U.S. Department of Transportation
National Highway Traffic Safety Administration

ODI RESUME

OFFICE OF DEFECTS INVESTIGATION
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Investigation: PE 16-007
Date Opened: 06/28/2016 **Date Closed:** 01/19/2017
Investigator: Kareem Habib **Reviewer:** Jeff Quandt
Approver: Stephen Ridella
Subject: Automatic vehicle control systems

MANUFACTURER & PRODUCT INFORMATION

Manufacturer: Tesla Motors, Inc.
Products: MY2014-2016 Tesla Model S and Model X
Population: 43,781

Problem Description: The Automatic Emergency Braking (AEB) or Autopilot systems may not function as designed, increasing the risk of a crash.

FAILURE REPORT SUMMARY

	ODI	Manufacturer	Total
Complaints:	0	0	0
Crashes/Fires:	0	0	0
Injury Incidents:	0	0	0
Fatality Incidents:	0	0	0

ACTION / SUMMARY INFORMATION

Action: This Preliminary Evaluation is closed.

Summary:

On May 7, 2016, a 2015 Tesla Model S collided with a tractor trailer crossing an uncontrolled intersection on a highway west of Williston, Florida, resulting in fatal injuries to the Tesla driver. Data obtained from the Model S indicated that: 1) the Tesla was being operated in Autopilot mode at the time of the collision; 2) the Automatic Emergency Braking (AEB) system did not provide any warning or automated braking for the collision event; and 3) the driver took no braking, steering or other actions to avoid the collision. On June 28, 2016, NHTSA opened PE16-007 to “examine the design and performance of any automated driving systems in use at the time of the crash.”

The Office of Defects Investigation (ODI) analyzed the following subjects as part of NHTSA’s examination of the design and performance of Tesla’s Autopilot system: 1) Automatic Emergency Braking (AEB) system design and performance in the subject Tesla and peer vehicles; 2) human-machine interface issues related to Autopilot operating mode; 3) data from crash incidents related to Tesla’s Autopilot and AEB systems; and 4) changes Tesla has implemented in the Autopilot and AEB systems.

NHTSA’s examination did not identify any defects in the design or performance of the AEB or Autopilot systems of the subject vehicles nor any incidents in which the systems did not perform as designed. AEB systems used in the automotive industry through MY 2016 are rear-end collision avoidance technologies that are not designed to reliably perform in all crash modes, including crossing path collisions. The Autopilot system is an Advanced Driver Assistance System (ADAS) that requires the continual and full attention of the driver to monitor the traffic environment and be prepared to take action to avoid crashes. Tesla's design included a hands-on the steering wheel system for monitoring driver engagement. That system has been updated to further reinforce the need for driver engagement through a "strike out" strategy. Drivers that do not respond to visual cues in the driver monitoring system alerts may "strike out" and lose Autopilot function for the remainder of the drive cycle.

A safety-related defect trend has not been identified at this time and further examination of this issue does not appear to be warranted. Accordingly, this investigation is closed. The closing of this investigation does not constitute a finding by NHTSA that no safety-related defect exists. The agency will monitor the issue and reserves the right to take future action if warranted by the circumstances. For more information about the analysis, see the attached report.

1.0 INTRODUCTION

On May 7, 2016, a 2015 Tesla Model S collided with a tractor trailer crossing an uncontrolled intersection on a highway west of Williston, Florida, resulting in fatal injuries to the Tesla driver. Data obtained from the Model S indicated that: 1) the Tesla was being operated in Autopilot mode at the time of the collision; 2) the Automatic Emergency Braking (AEB) system did not provide any warning or automated braking for the collision event; 3) the driver took no braking, steering or other actions to avoid the collision; and 4) the last recorded driver action was increasing the cruise control set speed to 74 mph less than two minutes prior to impact. The crash occurred on a clear day with dry road conditions. On June 21, 2016, NHTSA deployed a Special Crash Investigations team to the crash site to evaluate the vehicle and study the crash environment. NHTSA's crash reconstruction indicates that the tractor trailer should have been visible to the Tesla driver for at least seven seconds prior to impact. On June 28, 2016, NHTSA opened PE16-007 to "examine the design and performance of any automated driving systems in use at the time of the crash."

The Office of Defects Investigation (ODI) analyzed the following subjects as part of NHTSA's examination of the design and performance of Tesla's Autopilot system: 1) AEB design and performance in the subject Tesla and peer vehicles; 2) human-machine interface issues related to Autopilot operating mode; 3) data from crash incidents related to Tesla's Autopilot and AEB systems; and 4) changes Tesla has implemented in the Autopilot and AEB systems.

2.0 AEB SYSTEM

2.1 AEB technologies. Automatic Emergency Braking includes the following crash avoidance technologies: Forward Collision Warning (FCW), Dynamic Brake Support (DBS), and Crash Imminent Braking (CIB). An FCW is presented to the driver if the system predicts a crash with an object in the vehicle's forward path is imminent. To be effective, such alerts are provided with sufficient lead-time for the driver to assess the potential hazard, and to respond with the appropriate braking or steering needed to avoid the crash. If the driver chooses to avoid the crash by braking, but does not apply sufficient braking to do so, DBS automatically supplements their application. If the driver does not take action to avoid the crash, CIB automatically applies the vehicle's brakes so that it may be mitigated or avoided.

2.2 Background. AEB technologies have been in use for over 10 years. In September 2007, a NHTSA-sponsored project was initiated by the Crash Avoidance Metrics Partnership (CAMP) "to develop test methods for evaluating crash imminent braking systems and to establish benefits estimation methods for assessing their effectiveness at reducing the severity of potential injuries in vehicle crashes."[1] The final report from this project, released in September 2011, validated the effectiveness of radar, camera and radar/camera fusion systems as rear-end collision mitigation or avoidance technologies.[2] The report also identified several crash modes that were not validated by the project, including straight crossing path (SCP)[3] and left turn across path (LTAP) collisions:

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[1] Crash Imminent Braking (CIB) First Annual Report. (2010). DOT HS 811 340. National Highway Traffic Safety Administration. Washington, DC.

[2] Objective Tests for Imminent Crash Automatic Braking Systems Final Report Volume 1 of 2. (2011). DOT HS 811 521. National Highway Traffic Safety Administration. Washington, DC.

[3] The classic example of an SCP crash is a laterally approaching vehicle in a traffic intersection. Challenges associated with these crash modes increase as speeds of target and/or host vehicle increase.

> *The test methods representing* ***Straight Crossing Path*** [emphasis added], *Left Turn Across – Opposite Direction, Opposite Direction, and pole/tree crash scenarios were all designated as 'Test Method Not Validated – Beyond Scope of CIB Project.' While test scenarios were developed and demonstrated for these crash conditions, CIB system performance, regardless of system configuration or settings, were not capable of reliably responding to these tests. Due to the difficulty in predicting the pre-crash events that lead up to these crash types, the difficulty in balancing CIB activations for these crashes with potential increases in undesirable false activation, and many other factors, these scenarios are also not likely to be near-term deployable features of CIB systems and may be better addressed through other active safety technologies.*[4]

Figure 1 shows a straight crossing path test conducted as part of the CIB project. The report provides the following assessment of the test result, "The limited time the target is in the field of view prior to impact challenges the system's ability to perform threat assessment and apply the CIB system. A target is usually recognized very late or not at all prior to impact."[5]

Figure 1. CIB Project Straight Crossing Path Test Scenario.

Since model year (MY) 2010, NHTSA has conducted testing of FCW system performance as part of its New Car Assessment Program (NCAP). The tests include the rear-end collision crash modes validated by the CIB project: Lead Vehicle Stopped (LVS), Lead Vehicle Moving (LVM), and Lead Vehicle Decelerating (LVD). On November 5, 2015, the agency announced it would be adding AEB system evaluations to NCAP effective for the 2018 model year. In March 2016, NHTSA issued a joint statement with the Insurance Institute for Highway Safety (IIHS) providing information related to the commitment

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[4] Objective Tests for Imminent Crash Automatic Braking Systems Final Report Volume 1 of 2, page 84 (2011). DOT HS 811 521. National Highway Traffic Safety Administration. Washington, DC.

[5] Objective Tests for Imminent Crash Automatic Braking Systems Final Report Volume 2 of 2, page L-51 (2011). DOT HS 811 521A. National Highway Traffic Safety Administration. Washington, DC.

by 20 automobile manufacturers, representing 99 percent of the U.S. new-car market, to voluntarily make AEB "standard on virtually all light-duty cars and trucks with a gross vehicle weight of 8,500 lbs. or less no later than September 1, 2022, and on virtually all trucks with a gross vehicle weight between 8,501 lbs. and 10,000 lbs. no later than September 1, 2025." The predicted safety benefits cited in the statement are limited to rear-end crashes:

> *IIHS research shows that AEB systems meeting the commitment would reduce* ***rear-end crashes*** [emphasis added] *by 40 percent. IIHS estimates that by 2025 – the earliest NHTSA believes it could realistically implement a regulatory requirement for AEB – the commitment will prevent 28,000 crashes and 12,000 injuries.*[6]

The capabilites of AEB systems have continually improved in performance and capabilities as automobile manufacturers and suppliers refine sensor packages and the algorithms that perform the object classifications and make the braking decisions (e.g., pedestrian collision avoidance). Recognizing this, ODI surveyed a dozen automotive manufacturers and several major suppliers to determine if the AEB capabilities in crossing path collisions had changed since the CAMP CIB project was completed. None of the companies contacted by ODI indicated that AEB systems used in their products through MY 2016 production were designed to brake for crossing path collisions.

2.3 Tesla AEB system. The Tesla AEB system is a radar/camera fusion system that is functional when switched ON regardless of Autopilot status. The driver can switch AEB ON/OFF on the Driver Assist page accessible via a display mounted in the center of the dashboard. The AEB is default ON for each new ignition cycle. The driver can select the timing of FCW alerts with four options: Early, Medium, Late, or OFF. If FCW is OFF, the driver will still get a Brake Capacity Warning (BCW) when driving in Traffic-Aware Cruise Control (TACC) mode (see Section 3 below). BCW alerts the driver when the closing speed to a lead vehicle may be too great to avoid a collision with the standard TACC deceleration limits. Adjusting the timing of the FCW alert does not affect the activation timing of the Tesla AEB system.

Both the radar and camera sub-systems are designed for front-to-rear collision prediction mitigation or avoidance.[7] The system requires agreement from both sensor systems to initiate automatic braking. The camera system uses Mobileye's EyeQ3 processing chip which uses a large dataset of the rear images of vehicles to make its target classification decisions. Complex or unusual vehicle shapes may delay or prevent the system from classifying certain vehicles as targets/threats.

NHTSA conducted a series of test track-based AEB performance evaluations shortly after the May crash using a 2015 Tesla Model S 85D and a 2015 Mercedes C300 4Matic peer vehicle. The vehicles were tested in the three rear-end collision crash modes (LVS, LVM, and LVD) and three different vehicle operating modes: manual driving; adaptive cruise control (ACC) systems activated; and ACC and Lane Centering Control (LCC) systems activated. This testing confirmed that the AEB systems in the Tesla and peer vehicle were able to achieve crash avoidance in a majority of the rear-end scenarios tested; that ACC generally provided enough braking to achieve crash avoidance without also requiring CIB to

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[6] Fact Sheet, Auto Industry Commitment to IIHS and NHTSA on Automatic Emergency Braking. (2016). National Highway Traffic Safety Administration & Insurance Institute for Highway Safety. Washington, DC.

[7] The system is also designed to detect and avoid impacts with pedestrians and stationary objects in the path of the Tesla when operating with TACC enabled.

intervene; and that neither vehicle effectively responded to a realistic appearing artifical "target" vehicle in the SCP or LTAP scenarios.

ODI's analysis of Tesla's AEB system finds that 1) the system is designed to avoid or mitigate read-end collisions; 2) the system's capabilities are in-line with industry state of the art for AEB performace through MY 2016; and 3) braking for crossing path collisions, such as that present in the Florida fatal crash, are outside the expected performance capabilities of the system.[8]

3.0 AUTOPILOT

The Autopilot system is an advanced driver assistance system (ADAS), which controls vehicle speed and path by automated control of braking, steering and torque to the drive motors.[9] Figure 2 shows the components used by Autopilot to monitor the driving environment.[10] The major subsystems associated with operation in Autopilot mode are TACC and Autosteer.

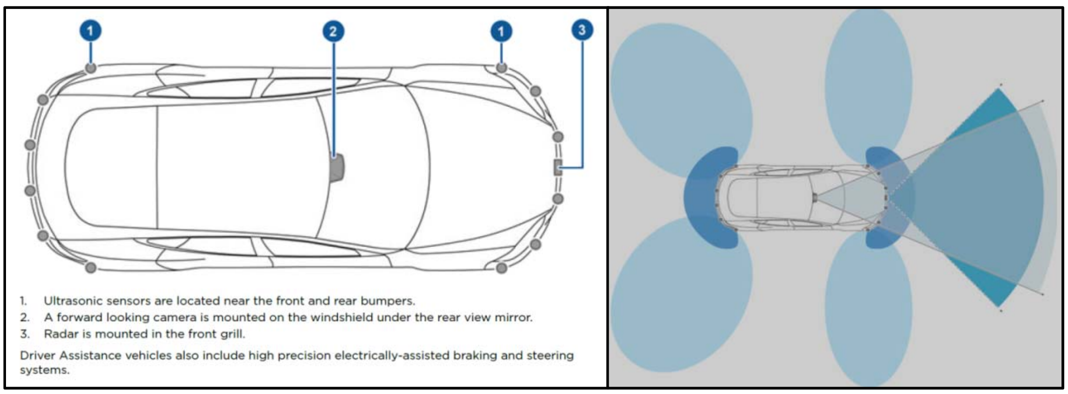

Figure 2. 2016 Tesla Model S Driver Assistance Sensors (left) and Fields of View (right).

3.1 Traffic-Aware Cruise Control (TACC). The Tesla TACC system uses information from the forward looking camera and radar sensor to determine if there is a vehicle in front of the Tesla in the same lane. If there is no vehicle in front of the Tesla, TACC maintains a set driving speed selected by the driver. When there is a lead vehicle detected that is travelling slower that the Tesla's set speed, the TACC will control motor torques to maintain a selected time-based distance from the lead vehicle.

The Tesla Model S owner's manual states that TACC "is primarily intended for driving on dry, straight roads, such as highways and freeways. It should not be used on city streets." The manual includes several additional warnings related to system limitations, use near pedestrians and cyclists, and use on winding roads with sharp curves or with slippery surfaces or poor weather conditions. The system does not prevent operation on any road types.

3.2 Autosteer. The Tesla Autosteer system uses information from the forward-looking camera, the radar sensor, and the ultrasonic sensors, to detect lane markings and the presence of vehicles and objects

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[8] Object classification algorithms in the Tesla and peer vehicles with AEB technologies are designed to avoid false-positive brake activations. The Florida crash involved a target image (side of a tractor trailer) that would not be a "true" target in the EyeQ3 vision system dataset and the tractor trailer was not moving in the same longitudinal direction as the Tesla, which is the vehicle kinematic scenario the radar system is designed to detect.

[9] NHTSA recognizes that other jurisdictions have raised concerns about Tesla's use of the name "Autopilot." This issue is outside the scope of this investigation.

[10] 2016 Tesla Model S Owner's Manual

to provide automated lane-centering steering control based on the lane markings and the vehicle directly in front of the Tesla, if present. The Tesla owner's manual contains the following warnings: 1) "Autosteer is intended for use only on highways and limited-access roads with a fully attentive driver. When using Autosteer, hold the steering wheel and be mindful of road conditions and surrounding traffic. Do not use Autosteer on city streets, in construction zones, or in areas where bicyclists or pedestrians may be present. Never depend on Autosteer to determine an appropriate driving path. Always be prepared to take immediate action. Failure to follow these instructions could cause serious property damage, injury or death;" and 2) "Many unforeseen circumstances can impair the operation of Autosteer. Always keep this in mind and remember that as a result, Autosteer may not steer Model S appropriately. Always drive attentively and be prepared to take immediate action." The system does not prevent operation on any road types.

4.0 HUMAN MACHINE INTERFACE

4.1 Automation Level. The Tesla Autopilot system is a Level 1 automated system when operated with TACC enabled and a Level 2 system when Autosteer is also activated. Figure 3 shows a summary of the levels of driving automation for on-road vehicles, including the division of responsibility at each level for the driver and system.[11] Level 1 and 2 system require continuous attention by the operator to monitor the driving environment and take immediate control when necessary. It is important that operators recognize this responsibility and understand the capabilities and limitations of the system.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 3. Summary of SAE International's Levels of Driving Automation for On-Road Vehicles.

The design of Level 2 partial autonomous systems should consider human-machine interface design factors, including:[12] 1) provide the operator with information about system limitations; 2) include a method for monitoring driver engagement with the driving task and assisting the driver with maintaining

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[11] https://www.sae.org/misc/pdfs/automated_driving.pdf

[12] Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts – Concepts of Operation. (2014). DOT HS 812 044. National Highway Traffic Safety Administration. Washington, DC.

attention to the environment; 3) minimize the potential for mode confusion to occur, through intuitive feedback from vehicle dynamics and/or warnings to the driver; and 4) consider restricting availability or performance when used on roads that are not in the intended use operating environments.

4.2 System limitations. Tesla provides information about system limitations at multiple levels, including: 1) the owner's manual; 2) in the release notes for new software releases, which refer to the owner's manual; 3) a user agreement required before enabling Autosteer for the first time or after an ignition cycle that concluded with Autosteer being switched off; 4) a dialog box that appears every time Autosteer is activated reminding the driver to "Always keep your hands on the wheel" and "Be prepared to take over at any time" (Figure 4); 5) the information in the user interface, which appears at all times while driving - the blue shaded circle around the white steering wheel indicates Autosteer is in operation, as opposed to when the background is gray meaning Autosteer is available should the driver decide to enable it (Figure 5).

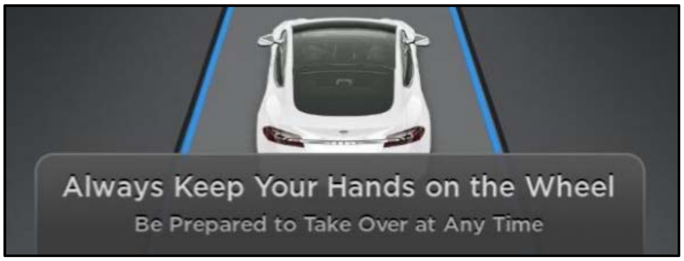

Figure 4. Dialog Box that Appears Every Time Autosteer is Activated.

Figure 5. Autopilot User Interface showing System Perceived Lane Lines, Other Vehicles, and Ultrasonic Objects.

4.3 Driver monitoring. Tesla monitors driver engagement[13] through the interactions with the steering wheel, turn signal, and TACC speed setting stalk. If the system does not detect the driver's hands on the steering wheel (assessed using microtorque measurements) or other signs of driver engagement for periods of time that vary depending on road class, vehicle speed, road curvature, and traffic conditions, an escalating series of warnings is presented. The warnings start with a visual alert indicating that hands on the steering wheel are required. If the driver does not respond to the visual warning, an audible chime is sounded after 15 seconds. A more pronounced chime is initiated if the driver does not respond after another 10 seconds. If the driver fails to respond to the third alert stage within five seconds, the system gradually slows the vehicle while maintaining position in the lane. Once the driver's hands are detected on the steering wheel, the warnings are suspended and Autopilot operation resumes.

As part of Tesla's 8.0 over-the-air (OTA) software update in September 2016, Tesla revised the timing of the hands-on warnings and added a feature that takes away the Autopilot driving feature for the remainder of the drive cycle if the driver fails to respond to the alerts adequately (known as an "Autopilot strikeout" – Figure 6).

Figure 6. Autosteer "Strike-Out" Alert.

4.4 Mode confusion. Unexpected system response during attempted activation or inadvertent override of Autosteer may leave the operator unaware of the state of the vehicle (i.e., "mode confusion"). Tesla's design is intended to protect against mode confusion at several levels, including: 1) information available in the user interface regarding Autopilot availability, Autopilot state, and successful and failed transitions between states; 2) providing audiovisual "Take Over Immediately" warning whenever the vehicle crosses a lane line or road edge, while the driver's hands are not detected on the steering wheel, within 40 seconds of an unsuccessful activation of Autosteer or an Autosteer override; and 3) if the driver attempts to activate TACC and Autosteer with a double-pull of the cruise stalk when Autosteer is not

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[13] Driver engagement refers to the driver's engagement in monitoring the driving environment and being prepared to take immediate action to avoid collisions, if necessary.

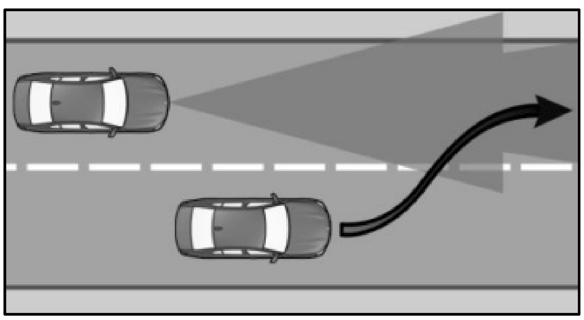
available, neither feature will activate and the Autosteer indicator icon will flash orange (Figure 7) and an audible alert will sound.

Figure 1. Unsuccessful Autosteer Activation Alert.

4.5 Road restrictions. According to Tesla, Autosteer is designed for use on highways that have a center divider and clear lane markings. The system does not prevent operation on any road types. The driver is responsible for deciding when the road type and other conditions are appropriate for system activation. The hands-on warnings occur more frequently as a function of vehicle speed, road class, and existence of heavy traffic.

5.0 CRASH INCIDENTS

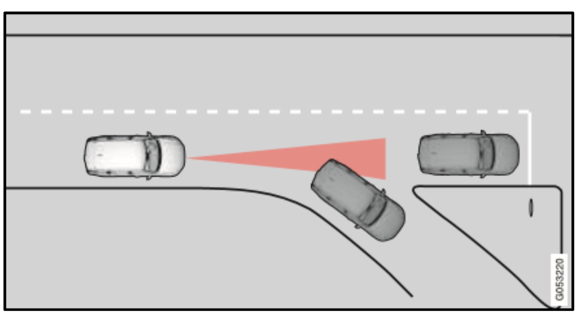
5.1 Autopilot crashes. ODI analyzed data from crashes of Tesla Model S and Model X vehicles involving airbag deployments that occurred while operating in, or within 15 seconds of transitioning from, Autopilot mode.[14] Some crashes involved impacts from other vehicles striking the Tesla from various directions with little to no warning to the Tesla driver. Other crashes involved scenarios known to be outside of the state-of-technology for current-generation Level 1 or 2 systems, such as cut-ins, cut-outs and crossing path collisions.



If a vehicle driving ahead of you suddenly swerves into your lane, the system may not be able to automatically restore the selected distance. This also applies to major speed differences to vehicles driving ahead of you, e.g., when rapidly approaching a truck.

2016 BMW 7-Series Owner's Manual, page 174

Figure 8. ACC Cut-In Scenario Warning. 2016 BMW 7-Series Owner's Manual.



WARNING

If ACC changes targets from a moving vehicle to a stationary one at speeds **above** 20 mph (30 km/h), the system will **not** react to the stationary vehicle and will accelerate to the previously set speed.

The driver must actively apply the brakes to slow/stop the vehicle.

Figure 9. ACC Cut-Out Scenario Warning, 2016 Volvo XC90 Owner's Manual.

[14] Data logs, image files, and records related to the crashes were provided by Tesla in response to NHTSA subpoenas.

Figures 8 and 9 show examples of warnings from peer vehicle owner's manuals indicating that these modes are challenging for ACC systems, in Level 1 or 2 operating modes, and may require action by the driver to avoid a collision. Similarly, in discussing ACC, the BMW manual describes system limitations, including that the system does not decelerate for cross traffic. [15]

5.2 Driver behavior factors. Many of the crashes appear to involve driver behavior factors, including travelling too fast for conditions, mode confusion, and distraction. Most of these involve late steering and/or braking actions by the driver to avoid the collision, but a few do not show any actions prior to impact. Highway incidents, which accounted for a little over half of the crashes reviewed by ODI, involved cut-ins, cut-outs, and sudden changes in traffic flow. Some crashes occurred in environments that are not appropriate for semi-autonomous driving (e.g., city traffic, highway entrance/exit ramps, construction zones, in heavy rain, and road junctions/intersections).

ODI's analysis of incidents related to mode confusion did not identify a pattern of failures indicating a potential design defect. Incidents included apparent mode confusion during attempted Autopilot activations and mode confusion after inadvertant overrides. The incidents associated with each of these scenarios were isolated events that involved different sets of contributing factors. Recent changes implemented by Tesla have been made to further reduce the potential for mode confusion in the subject vehicles.[16]

The Florida fatal crash appears to have involved a period of extended distraction (at least 7 seconds). Most of the incidents reviewed by ODI involved events with much shorter time available for the system and driver to detect/observe and react to the pending collision (less than 3 seconds). An attentive driver has superior situational awareness in most of these types of events, particularly when coupled with the ability of an experienced driver to anticipate the actions of other drivers. Tesla has changed its driver monitoring strategy to promote driver attention to the driving environment.

5.3 Driver distraction. Figure 10 shows the distributions of off-road glances by duration that were observed in a research study by General Motors of driver behaviors in vehicles with Limited-Ability Autonomous Driving Systems (LAADS)[17] when operated in SAE Level 1 and Level 2 modes.[18] The data show distractions occur in each operating mode and that the majority occur for 3 seconds or less when driving in ACC mode or with ACC and Lane Centering Control used together. ODI's analysis of field incidents found that most of the crashes developed in less than 3-4 seconds. Distractions greater than seven seconds, such as appears to have occurred in the fatal Florida crash are uncommon, but foreseeable.

[15] Tesla's Model S Owner's Manual is not as specific as the examples cited here; opting instead to identify a handful of scenarios under which a vehicle may not be detected, followed by a broad warning: "The limitations described above do not represent an exhaustive list of situations that may interfere with proper operation of Collision Avoidance Assist features. These features may fail to provide their intended function for many other reasons. It is the driver's responsibility to avoid collisions by staying alert and paying attention to the area beside Model S so you can anticipate the need to take corrective action as early as possible."

[16] This review included an assessment of the user interface in the subject vehicles, which has a larger display and symbols showing system status than peer vehicles with SAE Level 1 or Level 2 technologies reviewed by ODI.

[17] LAADS are defined in the study as systems that "can control vehicle speed and steering on public roads for substantial distances and time" and "in some situations requires that the driver/operator intervene to assure a safe and comfortable trip," with the latter element accounting for the "limited-ability." The study showed that vehicles with an "ACC and perfect Lane Centering (PADS)" system may have slightly more frequent longer duration off-road glances than vehicles with "ACC and imperfect Lane Centering (LAADS)" systems.

[18] Salinger, J. Human Factors for Limited-Ability Autonomous Driving Systems. (2012). General Motors Research.

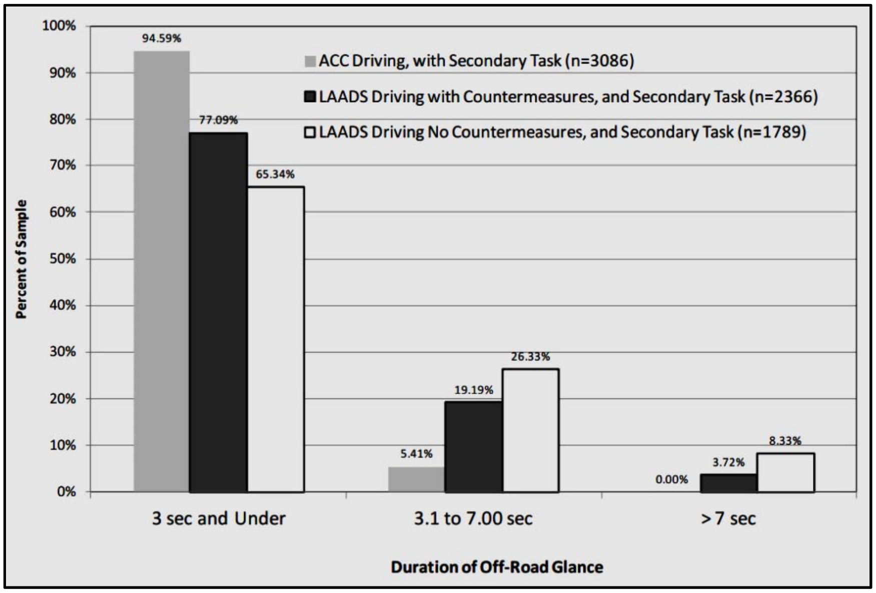


Figure 10. Percentage of Off-Road Glances Across Driving Mode for Short, Intermediate and Long Time Bins.

To probe the foreseeability issue further,[19] the Agency issued a Special Order to Tesla to evaluate the types of driver misuse, including driver distraction, that were considered by the company and any safeguards that were incorporated into the Autopilot design. It appears that over the course of researching and developing Autopilot, Tesla considered the possibility that drivers could misuse the system in a variety of ways, including those identified above - i.e., through mode confusion, distracted driving, and use of the system outside preferred environments and conditions. Included in the types of driver distraction that Tesla engineers considered are that a driver might fail to pay attention, fall asleep, or become incapactitated while using Autopilot. The potential for driver misuse was evaluated as part of Tesla's design process and solutions were tested, validated, and incorporated into the wide release of the product. It appears that Tesla's evaluation of driver misuse and its resulting actions addressed the unreasonable risk to safety that may be presented by such misuse.[20]

5.4 Crash rates. ODI analyzed mileage and airbag deployment data supplied by Tesla for all MY 2014 through 2016 Model S and 2016 Model X vehicles equipped with the Autopilot Technology Package, either installed in the vehicle when sold or through an OTA update, to calculate crash rates by miles travelled prior to[21] and after Autopilot installation.[22] Figure 11 shows the rates calculated by ODI for airbag deployment crashes in the subject Tesla vehicles before and after Autosteer installation. The data show that the Tesla vehicles crash rate dropped by almost 40 percent after Autosteer installation.

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[19] An unreasonable risks due to owner abuse that is reasonably foreseeable (i.e., ordinary abuse) may constitute a safety-related defect. *See United States v. Gen. Motors Corp*., 518 F.2d 420, 427 (D.C. Cir. 1975) ("Wheels").

[20] Driver misuse in the context of semi-autonomous vehicles is an emerging issue and the agency intends to continue its evaluation and monitoring of this topic, including best practices for handling driver misuse as well as driver education.

[21] Approximately one-third of the subject vehicles accumulated mileage prior to Autopilot installation.

[22] The crash rates are for all miles travelled before and after Autopilot installation and are not limited to actual Autopilot use.

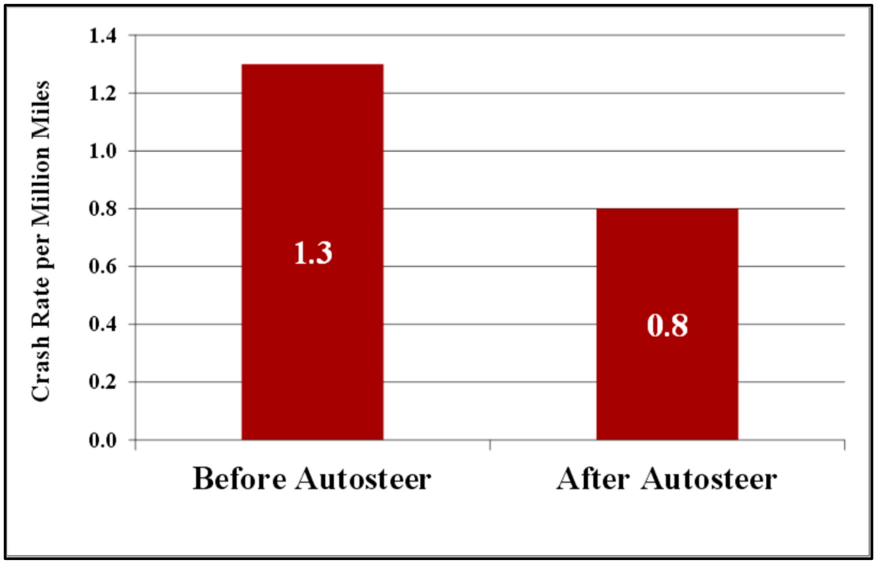

Figure 11. Crash Rates in MY 2014-16 Tesla Model S and 2016 Model X vehicles Before and After Autosteer Installation.

6.0 AUTOPILOT UPDATES

Since it released Autopilot in October 2015, Tesla has made continuous updates to the system's firmware that are made available to consumers as OTA updates. These updates have included changes to improve TACC, AEB and Autosteer performance, as well as adding new driver assistance safety features, such as In-Path Stationary Object (IPSO) braking and Pedal Misapplication Mitigation (PMM). In September 2016, Tesla released its 8.0 firmware update which included revisions in the driver monitoring strategy, as well as several enhancements to AEB, DBS, and TACC performance.

7.0 CONCLUSION

Advanced Driver Assistance Systems, such as Tesla's Autopilot, require the continual and full attention of the driver to monitor the traffic environment and be prepared to take action to avoid crashes. Automated Emergency Braking systems have been developed to aid in avoiding or mitigating rear-end collisions. The systems have limitations and may not always detect threats or provide warnings or automatic braking early enough to avoid collisions. Although perhaps not as specific as it could be, Tesla has provided information about system limitations in the owner's manuals, user interface and associated warnings/alerts, as well as a driver monitoring system that is intended to aid the driver in remaining engaged in the driving task at all times. Drivers should read all instructions and warnings provided in owner's manuals for ADAS technologies and be aware of system limitations.[23] While ADAS technologies are continually improving in performance in larger percentages of crash types, a driver should never wait for automatic braking to occur when a collision threat is perceived.

NHTSA's examination did not identify any defects in design or performance of the AEB or Autopilot systems of the subject vehicles nor any incidents in which the systems did not perform as designed. AEB

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[23] While drivers have a responsibility to read the owner's manual and comply with all manufacturer instructions and warnings, the reality is that drivers do not always do so. Manufacturers therefore have a responsibility to design with the inattentive driver in mind. *See* Enforcement Guidance Bulletin 2016-02: Safety-Related Defects and Automated Safety Technologies, 81 Fed. Reg. 65705.

systems used in the automotive industry through MY 2016 are rear-end collision avoidance technologies that are not designed to reliably perform in all crash modes, including crossing path collisions. Tesla appears to have recognized HMI factors, such as the potential for driver distraction, in its design process for the Autopilot system. Tesla's design included a hands-on the steering wheel system for monitoring driver engagement. That system has been updated to further reinforce the need for driver engagement through a "strike out" strategy. Drivers that do not respond to visual cues in the driver monitoring system alerts may "strike out" and lose Autopilot function for the remainder of the drive cycle.

A safety-related defect trend has not been identified at this time and further examination of this issue does not appear to be warranted. Accordingly, this investigation is closed. The closing of this investigation does not constitute a finding by NHTSA that no safety-related defect exists. The agency will monitor the issue and reserves the right to take future action if warranted by the circumstances.