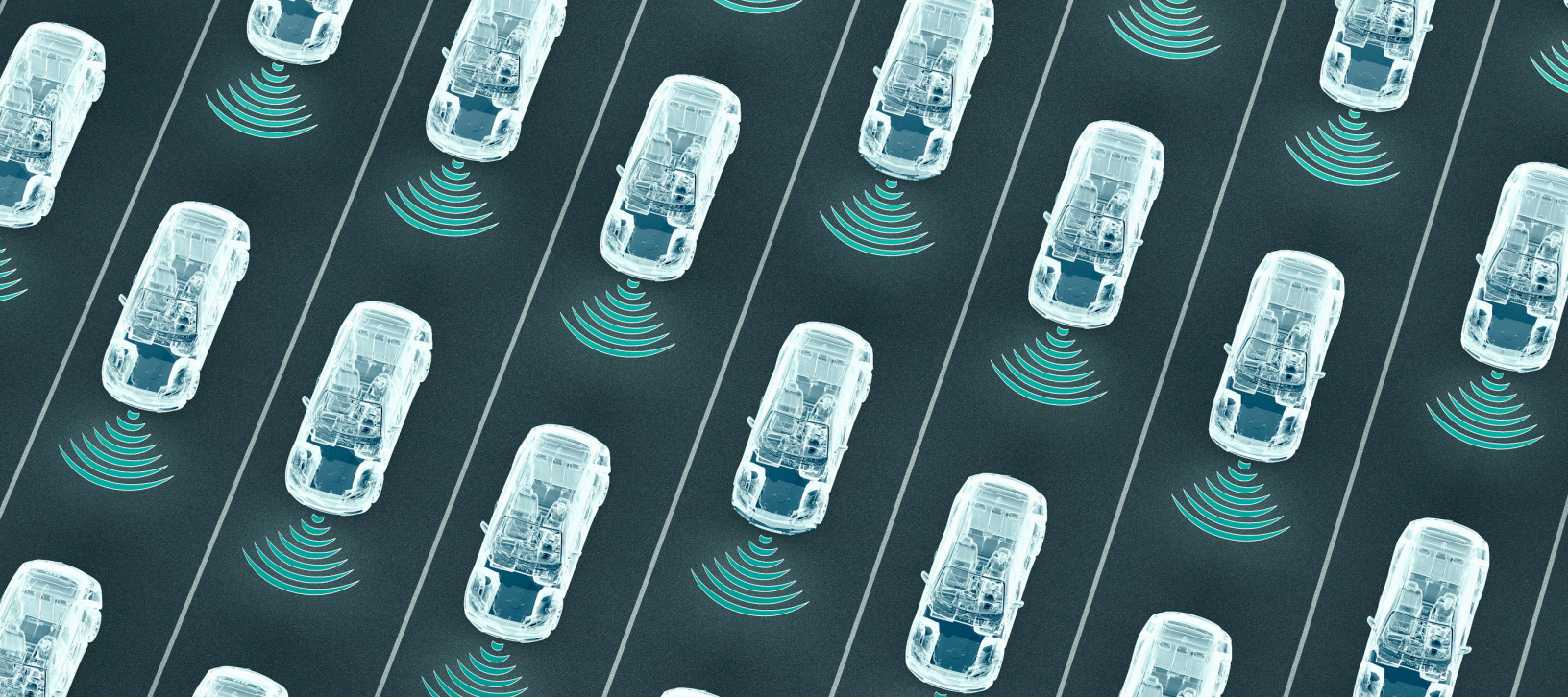




Partially Automated Driving Systems

INSIGHTS FROM
CONSUMER REPORTS



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About This Report

In October 2018, Consumer Reports published its first-ever ratings of partially automated driving systems, with Cadillac's Super Cruise topping the list, followed by Tesla's Autopilot, Nissan/Infiniti's ProPilot Assist, then Volvo's Pilot Assist. As these systems become increasingly available, CR is beginning to evaluate them with a focus on both capability and safeguards.



Cadillac's Super Cruise



Tesla's Autopilot



Nissan/Infiniti's ProPilot Assist



Volvo's Pilot Assist

This report provides a closer look at the rationale behind our testing—how and why the test criteria were selected, how the systems performed, and how they compare with each other. We hope to illuminate best practices and potential pitfalls as this technology begins to proliferate throughout the industry. The current systems are far from perfect, but there are some lessons that can be learned from each of them.

We present these findings and insights to automakers, regulators, and the industry as a whole to help ensure these features are designed, introduced, and marketed in a fair, honest, and safe manner. We welcome your feedback and value your partnership.

Executive Summary

The partially automated driving systems we see offer convenience features that, in some circumstances, can help make driving easier and relieve driver stress, but they also introduce new risks. Our concerns include designs that don't adequately take safety into account, as well as features that are advertised in a way that overstates their capabilities. This can lead drivers to develop a false sense of confidence and take their focus off the road. The more sophisticated these systems become, the more important it is to mitigate the risk to drivers, balancing capabilities with safeguards. Explicitly, it is premature to imply these systems are more or less safe than driving with no automation. And, given none of these systems are self-driving, it's imperative to ensure drivers are constantly engaged and monitoring the systems and the driving environment. This is one of the key takeaways of our evaluations of these systems, below.

Key Insights and Recommendations

Automakers should establish clear consumer expectations. Standardized terminology and transparent marketing are critical to ensuring the driver has correct expectations of the systems and understands the purpose, and limitations of the systems.

Systems need to be easy and intuitive to use. A driver needs to be able to adjust trajectory without having to disengage the system and should not feel "overruled" by the system. System status and controls need to be clear, uncluttered, and in the driver's line of sight.

Drivers need to know when it's safe to use systems. Systems should be designed to prevent usage in unsafe environments. Those that detect and clearly inform the driver when the systems should or should not be used will lead to safer operation and, ultimately, greater customer acceptance.

Systems should include driver monitoring technology. Systems should incorporate eye tracking and other tools adept at determining whether the driver is paying attention to the systems and the driving environment. Steering wheel torque or pressure is inadequate for measuring driver attention. Driver monitoring should be explored for all vehicles, not just those using partial automation.

All systems need an adept fallback process. If a driver does not or cannot respond to a warning, the system should try to prevent a crash.



Effective methods include pulsed braking, steering automation, and locking the system after abusing the process. Safe fallback should be available regardless of whether automation is engaged.

All Systems can and should do better. Though useful in stop-and-go traffic, all systems could be improved. They could do a better job detecting the lead vehicle's brake lights to simulate how a driver would react. This would probably increase a driver's comfort with the system.

"The best systems balance capability with safeguards—making driving easier and less stressful in the right situations. Without proper safeguards, over-reliance on the system is too easy, which puts drivers at risk."

—*Jake Fisher,*
Director of Auto Testing

"Consumers stand to gain a lot from the convenience of these systems, but only if automakers put safety first. We want to see automakers put the same emphasis on safety as they do on innovating and marketing these systems."

—*David Friedman,*
Vice President, Advocacy



Testing Approach: Balancing Capability With Safeguards

We chose to evaluate four advanced driver assistance systems that can automate steering and speed simultaneously: Cadillac Super Cruise, Tesla Autopilot, Nissan and Infiniti ProPilot Assist, and Volvo Pilot Assist. Though there are other systems that perform similarly, such as Honda Sensing and Toyota Safety Sense, they are not advertised as having similar driving automation. Mercedes-Benz once touted its Drive Pilot system as “self-driving” and has since backtracked after it was clear the cars were far from capable of driving themselves. It is no longer offered, and we have not yet tested its replacement. Future reports may include these and other systems.

Our evaluation demonstrates that there are drastically different ways to implement this technology. The systems range from fully hands-off operation in Cadillac’s Super Cruise to Volvo’s Pilot Assist, which acts more like momentary lane-keeping technology. However, these systems are all designed and marketed as a way to make driving easier.

Both performance and safeguards were considered in our ratings. The best system overall was deemed to have the greatest benefits to convenience while not putting the driver at undue risk. Automation benefits, as a supplement to the human driver, can be conceivable only if the drivers know when and where to safely use automation, use the features correctly, and maintain constant attention to the vehicle and environment.

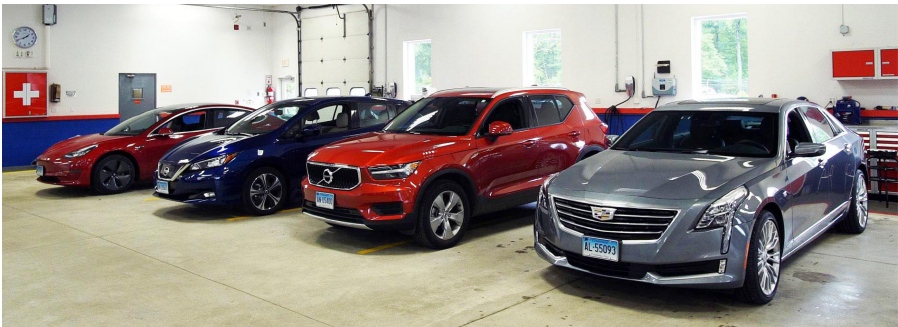
Multiple models were tested for each system, except Super Cruise, which was available only on one model at the time of testing. Our evaluation looked at the systems as they were operating in September 2018. The systems may perform slightly differently on each vehicle but do not significantly differ on the metrics evaluated and can therefore be examined as one system.

All four systems have been updated from their original software since purchasing the vehicles. Updates have included interface design, warning systems, timing interval changes, and even the performance of a braking system. Tesla periodically makes changes to Autopilot through over the air (OTA) updates and provides a brief description to the driver through the center screen and on-board manual. Each of the other systems received updates at a local dealership—those changes are not reflected in the owner’s manuals. In all instances, software changes are poorly communicated to owners.

The testers were deeply knowledgeable about operating the systems and very familiar with the vehicles. It should be noted that the systems may not deliver the same level of convenience until users are more familiar with them.



Results



In CR's ratings, Cadillac's Super Cruise came in first, Tesla's Autopilot came in second, followed by Nissan/Infiniti's ProPilot Assist, then Volvo's Pilot Assist system. Cadillac's Super Cruise provides the best balance of capabilities and safeguards. Autopilot scored highly for its capabilities and ease of use, while ProPilot Assist and Pilot Assist were better at keeping drivers engaged. Pilot Assist offers little benefits to the driver. (See chart below for more details.) The test results that follow were published on CR.org on Oct. 4, 2018.

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System Name	Overall Automation System Rating	Capability & Performance	Ease of Use	Clear When Safe to Use	Keeping Driver Engaged	Unresponsive Driver	Vehicles Tested
Super Cruise	⬆️	⬇️	⬇️	⬆️	⬆️	⬆️	Cadillac CT6
Autopilot	⬇️	⬆️	⬇️	⬇️	⬇️	⬇️	Tesla X/S/3
ProPilot Assist	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	Infiniti QX50/ Nissan Leaf
Pilot Assist	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	Volvo XC40/ XC60



Ratings Criteria Description & Rationale, Insights Test Specifics, and Test Results

What follows is an explanation of the thought process and rationale behind criteria selection, insights and recommendations, descriptions of how the tests were performed against each of the criteria, and the results.

CAPABILITY & PERFORMANCE

Description & Rationale

We scored each of the systems on automation capabilities intended to assist while driving. We looked at how well the cars stayed centered in their lane, how often they touched lane lines, and how many times they crossed those lines. We measured each system's performance on straightaways, curves, lane merges, and during lane changes. We also evaluated the systems' ability to control speed on the highway, in stop-and-go traffic, approaching a car ahead, and when the car ahead had left the lane.

Though this score assesses how well the system performs the task of lane centering, it is important to understand that some of the systems are intentionally designed not to perform this task too well, in order to make sure the driver stays alert and involved with driving. While Super Cruise and Autopilot attempt to continually automate steering, ProPilot Assist and Pilot Assist provide only some momentary assistance in turning the wheel and essentially operate in collaboration with the driver. However, this distinction is unclear to the consumer. ProPilot Assist is described as a Level 2 System in SAE classifications, which indicates that the system executes steering of the vehicle. Pilot Assist is described as a semi-autonomous system by Volvo and, until Consumer Reports called attention to it, was listed under the Autonomous Driving tab on Volvo's website.

The fact that driver error accounts for 94 percent of traffic crashes promotes a desire to take the human away from the wheel and let the cars do the driving. But today, there are no vehicles for a consumer to purchase that are capable of driving without a human at the wheel. Media headlines and automaker marketing have shaped consumer perceptions that some vehicles may be more capable of controlling



the vehicle than they are in reality. We do not want to discredit those that do perform well under optimal circumstances, but we want to stress that those conditions very rarely exist.

Insights

- Systems that fully automate steering can provide convenience, as long as they operate safely and reliably.
- Systems designed to simply make steering easier offer little benefit to the driver. In some cases, they can fight the driver’s intent and complicate the otherwise simple task of steering the vehicle.
- Though useful in stop-and-go traffic, all systems could be improved. They could do a better job simulating how a driver would react if the lead vehicle’s brake lights illuminate. This would probably increase a driver’s comfort with the system.

Test Specifics

Each vehicle was driven on the same 16-mile roadway with well-marked lines on a two-lane divided highway. Vehicles were set to the posted speed limit of 65 mph and were tested on clear, sunny days. Each system—other than Super Cruise*—was also tested on our enclosed track to assess performance of variable speeds on straightaways, curves, and back roads with variations of lane markings. Each system was also driven for thousands of miles by vehicle testers in normal driving prior to the official evaluation.

**Because of its safety feature which is designed to operate only on divided highways without intersections that have been mapped by General Motors, Super Cruise could not be tested on our track.*

Capability & Performance Test Results



System Name	Capability & Performance Score	Lane Centering	Stop & Go	Automated Lane Change
Super Cruise		Good in most situations.	Yes	No
Autopilot		Very good at holding center of lane.	Yes	Yes
ProPilot Assist		Useful only on fairly straight roads.	Yes, will not automatically resume after 3-second idling.	No
Pilot Assist		Can fight driver to push car out of center.	Yes, will not automatically resume after 3-second idling.	No

Super Cruise ⓘ

Overview: Cadillac's Super Cruise is designed to make driving on divided highways more convenient by not requiring the driver to operate the pedals or the steering wheel. Unlike the other systems, there is no requirement that the driver touch the steering wheel during operation. It is able to provide this function, adding safeguards to help prevent misuse of the system.

Strengths: Super Cruise is highly capable of controlling both speed and steering on divided highways. Its steering control performs reliably well during difficult scenarios, such as curves and hills. Acceleration and braking rates are generally smooth and relative to current speed of travel. Super Cruise is also capable of stop-and-go speed control without requiring the driver to re-engage the system. It utilizes data from extensive roadway mapping to aid the cameras and other sensors onboard the vehicle. These data take away a lot of the uncertainty of solely relying on onboard systems but also restrict its use to highways. When driving in a lane that ends, the driver is notified in advance that the system will disengage. The reason(s) for disengagement are not immediately clear, but the driver has plenty of time to take control before the system completely shuts down.

Weaknesses: Utilization of pre-mapped data has some downsides. Super Cruise occasionally favors the stream of pre-mapped data over forward-facing camera input when it comes to obstacles in the roadway. This can be an issue in construction zones that were not in place during the mapping or in ones that were in place during mapping but no longer pose a problem.

Autopilot ^

Overview: Tesla's Autopilot is designed to make driving easier by controlling speed and steering for the driver. It also can automate lane changing after activating a turn signal.

Strengths: Autopilot leads the pack for automation capability and quantity of features. It is reliable at maintaining center-lane placement. Compared with the other systems, it is able to sense and react to stopped vehicles in the same lane that are farther ahead, which makes it particularly capable in stop-and-go traffic. Acceleration rates at higher speeds are comfortable and responsive.

Weaknesses: As with any of these systems, unclear or missing lane lines can lead to unintended lane changes or worse. Autopilot is reluctant to notify the driver when it is unsure of the path to take. Without clear lane lines on both sides of the vehicle, the system will turn on but steers the vehicle erratically. Though some may perceive the system's ability to engage in many conditions as a testament to its capability, in reality it is a reflection of its inability to enforce the design criteria.



ProPilot Assist

Overview: Nissan/Infiniti's ProPilot Assist is designed to assist steering but not necessarily completely automate it. The system couples the steering assist with adaptive cruise control to try to make driving easier.

Strengths: ProPilot Assist can help the vehicle stay centered in the lane on straight pathways. To increase the likelihood of staying in your lane, the additional automated steering features need to be adjusted to their most conservative setting as a backup to the lane-centering feature. On fairly straight roads, the vehicle will attempt to re-center the car in the original lane.

Weaknesses: Depending on current speed and degree of curves, the vehicle tends to drift to the outer edge of the lane and may end up driving on the lane line or crossing over. However, if a large portion of the vehicle has drifted into an adjacent lane too quickly, ProPilot Assist may incorrectly draw the car farther into that lane and center it there, even if said lane is meant for the opposite direction of traffic. In addition, the automated speed control is uncomfortably slow when following another vehicle and returning to the set speed after the lead vehicle departs from the lane. The system struggles if the vehicle in front turns out of your way after quickly decelerating almost to a stop. In many cases, the system will just shut off.

Pilot Assist

Overview: Volvo's Pilot Assist is designed to make steering easier by assisting the driver in following lane markings and providing speed control.

Strengths: Pilot Assist is minimally capable of helping keep the vehicle in its lane. On long, straight, flat roadways, the system could potentially keep you within your current lane of travel for some time.

Weaknesses: On slight curves, hills, or a road with less-than-perfect road markings, the vehicle may still drift over the lane line. Although Pilot Assist does apply steering wheel torque and braking, it does not keep the car centered in the lane for more than a brief moment while ping-ponging between lane lines. The system behaves to approaching and crossing lane lines in a reactionary manner as opposed to actively centering, leaving the driver with little confidence in its abilities. If the driver chooses to turn on the system, they may end up fighting the resistance of the automatic steering instead of lightly keeping their hands on the wheel. If the system has "locked on" to a leading vehicle, it will prioritize the trajectory of that vehicle over maintaining lane placement. That means if the vehicle you are following changes lanes or sways, the Volvo will follow that path, sometimes bringing you into the adjacent lane. The automated speed control is uncomfortably slow when following another vehicle and returning to the set speed after the lead vehicle departs from your lane.



EASE OF USE

Description & Rationale

We evaluated the controls and displays for engaging the system and making adjustments, the feedback on system status, and other messaging displayed to the driver. With the increase in vehicle controls and screens, advanced technologies are appearing in all new vehicles, resulting in more vehicle controls and screens than ever. Accessing the settings for these systems is like playing hide-and-seek. The features are called different names in every car and often have levels of sensitivity that greatly affect how the systems perform. Multiple features of each system are sometimes displayed, cluttering the dashboard and increasing driver distraction. The types of feedback are important to ensure the systems aren't causing more harm than good.

Insights

- It's important for drivers to be able to adjust their trajectory easily, without having to disengage the system.
- Drivers should never feel "overruled" by the system.
- Multiple "sensitivity" settings of each component can be confusing for a driver.
- Too many cluttered controls or unmarked buttons reduce usability for systems that are novel to a driver.
- Providing the driver with information about what the car can "see" is useful, such as whether the system recognizes lane lines or adjacent vehicles.
- Visual information about the system's status needs to be in the driver's line of sight, preferably in a head-up display. The driver should never be forced to look away from the road to know whether the system is operational or detecting lane markings.

Test Specifics

Test criteria for usability and ergonomics of controls and displays, similar to CR's testing of all vehicles, were applied to these systems independent of overall vehicle usability. They include:

- Ability for drivers to engage and make adjustments to speed and steering automation.
- Feedback on what the system is doing and its state or status.
- Messaging and error information.
- Potential for unintentional misuse of controls or incorrect interpretation of system information.



Ease of Use Test Results



System Name	Ease of Use Score	Driver Interaction With Steering
Super Cruise		Hands-free when using in appropriate situations.
Autopilot		Automated steering, but driver must touch wheel.
ProPilot Assist		Driver steers, but system assists lane-keeping.
Pilot Assist		Driver steers, but system assists lane-keeping.

Super Cruise

Overview: Super Cruise is a unique system that is designed for hands-free driving, which helps clarify the role of the driver and the automation. However, it can be difficult to engage.

Strengths: Hands-free operation creates a very clear distinction of when the driver or the system is performing the task of steering. The driver can easily modify the path or change lanes by simply steering the wheel again. When the driver does this, the light bar on the steering wheel goes from green to blue, indicating that Super Cruise is in standby and the driver is responsible for steering the wheel. When the vehicle is once again in the center of the lane, the light returns to green, allowing the driver to let go of the wheel again. If the system cannot be engaged, it can provide specific messages explaining why.

Weaknesses: Engaging Super Cruise can be difficult. The driver must be within the designated boundaries and hold their lane placement on a straight section of road before pressing the steering wheel control. If the vehicle cannot detect two lane lines or the car is not centered, the system will not engage. The cluttered controls on the steering wheel and information on the displays make enabling and using the system overly complicated. Searching for driving-related information is difficult, despite the head-up display.

Autopilot

Overview: Though Autopilot is straightforward to engage and operate, the driver’s role isn’t clear. Drivers must hold onto the wheel, but any steering input causes a disengagement of the automatic steering system.

Strengths: Autopilot gets the highest rating of the four systems because it is easy for the driver to understand that it engages all-or-nothing

steering control. Because of this simplicity, enabling the system is a straightforward task once it's learned. It also provides the driver with an animation of what it can see. This includes lane lines and other vehicles. This information allows the driver a sense of how much confidence the system has with the given situation.

Weaknesses: The main usability weakness of Autopilot is its poor implementation to assure driver attention. Drivers must keep their hands on the wheel to operate the system, but any steering input intended to slightly change course will turn off the automatic steering. However, the sensors are not capacitive and need the driver to put some torque on the wheel for the system to sense them. This creates a job for the driver, to put some turning pressure on the wheel—but not too much. Furthermore, when the system is shut off this way, the automatic speed control is still active, which can create confusion for the driver. Audible alerts are sounded when automatic steering is shut off and when it's put back on. In an attempt to try to avoid this process, drivers may tolerate lane position that is less than ideal. Autopilot's automatic lane change tends to be more frustrating to use than simply turning the wheel, as in other systems. Drivers often have to wait a while after activating the turn signal for reasons that are not clear.

ProPilot Assist

Overview: ProPilot Assist is fairly easy to activate and use, but its purpose isn't clear.

Strengths: ProPilot Assist requires a one-time engagement of the system, which automatically re-engages for the remainder of the trip, meaning the driver doesn't have to constantly interact with it. The dashboard icon turns blue and an audible chime clearly indicates that the steering component is active. The collaborative steering allows some centering while still allowing the driver to choose their own trajectory.

Weaknesses: Multiple features must be adjusted to their most conservative setting in order for ProPilot Assist to provide some lane centering. Navigating the menus can be distracting. Operationally, ProPilot Assist works similar to other lane-keeping assist technology but presents itself as a higher-level autonomous system. During normal operation, an audible cue indicates when it starts and stops working. This may occur many times during a trip and can annoy the driver. Also, the audible cue may convey a message to drivers that the system is "taking over" the steering—which is not the design intent. In stop-and-go traffic, adaptive cruise control times out after 3 seconds of idling, requiring the driver to press either the accelerator pedal or the resume



button on the steering wheel. The speed control cannot be engaged at lower speeds unless following another vehicle.

Pilot Assist

Overview: Pilot Assist is complicated to engage and alternates between providing steering and not, without warning the driver.

Strengths: When Pilot Assist is active, it allows collaborative steering. The driver may need to work against the steering wheel resistance to steer the vehicle, then allow the vehicle to slowly move to the center of the lane when their effort is lessened.

Weaknesses: The driver must toggle from cruise control to Pilot Assist using unlabeled steering wheel controls and adjust following distance through hamburger menu icons (☰). Once a small dashboard icon subtly changes from white to green, the system automates steering control. Pilot Assist fluctuates in and out of providing steering control without an audible alert. This creates a distraction because drivers need to keep their eyes off the road to monitor a small icon's color to know whether the system is providing any steering correction. We found it easier to monitor the road instead and simply steer the vehicle manually. In stop-and-go traffic, the system times out after 3 seconds of idling, requiring the driver to press either the accelerator pedal or the resume button on the steering wheel.



CLEAR WHEN SAFE TO USE

Description & Rationale

All of these systems are designed to function under optimal roadway, environmental, and traffic scenarios, but we evaluated how easy and clear it is for the driver to understand when the system works best and when it doesn't. Lists of when and where not to engage automation are buried deep in the vehicle owner's manuals. Few manuals provide explicit statements as to when you can use the system, and those are usually qualified by stating that systems may not function properly even then. It is unreasonable to expect drivers to maintain an up-to-date knowledge of the restrictions—and even when all criteria for use are met, there are many variables that can change in an instant. Warnings in manuals mean little when the car will still engage the system well outside of its operational design domain (ODD). In some situations, the systems remain engaged in locations that otherwise prohibit the driver from initially enabling them. The reality is that the systems should be designed to prevent foreseeable misuse. It is in the best interest of the driver, passengers, and automaker to be clear about when systems can be safely used and to lock out their use when it is not safe.

Insights

- Consumers need clear and easy-to-access information about when partially automated driving systems and more advanced automation systems can be safely used.
- Including this information in the owner's manual alone does not provide enough direction for the driver.
- The system should be designed to prevent usage in unsafe environments.
- Partially or conditionally automated driving systems that detect and inform the driver when the systems should or should not be used will lead to safer operation and, ultimately, greater customer acceptance.

Test Specifics

We examined how clear it was to drivers, while in the vehicle, when and where the system was available to be used. When it was unavailable, we looked for messaging or feedback to inform the driver as to the parameters. Last, we tested each vehicle on roadways of different types, with different lane line patterns, at different speeds, in rain, and in varying traffic scenarios for enforcement of operational constraints.



Clear When Safe to Use Test Results

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System Name	Clear When Safe to Use Score	How Is the Operational Design Domain Enforced?
Super Cruise		Not available on roads that it shouldn't be used on.
Autopilot		Speed is limited on some roads, but it can be engaged with even a single faint line or a twisting road.
ProPilot Assist		Needs two lane lines.
Pilot Assist		Usually needs two lane lines.

Super Cruise

Overview: Super Cruise allows operation only on the roads that it is designed for.

Strengths: Super Cruise explicitly prohibits use outside of the geofenced boundaries pre-mapped with high-resolution LIDAR by GM. If the driver attempts to turn on the system when it is not within its operational perimeter, a message appears on the instrument cluster informing the driver that it is unavailable. When exiting a freeway or approaching a merging lane, Super Cruise provides adequate lead-time for the driver to retake control. It is not available on roads with intersections or on ones that allow cyclists or pedestrians.

Weaknesses: Utilization of pre-mapped data doesn't allow the system to quickly react to changing conditions. This can be an issue in construction zones that were not in place during the mapping or in ones that were in place during mapping but no longer pose a problem.

Autopilot

Overview: Like Cadillac does with Super Cruise, Tesla clearly states in the owner's manual that Autopilot should be used only on highways and limited-access roads. However, it's available to be used in almost every situation.

Strengths: On slower roads, speed is limited to only 5 mph over the speed limit. This can deter operation for many. However, the driver could manually press the accelerator pedal to increase their speed well above the threshold on any road.

Weaknesses: A major concern is that the icons that signal Autopilot can be activated appear in situations that are specifically prohibited, such as on roads without lane lines. Although the criteria for use are specified, the nearly perpetual availability of the system (via icons) puts too much onus on the driver to internalize and adhere to the operating parameters. If a single lane line (or something the vehicle interprets as a lane line) is present, the system can be engaged. Without lines on both sides of the vehicle, it will turn on but may erratically steer the vehicle, oftentimes off the roadway. It can remain engaged even when lane lines completely disappear. When this happens, the vehicle behaves differently in all situations. The car may follow another, erratically steer in an attempt to find a lane line, or shut off.

ProPilot Assist

Overview: ProPilot Assist provides some limits to system availability.

Strengths: Inclement weather and lack of two well-marked lane lines reliably prevent activation.

Weaknesses: Once the system is activated, limitations are spotty.

Pilot Assist

Overview: Pilot Assist does not provide the driver with feedback as to why it will not engage when an attempt is made to turn it on. Instead, the steering wheel icon may remain gray for an indeterminable length of time and then suddenly change to green, meaning it has activated.

Strengths: None.

Weaknesses: A single lane is the minimum required for operation, but Pilot Assist may confuse curbs and other defined edges as a lane line, allowing the system to be engaged.



KEEPING DRIVER ENGAGED

Description & Rationale

Though all of these systems can steer the wheel and control speed, they are not self-driving. However, it can be difficult for drivers to keep paying attention when it's not required in the immediate feedback loop. We assessed the ability of these systems to make sure that the driver stays ready to immediately take the controls when needed.

Allowing the driver to apply steering in conjunction with the automated system (collaborative steering) increases the likelihood the driver will remain engaged. Restricting steering input causes the driver to be out of the loop and has huge implications for maintaining driver attention. Steering wheel torque as a response to warning the driver does little more than create an annoyance and in no way should be considered a mechanism for ensuring driver attention. Adjusting the timing intervals for warning the driver to input steering torque has no correlation with improving driver attention because torque is fundamentally an incorrect way to ensure driver attention.

Insights

- Steering wheel torque is inadequate for measuring driver attention.
- Camera-based systems, particularly those with eye tracking, can help ensure the driver's eyes are looking toward the roadway, even though eyes on the road do not guarantee attention to the full driving task.
- Effective driver monitoring can be utilized in all modes of driver control and may also be helpful in adapting warnings to the driver's level of attention.
- Systems that underperform and are less capable at maintaining lane placement may inadvertently help keep the driver engaged.
- Driver-monitoring technologies can and should be explored as pure safety features that can benefit all drivers, not just those using partial automation systems.

Test Specifics

We looked for systems that effectively monitored the driver's attention to the road. Systems were also assessed for the driver's ability to make steering adjustments in conjunction with the automated system.



Keeping Diver Engaged Testing Results



System Name	Keeping Driver Engaged Score	Monitoring System	Collaborative Steering
Super Cruise		Eye Tracking	Yes, system goes into standby.
Autopilot		Steering Wheel Torque	No, driver steering shuts off autosteer.
ProPilot Assist		Steering Wheel Torque	Yes, required in most situations.
Pilot Assist		Steering Wheel Torque	Yes, required in most situations.

Super Cruise

Overview: Super Cruise requires the driver to look toward the road to operate the vehicle.

Strengths: Super Cruise utilizes infrared eye-tracking technology to ensure the driver’s eyes (even with sunglasses) are facing the forward roadway. It will remain active as long as the driver keeps their eyes facing the roadway, and it allows the driver to apply additional steering torque in conjunction with the automated steering.

Weaknesses: Looking at the driver’s eyes is a good way to make sure the driver is watching the road, but it’s not perfect. A system that monitors the driver’s scanning frequencies or reactions to changes in the driving environment could be even better. Due to the placement of the driver-facing camera, if sunlight hits it just right, it will not be able to see the driver’s eyes. In such cases, the system will not operate. It is disappointing that the eye-tracking system is not available unless the driver activates Super Cruise. Ironically, the Cadillac CT6 system has a teen driver mode that cannot leverage this attention-monitoring system, which would be highly beneficial.

Autopilot

Overview: Autopilot requires the driver to keep some steering torque on the wheel for the system to be operational. However, its performance is so good that one could drive hours on the highway without any driver input. This could lead to a dire situation if something unexpected were to suddenly happen.

Strengths: If a driver fails to respond three times to messages to put their hands on the steering wheel, they cannot use Autopilot for the remainder of their drive.



Weaknesses: Resting a hand on the steering wheel does not indicate that the driver is looking at the road. A driver could rest their hand on the steering wheel and close their eyes, and Autopilot would remain engaged. The system design promotes the driver to keep their hands off the wheel; any more than light torque immediately shuts down the system. The inability for the driver to apply steering in conjunction with Autopilot trains the driver to use the system in risky situations, lest he has to continually re-engage it.

ProPilot Assist ⓘ

Overview: ProPilot Assist requires some torque on the wheel to operate, but its relatively poor performance is fairly effective to make sure the driver stays engaged.

Strengths: A driver is likely to pay attention because they cannot rely on the system to keep them in their lane for long.

Weaknesses: Resting a hand on the steering wheel does not indicate that the driver is looking at the road. A driver could rest their hand on the steering wheel and close their eyes, and ProPilot Assist would remain engaged.

Pilot Assist ⓘ

Overview: Pilot Assist requires some torque on the wheel to operate, but its relatively poor performance is fairly effective to make sure the driver stays engaged.

Strengths: Pilot Assist has difficulty staying within its lane on curves and hills, which means the system is continually turning itself off. No audible prompt is given in these situations, requiring the driver to pay close attention to the small steering wheel icon on the instrument cluster. The lack of salient feedback and its poor performance do not allow the driver to confidently take their hands off the wheel or disengage from driving.

Weaknesses: Resting a hand on the steering wheel does not indicate that the driver is looking at the road. A driver could rest their hand on the steering wheel and close their eyes, and Pilot Assist would remain engaged.



UNRESPONSIVE DRIVER

Description & Rationale

If a driver does not or cannot respond to a warning to apply steering or look forward, the system should try to prevent a crash. Ideally, the system should safely stop the vehicle and pull off the road. Today, no system is capable of pulling off the road, but most systems slow the vehicle to a stop and turn on hazard flashers. This process is initiated only if the driver has turned on the driving automation system. Even when the driver is correctly using the system, it may malfunction at any time with or without notifying the driver, reiterating the need for driver engagement. Only Volvo's Pilot Assist turns off the lane-centering feature if the driver does not respond, creating a riskier situation. Systems that lack a fallback process in the rare circumstance a driver becomes incapacitated eliminate potential safety benefits of automation when they are needed the most.

Insights

- Pulsed braking is an effective method of alerting the driver.
- Utilizing steering automation when a driver is unresponsive safeguards the driver from unintentionally departing the roadway.
- Tools to keep an unresponsive driver on the road should not just be limited to when driving automation is activated.
- Locking the system after abusing the process multiple times is an effective way to deter the driver from abusing the system.

Test Specifics

Escalation processes were recorded when traveling at 65 mph on limited-access highways. Interval timing varies for each system depending on set speed and current speed of travel, as well as whether the vehicle is following another vehicle in close proximity.



Unresponsive Driver Test Results



System Name	System Fallback Score	First Warning	Second Warning	Third Warning	Comes to a Complete Stop	Keep Vehicle in Lane	Other
Super Cruise		Visual	Visual	Audible	Yes	Yes	Dials SOS contact.
Autopilot		Visual	Visual	Audible	Yes	Yes	Locks driver out after 3x.
ProPilot Assist		Visual	Audible	Braking	Yes	Yes	Pumps brakes to alert driver.
Pilot Assist		Visual	Audible	Canceled	No	No	

Super Cruise

Overview: Super Cruise will try to stop the vehicle safely if the driver is unresponsive.

Strengths: If repeated alerts are ignored, the vehicle begins braking, turns on the hazard lights, and stops in its lane. Super Cruise will then dial emergency services once the car comes to a complete stop.

Weaknesses: The stopping procedure will not occur unless the system is activated.

Autopilot

Overview: Autopilot will try to stop the vehicle safely if the driver is unresponsive.

Strengths: If repeated alerts are ignored, the vehicle begins braking, turns on the hazard lights, and stops in its lane.

Weaknesses: The Model 3's lack of a dashboard or head-up display means visual warnings are not within a useful field of view for an attentive driver watching the road. It is possible to receive and miss warnings, even if the driver's hands are on the wheel but aren't producing enough steering torque to be acknowledged by the system. The stopping procedure is not available if the driver is not using Autopilot.

ProPilot Assist

Overview: ProPilot Assist will try to stop the vehicle safely if the driver is unresponsive.

Strengths: ProPilot Assist does a very good job of trying to get the attention of an unresponsive driver. An audible alert is an attention-getting siren. Then the vehicle will pulse the brakes to help gain the

driver's attention. If repeated alerts are ignored, the vehicle begins braking, turns on the hazard lights, and stops in its lane.

Weaknesses: The stopping procedure will not occur unless the system is operating.

Pilot Assist

Overview: If a driver is unable to hold the wheel, the automated steering disengages but the speed remains set. If no other system is engaged, this will likely lead to a road departure, even though Pilot Assist has the capability to stop the vehicle in its lane.

Strengths: None.

Weaknesses: After several seconds of no input from the driver, Pilot Assist provides a visual message to apply steering. An audible chime comes shortly after. No additional warnings or braking are provided, and the system disengages at that point. Lane Keeping Aid with steering assistance, separate from the Pilot Assist system, must be previously turned on for the vehicle to provide any steering torque once Pilot Assist has been canceled. This reactionary steering after the vehicle has crossed the lane line is insufficient for maintaining lane placement, and the system does not apply braking to bring the vehicle to a stop. The result would likely lead to a crash if a driver became unconscious, even though the vehicle has the capability to automate steering and bring the car to a stop.



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