Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck Near Williston, Florida

May 7, 2016

Accident Report

NTSB/HAR-17/02
PB2017-102600

National
Transportation
Safety Board

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Highway Accident Report

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National
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Safety Board

490 L’Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2017. *Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck Near Williston, Florida, May 7, 2016.* Highway Accident Report NTSB/HAR-17/02. Washington, DC.

Abstract: At 4:36 p.m. eastern daylight time on Saturday, May 7, 2016, a 2015 Tesla Model S 70D car, traveling eastbound on US Highway 27A (US-27A), west of Williston, Florida, struck a refrigerated semitrailer powered by a 2014 Freightliner Cascadia truck-tractor. At the time of the collision, the truck was making a left turn from westbound US-27A across the two eastbound travel lanes onto NE 140th Court, a local paved road. The car struck the right side of the semitrailer, crossed underneath it, and then went off the right roadside at a shallow angle. The impact with the underside of the semitrailer sheared off the roof of the car. After leaving the roadway, the car continued through a drainage culvert and two wire fences. It then struck and broke a utility pole, rotated counterclockwise, and came to rest perpendicular to the highway in the front yard of a private residence. Meanwhile, the truck continued across the intersection and came to a stop on NE 140th Court, south of a retail business located on the intersection corner. The driver and sole occupant of the car died in the crash; the commercial truck driver was not injured. System performance data downloaded from the car indicated that the driver was operating it using the Traffic-Aware Cruise Control and Autosteer lane-keeping systems, which are automated vehicle control systems within Tesla's Autopilot suite. The crash investigation focused on the following safety issues: operational design domains for SAE International Level 2 vehicle automation, surrogate means of determining the automated vehicle driver's degree of engagement, event data recorders for automated vehicles, safety metrics and exposure data for automated vehicles, and connected vehicle technology and vehicle-to-vehicle requirements. The NTSB made safety recommendations to the US Department of Transportation, the National Highway Traffic Safety Administration (NHTSA), manufacturers of vehicles equipped with Level 2 vehicle automation systems, the Alliance of Automobile Manufacturers, and the Association of Global Automakers. The NTSB also reiterated safety recommendations to NHTSA.

For more detailed background information on this report, visit NTSB investigations website and search for NTSB accident ID HWY16FH018. Recent publications are available in their entirety on the Internet at NTSB website. Other information about available publications also may be obtained from the website or by contacting:

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This report was reissued on October 12, 2017, with corrections to pages vii and 43.

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Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AdaptIVe	Automated Driving Applications and Technologies for Intelligent Vehicles
AEB	automatic emergency braking
AV Policy	Federal Automated Vehicles Policy (NHTSA)
AVR	Automated Vehicle Research
BASIC	Behavior Analysis and Safety Improvement Category
BMI	body mass index
CAMI	Civil Aerospace Medical Institute (FAA)
CAMP	Crash Avoidance Metrics Partnership
CDL	commercial driver's license
CDLIS	Commercial Driver's License Information System
CFR	*Code of Federal Regulations*
DDEC	Detroit Diesel Electronic Controller
DOT	US Department of Transportation
ECU	electronic control unit
EDR	event data recorder
FAA	Federal Aviation Administration
FCW	forward collision warning
FDOT	Florida Department of Transportation
FHP	Florida Highway Patrol
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSSs	*Federal Motor Vehicle Safety Standards*
GPS	global positioning system

HAV	highly automated vehicle
HOS	hours-of-service
I-ADAS	intersection advanced driver assist systems
MCMIS	Motor Carrier Management Information System
mL	milliliter
MY	model year
ng	nanogram
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
ODD	operational design domain
ODI	Office of Defects Investigation (NHTSA)
OOS	out-of-service
SAE	SAE International
SD	secure digital
SR-24	State Road 24
TACC	Traffic-Aware Cruise Control
THC	tetrahydrocannabinol
THC-COOH	tetrahydrocannabinol carboxylic acid
US-27A	US Highway 27A
V2V	vehicle-to-vehicle
VTTI	Virginia Tech Transportation Institute

Executive Summary

Investigation Synopsis

At 4:36 p.m. eastern daylight time on Saturday, May 7, 2016, a 2015 Tesla Model S 70D car, traveling eastbound on US Highway 27A (US-27A), west of Williston, Florida, struck a refrigerated semitrailer powered by a 2014 Freightliner Cascadia truck-tractor. At the time of the collision, the truck was making a left turn from westbound US-27A across the two eastbound travel lanes onto NE 140th Court, a local paved road. The car struck the right side of the semitrailer, crossed underneath it, and then went off the right roadside at a shallow angle. The impact with the underside of the semitrailer sheared off the roof of the car.

After leaving the roadway, the car continued through a drainage culvert and two wire fences. It then struck and broke a utility pole, rotated counterclockwise, and came to rest perpendicular to the highway in the front yard of a private residence. Meanwhile, the truck continued across the intersection and came to a stop on NE 140th Court, south of a retail business located on the intersection corner.

The driver and sole occupant of the car died in the crash; the commercial truck driver was not injured.

System performance data downloaded from the car indicated that the driver was operating it using the Traffic-Aware Cruise Control and Autosteer lane-keeping systems, which are automated vehicle control systems within Tesla's Autopilot suite.

The National Transportation Safety Board (NTSB) became aware of the circumstances of the crash when the National Highway Traffic Safety Administration (NHTSA) began a defect investigation on June 28, 2016, which focused on the automatic emergency braking and Autopilot systems of the Tesla Models S and X, for model years 2014–2016. On learning of the May 7, 2016, Williston crash that prompted the NHTSA investigation, the NTSB initiated our investigation, which focused on the use of the Autopilot system.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the Williston, Florida, crash was the truck driver's failure to yield the right of way to the car, combined with the car driver's inattention due to overreliance on vehicle automation, which resulted in the car driver's lack of reaction to the presence of the truck. Contributing to the car driver's overreliance on the vehicle automation was its operational design, which permitted his prolonged disengagement from the driving task and his use of the automation in ways inconsistent with guidance and warnings from the manufacturer.

Safety Issues

The crash investigation focused on the following safety issues:

- Operational design domains for SAE International Level 2 vehicle automation,
- Surrogate means of determining the automated vehicle driver’s degree of engagement,
- Event data recorders for automated vehicles,
- Safety metrics and exposure data for automated vehicles, and
- Connected vehicle technology and vehicle-to-vehicle (V2V) requirements.

Recommendations

As a result of this crash investigation, the NTSB makes safety recommendations to the US Department of Transportation, NHTSA, manufacturers of vehicles equipped with Level 2 vehicle automation systems (Volkswagen Group of America, BMW of North America, Nissan Group of North America, Mercedes-Benz USA, Tesla Inc., and Volvo Car USA), the Alliance of Automobile Manufacturers, and the Association of Global Automakers. The NTSB also reiterates Safety Recommendations H-13-30 and -31 to NHTSA.

1 Factual Information

1.1 The Crash

1.1.1 Crash Events

At 4:36 p.m. eastern daylight time on Saturday, May 7, 2016, a 2015 Tesla Model S 70D car, traveling eastbound on US Highway 27A (US-27A) near mile marker 29 in Levy County, west of Williston, Florida, struck the right side of a 2003 Utility 3000R refrigerated semitrailer, which was being towed by a 2014 Freightliner Cascadia truck-tractor.[1] At the time of the collision, the truck was making a left turn from westbound US-27A across the two eastbound travel lanes onto NE 140th Court, a local paved road.[2] After the car struck the right side of the semitrailer, it crossed underneath the semitrailer and went off the right roadside at a shallow angle. The impact with the underside of the semitrailer sheared off the car's roof.

After leaving the roadway, the car continued through a drainage culvert and two wire fences. It then struck and broke a utility pole, rotated counterclockwise, and came to rest perpendicular to the highway in the front yard of a private residence. Overall, the car traveled about 910 feet after striking the semitrailer. The driver and sole occupant of the car died in the crash.

System performance data downloaded from the Tesla indicated that the driver was operating the car using features of its Autopilot suite: Traffic-Aware Cruise Control (TACC) and the Autosteer lane-keeping system. "Autopilot" is a proprietary name used by Tesla for a combination of vehicle automation systems that provide driver assistance. The car was also equipped with a forward collision warning (FCW) system and automatic emergency braking (AEB), but those systems did not activate. System performance data indicated that the vehicle speed just before impact with the semitrailer was 74 mph. The highway has a posted speed limit of 65 mph.

Following the crash, the truck continued across the intersection and came to a stop on NE 140th Court, south of a retail business on the intersection corner. The truck-tractor towing the semitrailer was undamaged, and the semitrailer experienced minimal impact damage. The truck driver was uninjured.

Ten days after the crash, the Florida Highway Patrol (FHP) recorded an interview with a driver who had been traveling behind the truck on westbound US-27A at an estimated speed of 60 mph. In July 2016, National Transportation Safety Board (NTSB) investigators also interviewed this witness. He said that when he first saw the truck, it was in the left turn lane at the intersection; he could not discern whether the truck was stopped or moving very slowly. He said he saw the Tesla on US-27A eastbound before the truck began to turn through the median, with no other traffic in the area. He described seeing the car crest the grade before the truck began its

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[1] Unless otherwise indicated, all times in this report are eastern daylight time.

[2] In this report, the vehicle consisting of the truck-tractor in combination with the semitrailer is referred to generically as the "truck"; the truck-tractor and semitrailer components may also be referred to separately.

left turn and crossed the median. He said that he saw the Tesla for several seconds before his view was blocked by the semitrailer. He said he thought the car driver would need to slow down to avoid a collision with the truck. As the truck entered the eastbound lanes, the witness lost sight of the car, which was then on the far side of the truck. He reported that as he approached the location of the westbound left turn lane for the intersection, he heard the crash and saw the car emerge from underneath the semitrailer, continue traveling eastward, and leave the roadway.

The witness said he made a U-turn at the intersection and followed the Tesla to its stopped location near a residential driveway. The witness stated that there were no obstructions to the lines of sight for the two vehicles, and that sun glare was not a problem at the time of the crash.

The FHP cited the truck driver for failure to yield right of way.[3]

1.1.2 Crash Scene

The crash occurred in the righthand eastbound travel lane of US-27A near mile marker 29, approximately 5 miles west of Williston in Levy County, Florida. Figure 1 provides an overhead view of the crash location.

Figure 1. Overhead view of the crash intersection, showing the route of the eastbound car traveling toward the crash location with a straight arrow, and the route of the westbound truck, turning south, with a curved arrow. (Source: Google Earth [modified])

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[3] In December 2016, the FHP investigation of the truck driver resulted in the issuance of a commercial uniform traffic citation for a noncriminal traffic violation.

At the crash location, US-27A is a four-lane divided highway with two through lanes in each direction separated by a 60-foot-wide paved median. Turn lanes extend for a length of approximately 550 feet in both the east- and westbound directions. The local road NE 140th Court runs due south, intersecting US-27A at a 109-degree angle. The intersection has a median crossover area between the two directions of travel on US-27A; the crossover area is about 130 feet long. The horizontal alignment of US-27A is straight both east and west of the intersection; the vertical alignment involves a descending grade in the eastbound direction. Figure 2 is a diagram of the scene. Figures 3 and 4 show the crash intersection as approached from the east- and westbound routes.

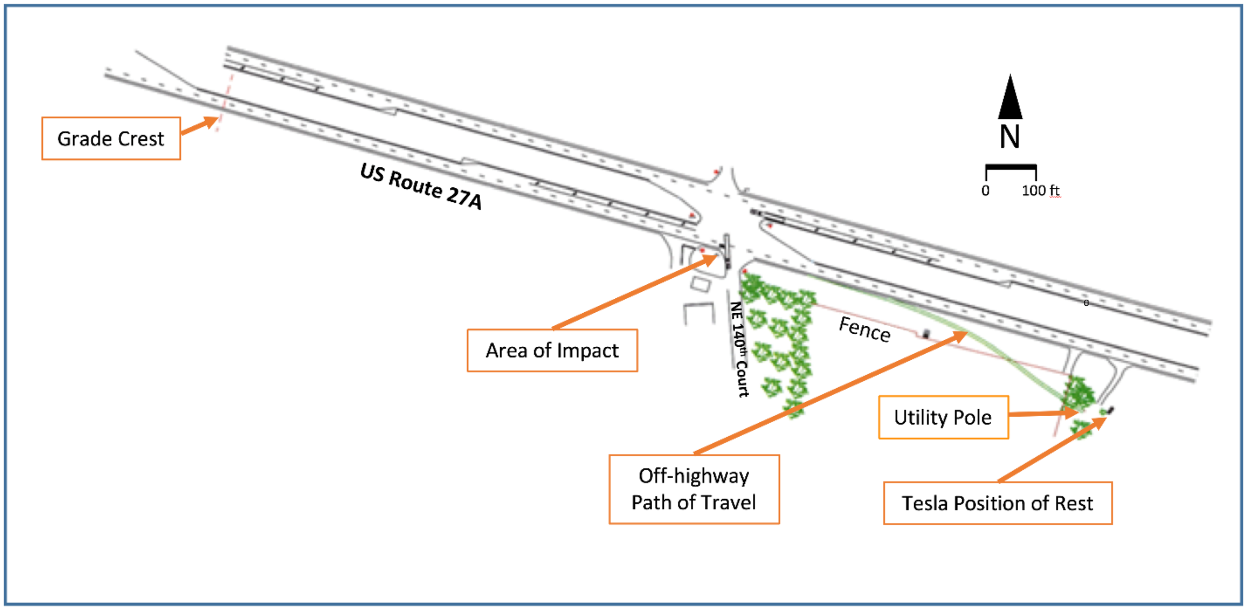

Figure 2. Diagram of the crash intersection, showing US-27A and NE 140th Court extending south (down toward the bottom of the diagram). The initial point of impact is on the south side of the intersection. After traveling off the highway, the Tesla struck a utility pole and came to rest near a residential driveway.

Figure 3. Approach to the crash scene from the US-27A westbound left turn lane, looking west as viewed from the truck's route of travel.

Figure 4. Approach to the crash scene from US-27A eastbound, looking east as viewed from the car's route in the righthand travel lane. (Based on the known length of the left turn lane, the distance to the intersection in this view is approximately 750 feet.)

The impact occurred within the intersection in the righthand lane of eastbound US-27A. Postcrash, debris from the car, including the exterior and interior roof panel structure, was located on the southwest corner of the intersection and in the travel lanes of NE 140th Court. Other debris trailed eastward from the area of impact along the car's path of travel. Investigators found no evidence of precollision roadway marks for the eastbound car or the truck crossing the intersection.

The collision occurred during daylight hours, the weather was clear, and the road was dry.[4] At the time of the crash, the sun would have been high in the sky, behind the car as it headed east.

1.1.3 Occupant Protection and Injuries

The 40-year-old male car driver was seated in the driver's seat and was restrained with a lap/shoulder belt at the time of the crash.[5] The driver sustained fatal blunt force trauma injuries to the head consistent with contact from the car's roof structure as it was displaced rearward or with contact from both the car's roof structure and the structure of the semitrailer.

According to the data recorded by the car, the airbags did not deploy when the car struck and passed under the semitrailer, most likely due to the car's low change in velocity during this portion of the crash. About 8.4 seconds after the initial impact with the semitrailer, the car's airbags deployed when it collided with the utility pole.

The truck driver, who was wearing his lap/shoulder seat belt, was not injured.

1.2 Vehicle Damage

1.2.1 Tesla Model S 70D Car

Damage to the car, as shown in figure 5, included separation of the roof panel, which exhibited fore-to-aft accordion-like compression. The forward-facing surfaces of the car's A-pillars were separated and deformed just below where the roof met the pillars. Additional impact evidence consisted of scrapes to the trailing edge of the hood just forward of the windshield. The scrapes were about 5 inches long and were located on the driver's side of the hood, about 5 inches from its longitudinal centerline (see figure 5, yellow arrow). The scrape widths were consistent with the length of the semitrailer's center side-marker lamp, which had been mounted below the side rail on the right side of the semitrailer. The static height of the trailing end of the hood was about 3 feet. Postcollision measurements indicated that the car's seatback headrests were at least 3.5 inches taller than the bottom edge of the semitrailer. The driver and front passenger seats were deformed rearward.

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[4] This information is based on FHP and Ocala International Airport records. The airport is 25.3 miles southeast of the crash site.

[5] Investigators determined that the driver used the three-point continuous loop lap/shoulder restraint based on postcrash photographs showing the driver properly belted; the data recorded by the vehicle; and the postcrash inspection of the vehicle, which showed the belt cut by first responders but still latched.

The damage to the car from the impact with the utility pole was centered 12.4 inches inboard of the left side in front of the wheel well. The impact of the front of the car with the utility pole displaced the left front fender and chassis structures (see figure 5, red arrow). Postcrash, the left (driver's) side wheelbase measured about 4 inches shorter than the right side. The battery pack of the electric car, located aft of the front axle, was not damaged.

Figure 5. Damaged car. Scrapes from the semitrailer's center side-marker lamp are indicated by the yellow arrow. Impact damage associated with the utility pole is indicated by the red arrow. (Source: Florida Highway Patrol)

1.2.2 Utility Semitrailer

Investigators examined the involved semitrailer, which was a 2003 Utility VS2RA 3000R refrigerated van-body trailer. The investigators' comparison of the semitrailer with the photographs the FHP took at the crash scene showed that the external condition and appearance of the semitrailer had not changed since the crash. Collision evidence consisted of minor impact damage to the lower sidewall rails on both sides of the semitrailer and the undercarriage between the opposing damaged rails. Damage to the passenger (right) side exhibited inward intrusion, while damage on the driver (left) side exhibited outward deformation. The damage on both sides exhibited two distinct areas of contact. The undercarriage damage consisted of a displaced transverse floor support rail between the damaged areas on the two sides.[6] A segment of windshield

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[6] The overall length of the combination vehicle was 71 feet 7 inches, based on as-built data provided by Freightliner, the truck-tractor manufacturer. Based on the semitrailer's overall calculated length, the impact would have been centered about 45 feet 5 inches rearward from the front of the truck-tractor at the time of the collision.

trim from the car was found entangled within the forward-most area of contact damage on the semitrailer. Figure 6 shows a postcrash photograph of the semitrailer, and figure 7 focuses on the damage to the semitrailer.

Figure 6. Damaged right side of the Utility semitrailer.

Figure 7. Closeup view of impact damage to the right side of the Utility semitrailer. The arrow indicates a segment of front windshield trim from the Tesla entrapped in the forward-most area of damage.

1.3 Tesla Model S 70D Car

This section first discusses the mechanical inspection of the car and then focuses on its automated vehicle control systems. The section also presents the recorded data that provided information about those systems and the car's operation.

1.3.1 Mechanical Inspections

Investigators examined the major mechanical systems on the car, which included the powertrain, steering, braking, and suspension systems. They identified no anomalies within the major vehicle systems.

The Tesla was equipped with electric power-assisted rack-and-pinion steering gear; all the steering arm linkages remained intact and connected. It was possible to rotate the steering gear from stop to stop by turning the steering wheel. All ball joint connections remained intact and showed no evidence of excessive wear or play.

The vehicle was equipped with two independent suspension systems. On the front steering axle, the mounting bolt for the forward lower control arm ball joint was broken at the steering knuckle in a manner consistent with impact damage. Investigators noted no other damage to the suspension system, including to the suspension components of the rear axle.

Both axles had disc brake assemblies. The brake calipers on either side of the disc were rigidly mounted with four pistons each. A functional check verified that the brakes were capable of working. When the brake master cylinder was actuated, all brake assemblies locked from hand rotation and released when the brake master cylinder was released.

1.3.2 Automated Vehicle Control Systems

The basic function of automated vehicle systems is to aid a driver in performing driving tasks. Some automated systems are safety systems that alert a driver to a potentially hazardous situation, such as FCW, or that take momentary control of vehicle functions, such as AEB. Other automated systems may be considered convenience systems, which supplement or fully control driving tasks.

In general, automated vehicle control systems consist of three main subsystems: (a) a sensor suite (optical, radar, LIDAR, and/or ultrasonic) designed to assess the nearby environment, (b) a data-processing suite designed to collect input data from the sensors and compute instructions, and (c) a servo suite designed to provide control inputs to the vehicle. These three subsystems provide performance monitoring, processing, and control. Information travels between subsystems using multiple controller area network busses.[7] The performance data associated with automated vehicle control systems are stored in the vehicle's memory and may be communicated through an over-the-air network to the manufacturer's central computer network.

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[7] A series of core SAE J1939 standards addresses vehicle networks.

The Tesla Model S was equipped with the following automated vehicle control systems: Autopilot (comprising TACC, Autosteer, and Auto Lane Change systems), Forward Collision Avoidance (comprising FCW and AEB), Speed Assist, Lane Assist, and Autopark.[8]

1.3.3 Autopilot Description

Although Tesla's Autopilot suite is a combination of three systems, when discussing Autopilot in this report, we primarily refer to the combined activation of two systems—TACC and Autosteer. (The driver may also activate Auto Lane Change to automatically move the car into a lane.) TACC is an adaptive cruise control system that maintains the set cruise speed, applies brakes to preserve a predetermined following distance when approaching a slower-moving vehicle ahead of the Tesla, and accelerates to the set cruising speed when the area in front of the Tesla is no longer obstructed. Autosteer automatically steers the car to keep it within its lane of travel. In short, TACC provides longitudinal control (acceleration and deceleration) and Autosteer provides lateral control (steering) of the car within the lane, making the Tesla Autopilot consistent with an SAE International (SAE) Level 2 automated vehicle system. (The SAE classification of automated vehicle technologies is discussed in section 1.7.1.)

When Autopilot is active, the system (1) monitors the traveling path, (2) maintains the set cruise speed, (3) maintains the Tesla's position in the traveling lane, (4) brakes when it detects slower-moving vehicles ahead of the Tesla, and (5) decelerates and follows a slower-moving vehicle in front of the Tesla at the predetermined following distance. Figure 8 shows a view of the Tesla instrument panel. This view represents to the driver that TACC is active, which is indicated by a blue-colored speedometer icon at the top left of the display; the operator-established cruising speed appears in numerals under the speedometer icon. The actual vehicle speed appears in large numerals in the top/center of the instrument panel display. When Autosteer is active, the driver sees an icon depicting a blue steering wheel in the upper right of the instrument panel display. When this icon is gray-colored rather than blue, it indicates that Autosteer is not active but is available.

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[8] (a) See appendix B for information on these automated systems and their capabilities. (b) The systems are discussed in the Human Performance Supplemental Report—Driver Assistance Systems in the NTSB public docket case file HWY16FH018.

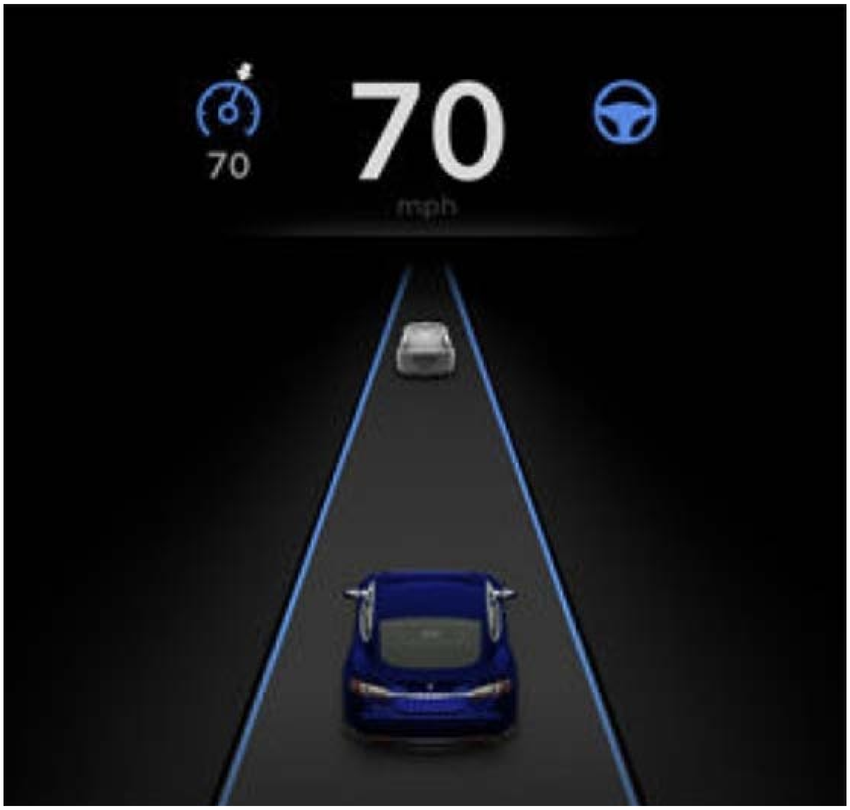

Figure 8. Tesla instrument panel. The blue speed dial at the top left indicates that TACC is active, and the blue steering wheel at the top right indicates that Autosteer is active. (Source: Owner's Manual for 2016 Tesla Model S [Tesla 2016])

1.3.4 Autopilot Availability and Constraints

On the Tesla, TACC is available only when traveling above 18 mph.[9] Once TACC is activated, Autosteer is available whenever the system detects lane markings. A driver can activate TACC by itself but can activate Autosteer only after activating TACC; that is, Autosteer is not available without TACC. In addition, Tesla imposes two types of constraints on the driver's use of Autopilot: these are (1) hard constraints that the system imposes automatically, and (2) soft constraints that Tesla provides as cautions to the driver through the instrument screen and instructions in the vehicle owner's manual.

Hard Constraints. System-imposed constraints on driver use of Autopilot include (1) setting an upper limit on lateral acceleration that affects the system alert sequence; (2) limiting the maximum cruising speed, depending on the detection of the speed limit on a restricted road; and (3) measuring the level of driver engagement and deactivating Autopilot if the level is

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[9] TACC can be activated at speeds lower than 18 mph, if a vehicle is detected in front of the Tesla.

insufficient.[10] In addition, as a general hard constraint, the driver can activate Autopilot only if the driver's seat belt is latched.

With respect to constraint (1), Autopilot has a lateral acceleration limit used to qualify "straight" roads that affects the timing duration of hands-off operation of Autopilot.[11] For constraint (2), when Autopilot cannot detect the speed limit, it allows a maximum cruise speed in TACC of 45 mph. When this occurs, the instrument panel displays the following message: "Driving on a Restricted Road." In such circumstances, the driver can manually accelerate to exceed the limited TACC speed, but when the driver releases the accelerator pedal, TACC slows the vehicle to the 45-mph cruise speed. With respect to constraint (3), Autopilot assesses the driver's level of engagement by monitoring driver interaction with the steering wheel through changes in steering wheel torque.[12] The system uses the driver's interactions with the wheel as a surrogate means of determining the driver's degree of engagement with the tasks of monitoring the road environment and the Autopilot system's performance.

Autopilot uses a sequence of warnings to encourage the driver to interact with the steering wheel. The first alert is a visual warning, which appears in the instrument panel display and reads "Hold Steering Wheel." If the system does not detect driver-applied torque on the steering wheel after this visual warning, it sounds an auditory chime. If there is again no driver interaction with the steering wheel, the system sounds a second, louder chime. If the driver still does not apply detectable torque to the steering wheel, the system presents a final visual warning in the instrument panel display, which reads "To Maintain Set Speed Place Hands On Steering Wheel." If the driver does not respond to the final visual warning, Autopilot decelerates the Tesla to a full stop in the current travel lane and activates the car's hazard flashers.[13] (This situation would likely occur only in the event of an incapacitated or completely unresponsive driver.)

On the crash-involved car, the timing for the initial visual warning ranged from 1 to 5 minutes when traveling above 45 mph, depending on the system conditions. However, when traveling 45 mph and below, the warning for hands-off driving would not occur, unless the car exceeded the lateral acceleration threshold, such as when traveling on certain curves. When traveling above 45 mph, the initial warning would occur earlier when another vehicle was not detected ahead of the Tesla—and later when following another vehicle. The timing of the visual warning did not depend on the type of roadway being traveled. (See figure 9 for a graphic indicating the warning conditions and alert timing sequences for the Autopilot system firmware that was running on the Tesla at the time of the crash [firmware version 7.1].)

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[10] With respect to constraint (1), vehicles experience lateral acceleration when going around curves. Under lateral acceleration, drivers experience a feeling of being pulled to the outside of the curve. Autopilot uses lateral acceleration as an indication of the degree of curvature in the travel route.

[11] The lateral acceleration thresholds for Autopilot are linearly interpolated over a range of speeds.

[12] Torque is force applied to an object (in this case, the steering wheel) to make it rotate about an axis (the steering column). The weight of the hands on the steering wheel is sufficient to register as driver interaction.

[13] In the Autopilot system in use on the crash Tesla, this sequence could be repeatedly restarted by engaging with the steering wheel.

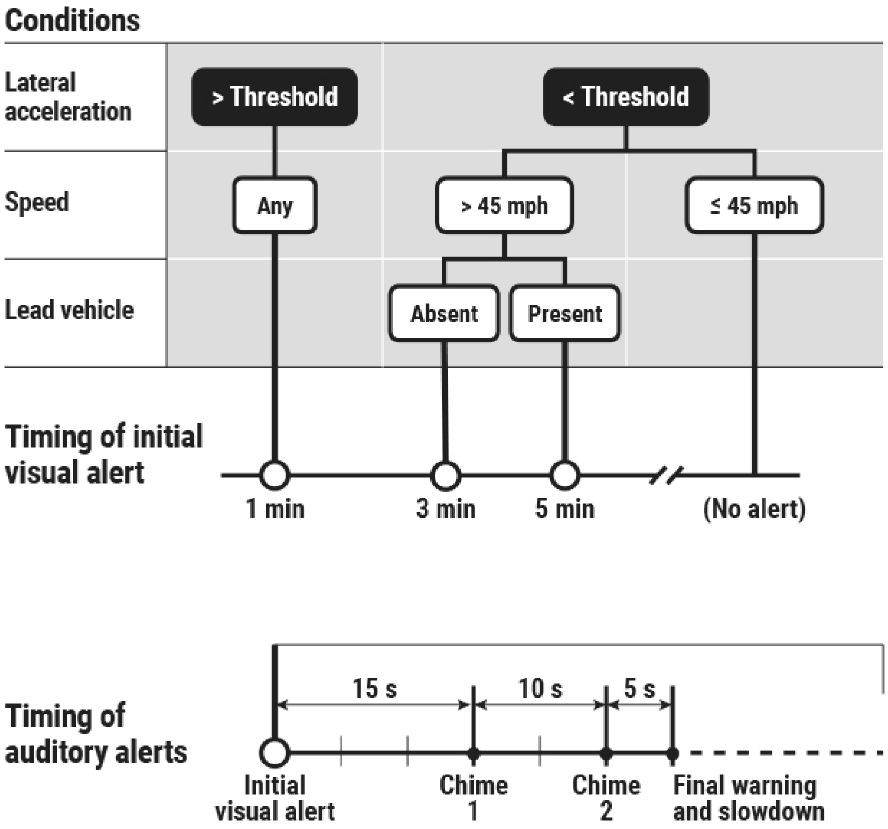

Figure 9. Autopilot system alert timing; top portion of figure provides timing of initial visual alert and bottom portion provides timing of auditory alerts. Following a visual alert, if the driver does not interact with the steering wheel, the Autopilot system proceeds to the auditory alert sequence as shown in the bottom portion of the figure (Tesla firmware version 7.1).

On the day of the crash, the Tesla driver was traveling from Cedar Key toward Ocala, Florida. (See figure 10 for route information.) He traveled along State Road 24 (SR-24) before turning eastbound onto US-27A, where the crash occurred.[14] SR-24 is a two-lane roadway without a center divider, and it is not a limited-access roadway.[15] Because it lacks a center divider, the Tesla's automation system considered SR-24 a "non-preferred" roadway for the use of Autopilot. The system allowed the Tesla to travel 5 mph above the speed limit while on SR-24; the speed limit on SR-24 is 60 mph. The roadway on which the crash occurred, US-27A, is a four-lane road with an earthen center median, but it is not a limited-access roadway.[16]

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[14] Tesla could not provide data to the NTSB on the car's route of travel. Investigators determined that the Tesla traveled on SR-24 based on the originating location, the limited options for the route of travel, the speed of travel, and turning information.

[15] Access control is a key factor in the functional classification of roads. All interstates are "limited-access" roadways, providing no access to abutting land users. Travelers use high-speed entrance and exit ramps to access limited-access roadways (Federal Highway Administration 2013, p. 14).

[16] Tesla uses a functional road classification system based on the HERE open location platform as the data source (accessed September 7, 2017). Road classification is discussed in section 1.6.3.

Figure 10. Route of the Williston car driver’s final trip.

The Tesla’s automation system considered US-27A a “preferred roadway”; consequently, the system would have allowed the Tesla to travel at speeds up to 90 mph while on US-27. According to vehicle data, about 2 minutes before the crash, while traveling on US-27A, the Tesla driver set the cruise speed to 74 mph. Because the Tesla was traveling on preferred roadway US-27A at that time, the vehicle’s actual velocity matched the driver-set cruise speed, which was 9 mph over the posted speed limit of 65 mph.

Soft Constraints. As a soft constraint to Autopilot use, Tesla provided written instructions in its owner’s manual about those types of roads on which Autopilot should and should not be used (Tesla 2016). The *Tesla Model S Owner’s Manual* stated that “Traffic-Aware Cruise Control is primarily intended for driving on dry, straight roads, such as highways and freeways” (p. 68). The manual also provided the following statement: “Warning: Do not use Traffic-Aware Cruise Control on city streets or on roads where traffic conditions are constantly changing and where bicycles and pedestrians are present” (p. 68). Similarly, with respect to the Autosteer system, the manual stated, “Warning: Autosteer is intended for use only on highways and limited-access roads with a fully attentive driver” (p. 74). In discussing restricted roads, the manual stated that “Autosteer is intended for use on freeways and highways where access is limited by entry and exit ramps” (p. 75). The manual also stated that “Autosteer is a hands-on feature. You must keep your hands on the steering wheel at all times” (p. 74).[17]

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[17] The 10-page-long section in the owner’s manual concerning driver assistance, which addresses TACC and Autosteer, contains 16 items designated as warnings and 4 items designated as cautions.

1.3.5 Tesla-Recorded Performance Data

The Tesla Model S stores data in nonvolatile memory using a removable secure digital (SD) card installed within the vehicle's electronic control unit (ECU). Parameter data are written continually to the ECU while the car is on. Typical parameters of vehicle system performance include steering angle, accelerator pedal position, driver-applied brake pedal application, vehicle speed, automated system states, and lead vehicle distance, among others. Some of these parameters are recorded continuously at a set sample rate; others are recorded only when the state of a system changes. All parameter data are timestamped using a global positioning system (GPS)-derived clock time as they arrive at the ECU.

The SD card typically maintains a complete record of all stored data for the vehicle's lifetime. Data from the SD card are episodically data-linked to Tesla using a virtual private network connection established via Wi-Fi or the vehicle's data-download capabilities. Any data stored since the last auto-upload event will exist only on the vehicle itself and must be recovered by the following means: (1) forcing an over-the-air upload, (2) using maintenance download equipment to connect directly to the vehicle, or (3) directly accessing the SD card after removing it from the dash-mounted electronics.

Tesla downloaded and provided to the NTSB parameter data for 53 distinct variables and text-based information related to 42 distinct error messages, covering a 42-hour period before the crash. In addition, image data from the vehicle's camera were recovered from the SD card.[18] However, the recovered image data did not contain information related to the crash.[19]

Figure 11 illustrates the periods of time during the crash trip when the driver interacted with the steering wheel. Vehicle performance data showed that for the 41-minute trip from Cedar Key, Autopilot was active for 37 minutes. During the trip, while Autopilot was in use, the system detected driver-applied torque on the steering wheel on seven different occasions for a total of 25 seconds. The longest period between alerts during which Autopilot did not detect the driver's hands on the steering wheel was nearly 6 minutes. For the entire trip, Autopilot was in some form of warning mode for a total of approximately 2 minutes.[20]

Vehicle-recorded data for the trip that originated in Cedar Key showed that the system displayed the initial visual warning to the driver seven times (displaying the text message "Hold Steering Wheel" on the instrument panel). The system progressed to the initial auditory warning (alert chime 1) six times during the trip. Progression to the second auditory warning (alert chime 2) did not occur during the trip, nor did the system initiate the Autosteer deactivation protocol.

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[18] By design, these data do not contain timestamp information.

[19] The stored images were consistent with an unrelated, noncrash event that preceded the crash.

[20] For more information about the recorded data, see the Driver Assistance System—Factual Report in the NTSB public docket case file HWY16FH018.

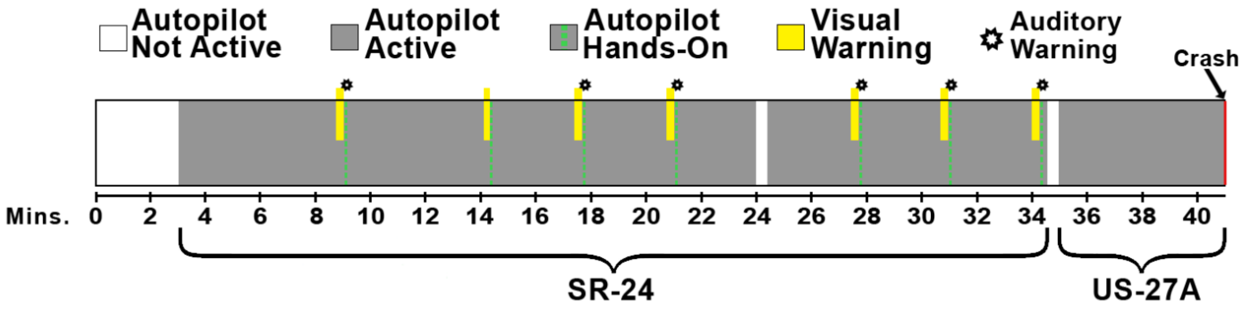

Figure 11. Chart showing how much time during the 41-minute crash trip that, while Autopilot was active, the driver had his hands on the steering wheel. Visual and auditory warnings are also indicated. (Timing provided is based on vehicle data and is approximate and relative.)

System Performance Data. The vehicle performance data revealed the following:

- The crash-involved Tesla's last trip began at 3:55:23 p.m. The car was stopped or nearly stopped about 4:19 p.m. and again about 4:30 p.m. The collision with the truck occurred at 4:36:12.7, as indicated by fault codes and system disruptions.
- The last driver input before the crash was to increase the TACC speed to 74 mph at 4:34:21, which was 1 minute 51 seconds before the crash. After that input, there was no driver interaction with Autopilot, no change in steering angle, and no brake lamp switch activation until the collision.
- During the last trip, TACC detected a vehicle ahead of the Tesla seven times. For the final 1 minute 35 seconds preceding the crash, TACC detected no lead vehicle in front of the Tesla.
- About 9.7 seconds before the collision, the motor torque demand steadily decreased (indicating that the vehicle was on a descending grade). The reported torque demand dropped to zero at the time of the first fault report.
- No brakes were applied before or during the collision.
- Vehicle headlights were not on at the time of the collision.
- The driver was wearing his seat belt during the trip.
- Throughout the approach to the collision with the truck, the electronic power assist steering exhibited no substantial changes in steering angle.
- There was no record indicating that the Tesla's automation system identified the truck that was crossing in the car's path or that it recognized the impending crash. Because the system did not detect the combination vehicle—either as a moving hazard or as a stationary object—Autopilot did not reduce the vehicle's speed, the FCW did not

provide an alert, and the AEB did not activate. All recorded data were consistent with the FCW and AEB systems being enabled when the crash occurred.[21]

Crash Event Data Recorder. The Tesla Model S involved in this crash did not have, nor was it required to have, an event data recorder (EDR).[22] As noted, it did have an ECU that recorded many vehicle performance parameters. Because there is no commercially available tool for retrieval and review of the ECU data, NTSB investigators had to rely on Tesla and its proprietary software to retrieve and interpret the data.

1.3.6 Postcrash Changes to Autopilot

Following the crash, Tesla made design changes to version 7.1 of its Autopilot firmware and hardware. On September 23, 2016, Tesla made a fleetwide firmware update to version 8. The firmware update affected the driver interface and warning logic.

Firmware version 8 reduced the period of time that the Autopilot system allows a driver to have hands off the steering wheel before being warned/alerted. Version 8 also provides that if the driver is warned on three separate occasions by alerts, Autosteer will deactivate and be unavailable for an hour or until an ignition restart. That firmware change also added a preferred road constraint to the alert timing sequence. In version 8, on preferred roads, no alerts are made when the vehicle is traveling below 8 mph; at speeds 8–45 mph, the first alert displays after 10 minutes of hands off the steering wheel; at speeds above 45 mph, the first alert timing for hands off the steering wheel depends on whether the system detects a vehicle ahead of the Tesla (alert displays in 3 minutes if there is a lead vehicle, but in 2 minutes if there is not). See appendix C for the alert timing sequence for Autopilot version 8.

1.4 Car Driver Information

The driver of the car was a 40-year-old male. Due to the requirements of his job, he traveled frequently. He had purchased the Tesla Model S new in 2015.

At the time of the crash, the driver held an Ohio Class D driver's license with motorcycle endorsement and no restrictions.[23] His license was renewed in February 2015 and had an expiration date in January 2019. Ohio Motor Vehicles records indicated that the driver had nine traffic violations between July 2010 and September 2015. Eight of those violations were for speeding, and one was for failing to obey a traffic signal.[24] The records indicated that the driver had not been involved in a reportable crash, and his license had not been suspended, revoked, or denied.

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[21] Although these systems can be deactivated by the driver, vehicle data indicated that they were enabled.

[22] An EDR is a device or function that records the vehicle's dynamic time-series data during the time just before a crash event (for example, vehicle speed versus time) or during a crash event (for example, delta–V versus time), intended for retrieval after the crash event. Title 14 *Code of Federal Regulations* Part 563 details the requirements for EDRs.

[23] Ohio Class A, B, and C licenses are commercial licenses. A Class D license is a noncommercial passenger class license; it can have a motorcycle endorsement or be a motorcycle-only license.

[24] The driver's last speeding ticket was issued in September 2015; he was ticketed for traveling 64 mph in a 35-mph zone.

1.4.1 Precrash Activities

The driver spent the week before the crash—May 1 to 7—with family members in Orlando, Florida. Family members reported that the driver had slept well throughout the vacation and appeared relaxed. They also stated that he left Orlando about 10:00 a.m. on May 7, headed to a job scheduled for later that day in Cedar Key, Florida. En route, he stopped in Ocala, Florida, to charge his electric car. After completing the job in Cedar Key, the driver sent his sister a text message to inform her that he was leaving to travel to the next job site, which was in Swamp Fox, North Carolina.

Postcrash review of the data from the Tesla showed that the car slowed to a near stop 6.4 minutes before the crash, at which point the driver assumed manual control of the vehicle. Autosteer was activated about 6.2 minutes before the crash. The reported average vehicle speed over this period indicates that Autosteer was activated about 6.7 miles before the crash, which would place the vehicle near the intersection with SR-24 in Bronson, Florida. US-27A through the intersection with SR-24 in Bronson is not configured as a divided highway. US-27A became a divided highway approximately 1.0 mile east of that intersection.

1.4.2 Health

According to his driver's license, the car driver was 5 feet 9 inches tall and weighed 190 pounds.[25] The driver's family stated that he did not drink alcohol or smoke and was in excellent health overall. The driver did not have a regular personal physician. Insurance records did not indicate that he had been prescribed any medications, and pharmacies near the driver's residence revealed no records of medications. At the NTSB's request, the Federal Aviation Administration (FAA) Civil Aerospace Medical Institute (CAMI) Bioaeronautical Sciences Research Laboratory performed a postcrash toxicological analysis of the driver's blood. The results were negative for alcohol and other drugs.[26]

1.4.3 Portable Electronic Devices

NTSB investigators located the car driver's cell phone, two laptop computers, and several other Internet-connected devices associated with his employment.[27] Investigators did not uncover evidence that any of the devices had been in use at the time of the crash. Due to damage, however, examination results were inconclusive for the cell phone and one laptop.

A review of the driver's cell phone records indicated that his first outgoing phone activity on May 7, 2016—the day of the crash—took place at 5:15 a.m. That morning, he had sent and received about 40 text messages by 10:00 a.m., the approximate time of his departure from Orlando. No phone activity took place between 10:00 a.m. and 1:00 p.m. The driver's phone

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[25] These data indicate he had a body mass index (BMI) of 29.8 (kg/m^2). An adult with a BMI over 25 is considered overweight; one with a BMI greater than or equal to 30 is considered obese.

[26] Analyses conducted by the laboratory detect amphetamines, opiates, marijuana, cocaine, phencyclidine, benzodiazepines, barbiturates, antidepressants, antihistamines, and commonly used prescription drugs.

[27] The cell phone and one laptop were found in the vehicle when it was inspected; a second laptop that had been returned to the family was provided to NTSB investigators.

records indicate that he received and sent text messages between 1:00 p.m. and 2:00 p.m., about the time he was completing the work at Cedar Key.

The driver's sister reported that she received a text message from the driver at 4:03 p.m. on the day of the crash, but investigators could not identify a device or time associated with that message. The driver's cell phone records do not indicate phone use for conversation or texting near the time of the crash.

1.5 Truck Driver, Motor Carrier, and Truck Information

This section addresses the commercial truck driver and his owner-operator trucking business.

1.5.1 Truck Driver

Background. The truck driver was a 62-year-old male, who was 5 feet 8 inches tall and weighed 246 pounds.[28] The truck driver refused interview requests from NTSB investigators, but his attorney provided some documentation. According to his attorney, for the 6 years preceding the crash, the truck driver had been the owner and sole operator of the motor carrier Okemah Express LLC.[29]

At the time of the crash, the truck driver had a Florida Class A commercial driver's license (CDL) without any endorsements or restrictions.[30] His CDL was renewed in November 2012 and had an expiration date in January 2021. His medical certificate was valid for 2 years, until September 28, 2017. According to the documentation of the September 18, 2015, medical examination he underwent for recertification for commercial driver fitness, the driver did not report having any medical conditions or using any medications.

An inquiry using the Commercial Driver's License Information System (CDLIS) revealed that the truck driver had three traffic violations while driving commercial motor vehicles—two from 2013 for failure to obey traffic control devices and one from 2015 for an improper lane change.[31] Additionally, the CDLIS report showed that his commercial driving privilege had been

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[28] NTSB investigators took the truck driver's height and weight data from his medical certification information. These data indicate that he had a BMI of 37.4 (kg/m^2). The FHP crash report indicates that the driver was 5 feet 10 inches tall and that he weighed 245 pounds, corresponding to a BMI of 35.2. An adult with a BMI over 25 is considered overweight; one with a BMI greater than or equal to 30 is considered obese.

[29] Motor carrier records indicate that the carrier operated under a different name from 2002 to 2005 with a principal place of business in Okemah, Oklahoma. In 2005, the carrier changed its name and corporate structure to Okemah Express LLC.

[30] A Class A CDL permits the driver to operate a tractor-trailer combination vehicle that has an actual weight, declared weight, or gross vehicle weight rating of 26,001 pounds or more, provided that the towed vehicle weighs more than 10,000 pounds.

[31] CDLIS is a nationwide computer system that enables state driver licensing agencies to ensure that each commercial driver has only one driver's license and one complete driver record. State driver licensing agencies use CDLIS to complete various procedures, including (1) transmitting out-of-state convictions and withdrawals, (2) transferring the driver's record when a CDL holder moves to another state, and (3) responding to requests for driver status and history.

withdrawn on five separate occasions since 1984.[32] His motor vehicle records indicated that he had not been involved in any other reportable crash.

A review of the truck driver's roadside inspection history showed that he had undergone 18 inspections in 10 state jurisdictions; 11 inspections found hours-of-service (HOS) violations. HOS violations for the carrier resulted in its being in HOS alert status from November 2010 to September 2011 and again from July 2012 until April 2015.[33] Based on this HOS alert history, the Federal Motor Carrier Safety Administration (FMCSA) issued the carrier a warning letter, dated March 25, 2011. The carrier's record-of-duty status for the 6 months before the crash indicated a continuing issue of noncompliance with the HOS requirements at 49 *Code of Federal Regulations* (*CFR)* Part 395.[34]

Precrash Activities. NTSB investigators used the truck driver's logbooks and cell phone records obtained through subpoena to reconstruct his activities before the crash. On the 3 days before the crash (Wednesday, May 4, through Friday, May 6), his phone activity began about 10:00 a.m. each morning and ended about 9:00 p.m., 4:00 p.m., and midnight, respectively.[35]

On the day of the crash, Saturday, May 7, the truck driver's logbooks show that he slept in the truck's sleeper berth from midnight to 8:00 a.m. During the day, the driver was involved in 31 phone calls and 4 text messages. By cross-referencing his logbook information with cell phone records, investigators determined that, while on duty and driving that day, the truck driver conducted 15 phone conversations and received 2 inbound text messages. His phone records do not show activity at the time of the crash.[36]

Postcrash Toxicology. The truck driver remained on scene, interacting with FHP officers and first responders, for more than 90 minutes following the crash. The FHP did not record any behavioral evidence of impairment. At FHP direction, a blood sample was obtained from the truck driver. According to the FHP Blood Withdrawal/Fatal Traffic Crash Checklist, on-scene paramedics drew blood from the truck driver approximately 1.5 hours after the crash (at 6:11 p.m. and 6:12 p.m. for two tubes). A portion of the sample was sent for toxicological analysis to the Florida Department of Law Enforcement laboratory. It tested positive for tetrahydrocannabinol (THC) and its metabolites, and negative for nine other common classes of abuse drugs. The laboratory's analysis of THC was considered by the State's Attorney, but the FHP Case Closing Report, dated December 18, 2016, resulted in a noncriminal traffic violation.

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[32] Violations for speeding or failure to comply with traffic control signage or devices occurred in 1984, 1991 (two violations), 2005, and 2013.

[33] To quantify operator performance, the Federal Motor Carrier Safety Administration Safety Measurement System uses data on a motor carrier based on roadside inspections (including all safety-based violations), state-reported crashes, and Federal Motor Carrier Census information. Unsafe carriers, which exceed the designated thresholds in the Behavior Analysis and Safety Improvement Categories (BASICs), are noted by alerts. For the two cited periods, the carrier had a BASIC alert in the HOS category.

[34] (a) The driver did not maintain any of the required documents mandated by the *Federal Motor Carrier Safety Regulations*. (b) Several months after the crash (in February 2017), the carrier received an FMCSA warning letter for an alert in the "Unsafe Driving" BASIC.

[35] See NTSB public docket case file HWY16FH018, HP Factual Report Attachment 7: Truck driver's motor vehicle records, and Attachment 8: Truck driver's cell phone records.

[36] The driver concluded a call at 4:11 p.m., about 25 minutes before the crash occurred.

That record of the investigation documented four FHP officers on scene and stated that the trooper responsible for overseeing the blood draw "did not observe any signs of impairment" in the truck driver.

NTSB investigators sent a portion of the blood sample to the FAA CAMI laboratory for further analysis. The laboratory identified 3.1 nanograms/milliliter (ng/mL) of THC and 66.2 ng/mL of tetrahydrocannabinol carboxylic acid (THC-COOH) in the sample. THC is the main psychoactive compound in marijuana; THC-COOH is its primary (inactive) metabolite. (The truck driver's drug use will be discussed further in section 2.3 of this report.)

Following the crash, US Department of Transportation (DOT) postcrash drug and alcohol testing was not performed. DOT regulations require a carrier to submit the crash-involved truck driver for drug and alcohol screening following certain types of crashes, including those that involve a fatality. The carrier did not comply with this regulation.[37]

1.5.2 Motor Carrier Operations

Okemah Express LLC was a "for-hire" carrier of general freight, fresh produce, grain, meat, and refrigerated food that operated with one vehicle and one driver. The company's primary place of business was Palm Harbor, Florida.

Okemah Express had six roadside or terminal inspections during the year preceding the crash (from May 2015 to May 2016). Those six inspections resulted in one driver out-of-service (OOS) violation and no vehicle OOS violations. The Motor Carrier Management Information System (MCMIS) profile indicated that the carrier had no DOT-reportable crashes in 2015.

At the time of the crash, the carrier's Safety Measurement System profile displayed no BASIC alerts. The carrier provided no driver qualification file and did not have records indicating that it maintained a drug testing program, as required by 49 *CFR* Parts 40 and 382.

The FMCSA did not perform a postcrash compliance review of Okemah Express.

1.5.3 Postcrash Inspection of the Truck-Tractor and Semitrailer

The FHP postcrash inspection of the 2014 Freightliner Cascadia truck-tractor did not reveal any mechanical issues. The truck-tractor was not damaged in the crash, and the FHP released it following postcrash inspection. By the time the NTSB investigation began, the truck-tractor was back in service and was not examined by NTSB investigators.

The engine of the 2014 Freightliner was managed by a Detroit Diesel Electronic Controller (DDEC) that could record certain data associated with vehicle operation. The FHP provided NTSB investigators with a copy of a report of a May 10, 2016, data download conducted

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[37] Title 49 *CFR* 382.303 details the requirements for postaccident drug and alcohol testing. Under this part, carriers who employ drivers who operate CDL-required commercial motor vehicles are subject to six testing procedures. Title 49 *CFR* 382.303(g)(1) and (2) allow a carrier to fulfill this requirement by obtaining the results of the tests conducted by federal, state, or local officials. The carrier did not receive any test results and did not qualify for exemption from the postaccident drug test requirement.

by a third party that accessed the DDEC control module. The report indicated that postcrash movement of the truck-tractor on May 8, 2016, made certain data associated with vehicle operation at the time of the May 7, 2016, crash event unavailable.

The FHP conducted a postcrash mechanical inspection of the 2003 Utility 3000R refrigerated semitrailer on May 12, 2016. That inspection identified missing and broken frame crossmembers and inoperable intermediate marker lamps. It also found an air leak at a connection between axles 4 and 5. No brakes were found to be out of adjustment.

NTSB investigators located the semitrailer, which Okemah Express had sold to a salvage yard following the crash, and inspected it on July 14, 2016. The inspection included visually examining its brake linings, air lines, and foundation brake components. All brake linings exceeded the minimum requirements of 0.25 inch. The thermoplastic emergency brake air line attached to the right side of the axle was worn through to the inner (second) color layer; this is an OOS condition, according to North American Standard Out-of-Service Criteria. The emergency brake hose, forward of the front axle, contained a non-DOT approved fitting. The semitrailer's suspension consisted of air springs, shock absorbers, cantilever arms, and solid axles; investigators identified no damage to the suspension.

The semitrailer did not have, nor was it required to have, side underride protection guards. In the United States, standards for side underride protection guards for trailers do not exist. European Union regulations address the performance of side guards on trailers; they are designed to protect vulnerable road users, such as pedestrians and bicyclists, from falling under the trailer and being caught in the wheels (United Nations Economic Commission for Europe 2004).

1.6 Highway Factors

1.6.1 Road Description and Characteristics

US-27A at the crash location is a rural four-lane road divided by a grassy median.[38] Travel lanes are 12 feet wide, and the median is approximately 60 feet wide. The left and right shoulders are about 2 and 5 feet wide, respectively. US-27A is not a limited-access roadway because it has intersections, business access, and private driveway access.[39]

According to the Florida Department of Transportation (FDOT), in the past 5 years, 84 crashes took place in the 10-mile segment of US-27A that centers on the intersection of US-27A and NE 140th Court; of those, 4 were fatal crashes involving 7 fatalities. Property-damage-only crashes accounted for 37 percent of the crashes. Seven nonfatal crashes occurred in close proximity to the intersection of US-27A and NE 140th Court; three of the seven crashes were designated as taking place at the intersection.

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[38] A median is the portion of the highway separating opposing directions of the travelway. Median width is expressed as the dimension between the edges of the traveled way, including the width of the shoulders, if any.

[39] A limited-access roadway has on-ramps and off-ramps to control the flow onto and off the roadway. On-ramps and off-ramps enable vehicles to merge into the traffic flow while traveling in the same direction as the main traffic flow. There is no crossing traffic on a limited-access roadway.

1.6.2 Road Geometry and Traffic Volume

The eastbound approach to the intersection exhibits a descending grade of about 2.15 percent. Based on highway profile plans from FDOT, the height of the grade crests approximately 1,132 feet west of the center of the NE 140th Court intersection. The grade descends for about 1,459 feet, leveling off about 327 feet east of the intersection. Farther east, the highway appears essentially level, although the profile plans indicate a very slight (0.08 percent) descending grade for at least another 2,400 feet. Other than the vertical curve, the highway is essentially straight for several miles east and west of the intersection.[40]

The average daily traffic for 2015 on US-27A was about 8,800 vehicles with a slightly higher percentage of traffic (about 5 percent more) traveling westbound. A speed study conducted on August 24, 2016, on US-27A for both east- and westbound traffic near the intersection with NE 140th Court found that the 85th percentile speed was 69 mph.[41] In 2003, this section of the roadway was reconstructed from a two-lane to a four-lane configuration with a design speed of 68 mph. It was resurfaced in 2013 to a design speed of 70 mph.[42] At the time of the crash, the posted speed limit was 65 mph.

A signal warrant analysis considered the traffic volume, turning movements, and pedestrian use of the crash intersection. With respect to whether US-27A at NE 140th Court should have been a signalized intersection, conditions at this location met none of the five applicable signal warrants in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (Federal Highway Administration [FHWA] 2009).

1.6.3 Road Classification

FDOT functionally classifies US-27A at the crash location as “rural principal arterial other,” which is a classification comparable to the American Association of State Highway and Transportation Officials (AASHTO) designation of “other principal arterial” (AASHTO 2011). This class of roadway provides direct access to cities and larger towns. According to AASHTO, the principal arterial system is stratified into three classifications: (1) interstate highways, (2) other freeways and expressways, and (3) other principal arterials. On rural arterial roadways, access to abutting land can be provided by driveways to specific parcels and at-grade intersections with other roadways (AASHTO 2011, pp. 1–9).

The functional classification of a roadway characterizes its design, including its expected speed and capacity. The six AASHTO categories are as follows: interstates, other freeways and expressways, other principal arterials, minor arterials, collectors, and local roads. Each classification can be subcategorized as urban or rural. The FHWA summarizes the relationship between the design concepts and the three broad categories of functional classification (FHWA 2013). With respect to traffic access, the first three AASHTO categories are described as follows:

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[40] The GPS coordinates for the crash area are 29.4106 N / -82.53979 W for the location of impact and 29.409516 N / -82.537291 W for the location of the car at rest.

[41] The 85th percentile speed is the speed at which 85 percent of the vehicle traffic is traveling either at or below.

[42] See FDOT State Project 34010-3539.

interstates—fully controlled; freeways and expressways—fully/partially controlled; and other principal arterials—partially uncontrolled.

The Tesla owner's manual included numerous statements that drivers should use Autopilot on highways and limited-access roads (as discussed in section 1.3.4). But the firmware's logic did not restrict the system's use based on functional road classification; the system had no hard constraint concerning road classification.

1.7 Regulation and Policy Concerning Automated Vehicles

Individual states are responsible for registering motor vehicles and regulating the operation of motor vehicles on public roads in their states. The National Highway Traffic Safety Administration (NHTSA) is responsible for setting safety standards for vehicle systems; however, many vehicle aspects are not covered by a Federal Motor Vehicle Safety Standard (FMVSS).[43] For new and developing technologies, manufacturers design and test new systems and determine when they will be added to the fleet. As a technology matures and enters fleet production, NHTSA may define an FMVSS for the system on new vehicles. For example, electronic stability control systems, which reduce loss of wheel traction, were first developed in the late 1980s and began to appear on new cars in the 1990s. After the systems had been demonstrated to be effective in reducing crashes, NHTSA established FMVSS 126 for electronic stability control systems for light vehicles, which required these systems for all such vehicles, effective September 1, 2011.[44]

1.7.1 Levels of Automation

The SAE has an On-Road Automated Driving Committee. In September 2016, that committee issued a revised *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*.[45] The revision incorporated lessons learned from both industry and government research groups, including the Automated Driving Applications and Technologies for Intelligent Vehicles (AdaptIVe) Consortium, the Crash Avoidance Metrics Partnership (CAMP), and the Automated Vehicle Research (AVR) Consortium (CAMP 2016).[46]

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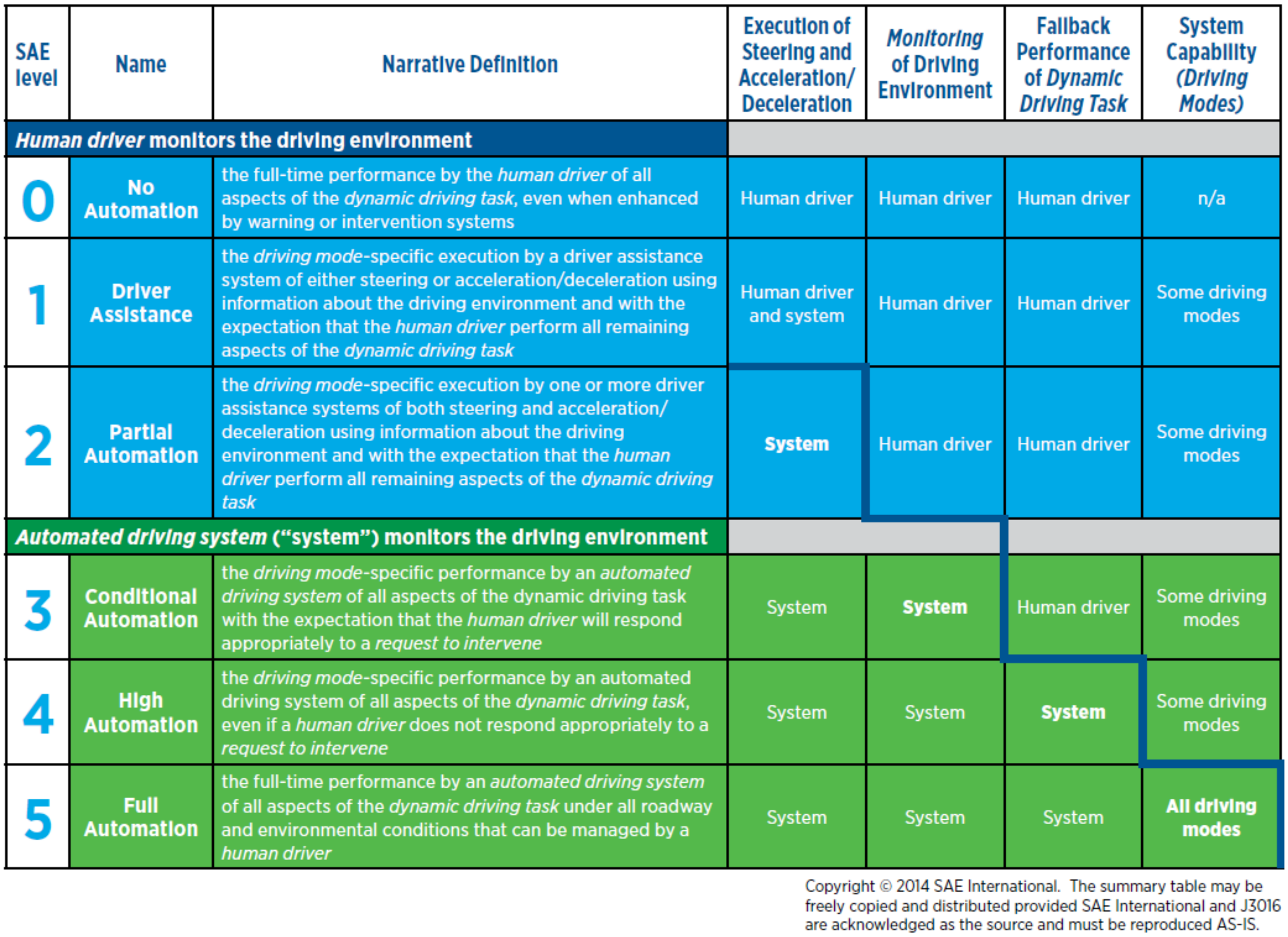
[43] The *Federal Motor Vehicle Safety Standards* (*FMVSSs*) are regulations specifying the design, construction, performance, and durability requirements for motor vehicles and regulated automobile safety-related components, systems, and design features. The requirements are specified in such a manner "that the public is protected against unreasonable risk of accidents occurring as a result of the design, construction, or performance of motor vehicles and is also protected against unreasonable risk of death or injury in the event accidents do occur." (See P.L. 89–563, 80 Stat. 718: National Traffic and Motor Vehicle Safety Act of 1966.)

[44] See 72 *Federal Register* 17236 (April 6, 2007), final rule amending 49 *CFR* Parts 571 and 585, *Federal Motor Vehicle Safety Standards*, "Electronic Stability Control Systems," docket no. NHTSA-2007-27662.

[45] See Surface Vehicle Recommended Practice J3016. The SAE first published SAE J3016, which was developed by the SAE On-Road Automated Driving Committee, on January 16, 2014. That 12-page standard provided detailed definitions only for the three highest levels of automation. The revised 30-page standard released on September 30, 2016, provided a taxonomy for all six levels of driving automation.

[46] (a) AdaptIVe is a consortium of 28 partners from 8 countries that was formed in 2014 and is supported by the European Union and the European Council for Automotive R&D EUCAR. See AdaptIVe project, accessed September 7, 2017. (b) CAMP originated as a partnership formed in 1995 between vehicle manufacturers Ford and General Motors to accelerate the implementation of crash avoidance countermeasures in cars. The consortium has since expanded to include Mercedes-Benz, Nissan, Toyota, and Volkswagen.

The revised taxonomy included definitions for six levels or degrees of driving automation, as shown in figure 12.



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 12. Summary of SAE taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. (Source: SAE International J3016 [SAE International 2016])

According to these definitions, the Tesla car involved in the Williston crash was equipped with a Level 2 automated driving system. Level 2 systems provide lateral control (lane-keeping or steering) and longitudinal control (adaptive cruise control or acceleration/deceleration). When operating a Level 2 vehicle, the driver is responsible for monitoring the driving environment.

1.7.2 Federal Automated Vehicles Policy

In September 2016, NHTSA issued its Federal Automated Vehicles Policy (AV Policy) as agency guidance (NHTSA 2016). The policy specifically incorporated the SAE's six-level taxonomy described above for levels of automation. Using the SAE levels, NHTSA drew a distinction between Levels 0–2 and Levels 3–5 based on whether the human operator or the automated system is primarily responsible for monitoring the driving environment. Vehicles in the second group (Levels 3–5) are referred to as highly automated vehicles (HAV).

For the purposes of this investigation, the following summary points characterize NHTSA’s AV Policy (NHTSA 2016):

- The AV Policy principally addresses HAVs—those vehicles in Levels 3–5—rather than focusing on those in Levels 0–2.
- Lower-level systems primarily rely on the human driver when active and operating; HAV systems do not. However, this distinction does not restrict manufacturers and other entities from applying the AV Policy guidance to the development, testing, and deployment of lower-level systems.
- HAV manufacturers should have a documented process for testing, validating, and collecting data from events, incidents, and crashes to record malfunctions, degradations, and failures in a way that can be used to understand and improve system performance.
    - For crash reconstruction purposes, the data should be stored, maintained, and readily available for retrieval by the manufacturer and NHTSA.
    - Enhanced EDRs would enable NHTSA to reconstruct the circumstances of crashes and gain an understanding of how an automated vehicle involved in a crash or incident sensed and responded to its driving environment immediately before and during the crash or near-crash event.

1.8 NHTSA Defect Investigation

On June 28, 2016, in response to the May 7, 2016, Williston crash, NHTSA’s Office of Defects Investigation (ODI) opened an investigation (PE 16-007) to consider whether the AEB and Autopilot systems on the Tesla Model S and Model X functioned as designed. The ODI examined the following: (1) AEB design and performance in Tesla vehicles and peer vehicles, (2) human-machine interface issues related to the Autopilot operating mode, (3) data from crash incidents related to Autopilot and AEB, and (4) postcrash changes that Tesla made to its Autopilot version 8 and AEB systems. On January 19, 2017, NHTSA issued an ODI Resume report stating that the preliminary evaluation was closed. The report stated, “NHTSA’s examination did not identify any defects in design or performance of the AEB or Autopilot systems of the subject vehicles [2014–2016 Tesla Model S and Model X] nor any incidents in which the systems did not perform as designed.” The report further stated that “AEB systems used in the automotive industry through MY 2016 [model year 2016] are rear-end collision avoidance technologies that are not designed to reliably perform in all crash modes, including crossing path collisions.” (NHTSA 2017, p. 1)

The ODI report also referenced past NHTSA research. Beginning in 2007, NHTSA began to develop test methods for assessing the effectiveness of crash-imminent braking systems (Carpenter and others 2011). The four-phase project (1) used crash reports to identify crash scenarios to develop preliminary functional requirements; (2) developed system and component performance capabilities and identified target systems for testing; (3) developed, demonstrated, and validated tests; and (4) developed benefits estimations. The project identified eight vehicle-to-vehicle (V2V) crash types. The project could not demonstrate and validate two types of scenarios—straight crossing path events and left turn across path events; these two scenarios are the crash types most closely associated with the Williston crash sequence. The ODI investigation surveyed a dozen automated system manufacturers and several suppliers; none indicated that their AEB systems through model year 2016 were designed to brake for crossing path collisions (NHTSA 2017, p. 3).

2 Analysis

2.1 Introduction

2.1.1 Automated Vehicle Control Systems

For mass market vehicles in diverse driving environments, it has proven difficult to automate the full range of driving tasks. Automated vehicle control systems must be designed to handle both the common, expected control tasks encountered by human drivers and the unexpected and unusual tasks as well. Functionally, automated vehicle control systems detect and respond to objects and events, but the current systems have operating limitations with respect to the types of situations they can handle reliably and well. Such limitations are associated with the conditions in which the automated system is intended to operate.

Level 2 automated systems simultaneously control lateral lane-keeping movements and longitudinal vehicle following distances.[47] Level 2 systems can execute steering and acceleration/deceleration tasks, but the degree of automation is, by definition, partial.

Automated vehicle control systems can operate a vehicle on the road, but in certain situations, the existing systems have significant limitations that require driver intervention. Although system designers understand the limits of partial automation, the driving public may not.[48] Eventually, as highway vehicles progress through increasing degrees of automation and incorporate additional technological advances, vehicle engineers will shift the driving responsibility from the human driver to a fully autonomous system. But until automated vehicle systems mature, driver engagement remains integral to the automated driving system.

2.1.2 Structure of the Analysis

The Analysis begins with an account of several factors that did not affect the crash (section 2.2). A section discussing the truck driver's use of drugs follows this material (section 2.3). Then, the Analysis discusses the safety issues identified in this investigation, organized into sections as follows:

- Operational design domains for SAE Level 2 vehicle automation (section 2.4),
- Surrogate means of determining the automated vehicle driver's degree of engagement (section 2.5),
- EDRs for automated vehicles (section 2.6),

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[47] Intelligent cruise control systems in recent vehicle models provide Level 1 driver assistance capability.

[48] *Consumer Reports* reviewed 280 model year 2017 vehicles and included an "Alert" for 14 models, stating that "This vehicle can be outfitted with a semiautonomous driving package. *Consumer Reports* believes automakers should take stronger steps to ensure that vehicles with these systems are designed, developed, and marketed safely. Please heed all warnings and keep your hands on the wheel" (*Consumer Reports* 2017).

- Safety metrics and exposure data for automated vehicles (section 2.7), and
- Connected vehicle technology and V2V requirements (section 2.8).

2.2 Factors Not Affecting the Crash

2.2.1 Driver, Vehicle, and Highway Factors

The following bulleted statements relate to the drivers:

- Based on cell phone records, work schedules, and witness accounts, investigators found no evidence of fatigue for either driver.
- Although the truck driver had engaged in numerous cell phone conversations while driving in the hours before the crash, investigators discovered no evidence that he was distracted by cell phone use at the time of the crash.
- Both drivers held valid driver's licenses, and the truck driver had a current medical certificate.
- Based on toxicological analysis, the car driver was not impaired by alcohol or other drugs.

The following bulleted statements relate to the vehicles involved in the crash and the roadway they were on at the time of the crash:

- Investigators found no mechanical problems that would have affected either vehicle's handling or stopping performance.
- Investigators found no evidence of precollision roadway marks, such as would be associated with evasive maneuver by the eastbound Tesla; moreover, no record in the Tesla's performance data indicated that the vehicle systems or the driver initiated braking or steering input immediately before the crash.
- Investigators conducted a signal warrant analysis of the crash intersection. Neither the road design of nor the levels of traffic on US-27A at the intersection of NE 140th Court warranted a traffic signal.

The NTSB concludes that no investigative evidence indicates that either driver was fatigued, that cell phone use distracted the truck driver, that the car driver was impaired by alcohol or other drugs, that any mechanical system on either vehicle failed, or that the highway design was inappropriate; consequently, these were not factors in the crash.

2.2.2 Sight Distance

Highway Features. The highway had a heading that was straight, but the line of sight available to opposing drivers operating near the intersection was affected by a vertical crest in the road west of the intersection.[49] Using highway profile data provided by FDOT and applicable AASHTO intersection sight distance calculation methodology, the sight distance for the truck driver was calculated at 1,132 feet, as measured from the area of impact (AASHTO 2011).[50] Based on the Tesla's 74-mph approach speed and the calculated line-of-sight distance, both drivers could potentially have had up to 10.4 seconds to observe and respond to one another.[51]

According to FDOT, the highway design speed was 70 mph. For left-turning combination vehicles, AASHTO guidelines recommend intersection sight distances of 781 and 842 feet for highway design speeds of 65 and 70 mph, respectively. Those distances are based on a minimum gap time of 8.2 seconds (7.5 seconds for a combination vehicle plus 0.7 second for crossing the additional through lane).[52] Therefore, the calculated sight distance of 1,132 feet for the truck driver exceeded the minimum sight distance that AASHTO recommends for a roadway of this design speed.

The median crossover associated with the intersection had an opening along the distance of the travelway that provided sufficient area to safely "store" the 72-foot-long combination vehicle.[53] The highway configuration should not have influenced the truck driver to hurry through the turn.

Witness Account. A witness who had been traveling westbound on US-27A behind the crash-involved truck said that he saw the truck in the left turn lane at the intersection. The witness described seeing the eastbound Tesla crest the grade before the truck began its left turn. He said he saw the Tesla for several seconds before the semitrailer blocked his view of the car.

The witness described reaching the westbound left turn lane for the intersection after the impact occurred. The witness said he was traveling about 60 mph. The fact that the witness had time to slow his speed, make a U-turn at the intersection, and follow the Tesla on its postimpact route suggests that he was traveling about 0.25 mile behind the truck, which could explain why he could not be sure whether the truck only slowed or came to a full stop in the turn lane before

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[49] The eastbound approach to the intersection has a descending grade of approximately 2.15 percent.

[50] AASHTO guidelines recommend an average eye height of 7.6 feet for truck drivers. A target height of 3.5 feet is recommended for passing and intersection sight distances.

[51] Two additional line-of-sight distances were considered. The truck driver began his turn from the westbound turn lane from an estimated position that would have involved a slightly longer sight distance. The Tesla driver's sight distance would have been slightly shorter because his height was lesser. Because of the known travel time for the Tesla along the eastbound roadway, and because that was a median of the possible calculations, the discussion used that distance to impact. The choice of calculation had no appreciable effect on the calculated response time of 10.4 seconds.

[52] See AASHTO 2011, table 9-13, "Gap Time for Left Turn from Major Road."

[53] Dimensions are based on 3D scanning of the highway. The median left turn lane is an auxiliary lane for left-turning vehicles. The median, left turn lane, and shoulders totaled 78 feet in width. (See AASHTO 2011, section 9.8.2, for minimum designs for median openings.)

turning through the intersection. The witness saw no obstructions to the lines of sight for the two vehicle drivers and said that sun glare was not a problem.

Based on the foregoing information concerning the car speed, the highway features and design, and the witness's report of the vehicles' locations and movements preceding the crash, the NTSB concludes that there was sufficient sight distance to afford time for either the truck driver or the car driver to have acted to prevent the crash.

In the context of right of way, the truck driver had the duty to yield to the Tesla.[54] Following the crash, the FHP cited him for failure to yield.

2.2.3 Side Underride Protection

The semitrailer of this truck did not have, nor was it required to have, side underride protection guards. European regulations concerning underride protection do not address impact by a vehicle. Thus, even if the semitrailer had been equipped with side underride guards designed to the European regulations, they would not have significantly mitigated the severity of the crash. Although research into the potential benefits of trailer side guards designed for vehicle impacts has indicated some benefit achieved by their reducing the incompatibility between passenger cars and trailers (Brumbelow 2012), guards designed to prevent passenger vehicle underride are typically tested at 56 kilometers per hour (35 mph). Given that the Tesla struck the semitrailer at 74 mph—more than double the test speed—it is unlikely that the injury outcome of the crash would have been significantly improved by side underride guards on the semitrailer.

2.2.4 Forward Collision Warning and Automatic Emergency Braking

On the 2015 Tesla Model S, the FCW/AEB system uses vehicle-resident camera and radar sensors and computer processing to provide warnings to the driver and to activate braking to prevent or mitigate an imminent crash. The system is designed to recognize and detect slow, stopped, and decelerating vehicles when they are traveling ahead of the Tesla in the same lane. TACC, when enabled, incorporates an AEB feature that can respond to an object that the camera system detects in the Tesla's path but cannot classify as a vehicle. Such an unclassified object in the path of the Tesla must be detected by both the camera and the radar for the AEB to activate.

A postcrash review of the Tesla's performance data determined that no status messages indicated that AEB or FCW was disabled during the last trip segment. The recorded data showed no indication of an FCW event, an AEB event, or any other event indicating detection of a vehicle or an object at or just before the time of the crash. The NTSB concludes that the Tesla's automated vehicle control system was not designed to, and did not, identify the truck crossing the car's path or recognize the impending crash; consequently, the Autopilot system did not reduce the car's velocity, the FCW system did not provide an alert, and the AEB did not activate.

Current Level 2 vehicle automation technologies cannot reliably identify and respond to crossing vehicle traffic. NHTSA's ODI report on the Tesla Models S and X, which was prompted by the Williston crash, states: "None of the companies contacted by ODI indicated that AEB

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[54] See Florida State Statute 316.123—"Vehicle Entering Stop or Yield Intersection," accessed September 7, 2017.

systems used in their products through MY 2016 production were designed to brake for crossing path collisions" (NHTSA 2017, p. 3). As part of its defect investigation, NHTSA conducted a series of test-track-based AEB evaluations on the Tesla Model S, as well as a peer vehicle system.[55] The testing confirmed that the Tesla AEB system avoided crashes for the majority of rear-end scenarios, and its TACC generally provided enough braking to avoid rear-end crash scenarios; but neither test vehicle effectively responded to "target vehicles" in straight crossing path or left turn across path scenarios. NHTSA concluded that there was no defect in the design of the Tesla crash avoidance and mitigation systems.

2.3 Truck Driver Drug Use

The FHP had a blood sample taken from the truck driver following the crash. Law enforcement's toxicological analysis of the sample was positive for THC, the active ingredient in marijuana. A portion of that blood draw was also sent to the FAA CAMI laboratory for analysis; it also tested positive for THC, at 3.1 ng/mL.

According to 21 *United States Code* Section 812, marijuana is a Schedule I controlled substance. Although some states and the District of Columbia permit its use for medicinal and recreational purposes, it is unacceptable for any safety-sensitive employee subject to DOT drug regulations to use marijuana.[56] Florida has no current statute regarding the level of THC that indicates impairment.[57]

THC has mood-altering effects that may include euphoria, relaxation of inhibitions, disorientation, time/image distortion, and psychosis. Significant performance impairments are usually observed for at least 1–2 hours following marijuana use, and residual effects have been reported for up to 24 hours.[58] Blood THC levels peak during the act of smoking and then decline rapidly as the drug is distributed into highly vascular tissues, including the brain. The rate of decline then slows as THC is absorbed into adipose tissue. In one study, peak THC plasma levels in six volunteers averaged 84 ng/mL (range 50–129 ng/mL) at an average of 8.4 minutes after beginning to smoke a cigarette containing 15.8 milligrams of THC (the volunteers were allowed 11 minutes to smoke the cigarette). By 3.0 hours after beginning to smoke, volunteers' THC levels averaged 1.2 ng/mL (Huestis, Henningfield, and Cone 1992).

THC metabolism varies among individuals and is also influenced by the chronicity of its use. Terminal half-life, a measure of the amount of time for half of a drug to be eliminated after the initial rapid distribution is complete, ranges from 20–57 hours for infrequent users and from 3–13 days for regular users after smoking (Wall and Perez-Reyes 1981, Agurell and others 1986). Part of the reason for this disparity is that THC and its metabolites accumulate in adipose tissue and are then released slowly back into the bloodstream. Chronic marijuana-using volunteers

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[55] The peer vehicle was the 2015 Mercedes C300 4Matic.

[56] See DOT "Medical Marijuana" Notice and DOT "Recreational Marijuana" Notice, both accessed September 7, 2017.

[57] See Governors Highway Safety Association webpage on drug-impaired driving laws by state, accessed September 7, 2017. (Website is updated when states report changes.)

[58] See NHTSA factsheet on marijuana, accessed September 7, 2017.

confined to a secure facility to ensure abstinence have been found to have THC levels as high as 2 ng/mL after as many as 7 days of abstinence (Bergamaschi and others 2013).

Using a single determination of THC level following a crash to extrapolate back to a smoker's THC level at the time of the crash is difficult, unless the timing of the last dose is known. The task is particularly complex when the tested level is below 5 ng/mL, as was the case with the Williston truck driver (Hartman and others 2016). In addition, most studies have been performed with drivers who have been smoking marijuana rather than ingesting it. The variation in absorption from the gut, as well as differences in metabolism for ingested marijuana, make extrapolating backward even more difficult for users who have ingested, rather than smoked, the drug. In the case of the Williston truck driver, the NTSB does not know how he used marijuana or when he last did so before the crash. The truck driver did not exhibit impaired behavior to FHP officers or other first responders following the crash. The FHP Case Closing Report for this crash stated that the trooper overseeing the blood draw "did not observe any signs of impairment" in the truck driver. Therefore, the NTSB concludes that, although the results of postcrash drug testing established that the truck driver had used marijuana before the crash, his level of impairment, if any, at the time of the crash could not be determined from the available evidence.

2.4 Operational Design Domains for Level 2 Vehicle Automation

In September 2016, NHTSA released its AV Policy, which characterizes how it will address increasing levels of vehicle automation, focusing on HAVs in the SAE categories defined as Level 3, Conditional Automation; Level 4, High Automation; and Level 5, Full Automation (NHTSA 2016).[59] Manufacturers are not required to follow the vehicle performance guidance in the AV Policy, but it provides a framework for operation, testing, and safety assessment of vehicle automation.

With respect to vehicles with no or limited automation (Levels 0–2), the AV Policy gives some guidelines for Level 3–5 systems that could apply to Level 2 systems, but it does not provide vehicle performance guidance explicitly for Level 2 systems, such as those on the Tesla involved in the Williston crash. Regarding the features and qualities necessary for all vehicle automation systems, the AV Policy states—

> Most of the Guidance elements and considerations specified under the cross-cutting areas of Vehicle Performance Guidance for HAVs, such as "Data Recording and Sharing," "Privacy," "System Safety," "Vehicle Cybersecurity," "Human Machine Interface," "Crashworthiness," and "Consumer Education and Training" should generally apply to the full spectrum of automated vehicle systems.

Addressing the need for driver involvement in vehicle automation systems, the AV Policy states—

> There is a clear technical distinction between HAV systems (those classified as SAE Level 3, Level 4, and Level 5) and lower levels of automation (SAE Levels 2

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[59] See AV Policy, accessed August 21, 2017. Also, see figure 12 of this report for the SAE automation levels.

and below) based on whether the automation system relies on the human driver when engaged and operating.

The AV Policy includes within its framework guidance specific to HAV systems. It states that "The Operational Design Domain (ODD) concept, Object and Event Detection and Response (OEDR) and associated tests and validation methods discussed in this Guidance are primarily focused on HAV systems (those classified as SAE Level 3, Level 4 and Level 5)."

The ODD refers to the conditions in which the automated system is intended to operate. Examples of such conditions include roadway type, geographic location, clear roadway markings, weather condition, speed range, lighting condition, and other manufacturer-defined system performance criteria or constraints. In the case of an automated lateral control system that cannot detect crossing-path traffic, such as Autopilot, the manufacturer may establish an ODD for limited-access roadways and design the system so that the vehicle will not permit activation of the automated control system unless that ODD is met.

The ODD concept is as important for Level 2 vehicle automation as it is for the HAVs in Levels 3–5. That is, Level 2 automated systems have more operational design limitations than HAVs do and so should also limit system operation to the manufacturer's designated ODDs. The Insurance Institute for Highway Safety recognized the importance of ODDs in its comments on the AV Policy, as follows: "Driving automation systems should self-enforce their use within the operational design domain rather than relying on users to do so" (Kidd 2016).

As detailed in section 1.3.4 of this report, Tesla constrained Autopilot operation based on seat belt use, speed, and the presence of a lead vehicle. The owner's manual stated that Autopilot should only be used in preferred road environments, but Tesla did not automatically restrict the availability of Autopilot based on road classification. The driver of the Tesla involved in the Williston crash was able to activate Autopilot on portions of SR-24, which is not a divided road, and on both SR-24 and US-27A, which are not limited-access roadways.[60] Simply stated, the driver could use the Autopilot system on roads for which it was not intended to be used.

Tesla's manufacture of cars equipped with Autopilot preceded NHTSA's issuance of its AV Policy, and that policy applies to SAE Levels 3–5 rather than Level 2 automated vehicles, but Tesla clearly understands the ODD concept and advised drivers to use the Autopilot systems only on limited-access roadways. Following the crash, Tesla modified its Autopilot firmware to add a preferred road usage constraint, which affects the timing of the hands-off driving alert. But despite these modifications, a Tesla driver can still operate Autopilot on any roads with adequate lane markings.

Today's vehicle automation systems can assess the vehicle's route and determine whether it is appropriate to the system's ODD.[61] But Tesla's Autopilot remains available to the driver, even

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[60] Postcrash data show that the driver had the cruise speed set to 70 mph for almost 29 minutes before he turned off non-preferred roadway SR-24 onto US-27A. Moreover, he activated Autosteer about 6.18 minutes before the crash event, which, based on speed and distance data, would have placed the car on a portion of US-27A that is not configured as a divided highway.

[61] Tesla's Autopilot system uses vehicle GPS data, commercially available road data, and camera recognition of speed signs to determine the type of road and the speed limit of the roadway on which the vehicle travels.

under some conditions that do not meet its ODD. This situation allows the driver to activate automated systems in locations and circumstances for which their use is not appropriate or safe. The NTSB concludes that if automated vehicle control systems do not automatically restrict their own operation to those conditions for which they were designed and are appropriate, the risk of driver misuse remains. Therefore, the NTSB recommends that manufacturers of vehicles equipped with Level 2 vehicle automation systems incorporate system safeguards that limit the use of automated vehicle control systems to those conditions for which they were designed. The NTSB further recommends that NHTSA develop a method to verify that manufacturers of vehicles equipped with Level 2 vehicle automation systems incorporate system safeguards that limit the use of automated vehicle control systems to those conditions for which they were designed. Finally, to ensure that vehicle manufacturers that do not currently produce vehicles equipped with Level 2 automation but may do so in the future are aware of the significance of this issue, the NTSB recommends that the Alliance of Automobile Manufacturers and the Association of Global Automakers notify their members of the importance of incorporating system safeguards that limit the use of automated vehicle control systems to those conditions for which they were designed.

2.5 Surrogate Means of Determining the Automated Vehicle Driver's Degree of Engagement

Based on system design, in an SAE-defined Level 2 automated vehicle, it is the driver's responsibility to monitor the automation, maintain situation awareness of traffic conditions, understand the limitations of the automation, and be available to intervene and take over for the system at any time. In practice, however, human drivers have cognitive limitations that make fulfilling this responsibility difficult because people are poor at monitoring automation and do not perform well on tasks requiring passive vigilance (Parasuraman, Molloy, and Singh 1993; Parasuraman and Riley 1997; Moray and Inagaki 2000; and Parasuraman and Manzey 2010). Moreover, there is evidence that drivers lack a complete understanding of advanced automation systems, including their functionality and limitations (McDonald and others 2016).

Manufacturers try to make systems safer by encouraging driver engagement through the incorporation of design solutions that monitor driver behavior and issue warnings when engagement seems lacking. Several vehicle models with Level 2 automated systems use steering wheel torque to monitor driver engagement.[62] However, driving is a highly visual task, so the driver's touching the steering wheel may not accurately indicate that he or she is fully engaged with the driving task. Simply checking whether the driver has placed a hand on the steering wheel gives little indication of where the driver is focusing his or her attention.[63] The NTSB concludes that because driving is an inherently visual task and a driver may touch the steering wheel without visually assessing the roadway, traffic conditions, or vehicle control system performance,

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[62] Examples of such vehicles with Level 2 automation other than Teslas include the Infiniti Q50, Mercedes-Benz S65, BMW 50i, Audi A7, and Volvo XC60.

[63] In the event of an incapacitated driver, the system slows the vehicle to a stop in its travel lane and activates the hazard flashers. We anticipate that more advanced future systems will remove the vehicle from the travel lane before stopping it.

monitoring steering wheel torque provides a poor surrogate means of determining the automated vehicle driver's degree of engagement with the driving task.

On-road driver behavior has been the subject of substantial naturalistic driving research. Currently, the Virginia Tech Transportation Institute (VTTI) is conducting a naturalistic driving study using vehicles with Level 2 automation capabilities from five different manufacturers.[64] Data from both forward- and driver-facing cameras are being collected to better understand driver behavior. A similar study, conducted by Volvo, is underway in Sweden.[65] These longer-term naturalistic studies are essential to understanding drivers' interactions with automated systems and the extent to which they may misuse them. These studies also address different approaches to system monitoring, such as the use of eye-tracking cameras, which have long been used in driving simulation research. Toyota has deployed an eye-tracking system on its Lexus brand vehicles, and Volvo has announced plans to use eye-tracking technology in its Driver State Estimation system. The Driver Attention System on the 2018 Cadillac CT6 Super Cruise vehicle uses a small camera located at the top of the steering column; the camera focuses exclusively on the driver and uses infrared light to track the driver's head position.

The time intervals permitted before an automated system issues an alert are a vital component of the monitoring system. Although the operational design of the Tesla Autopilot requires an attentive driver as an integral system element, the Autopilot on the Williston crash vehicle allowed the driver to operate in the automated control mode for almost 6 minutes, during which the system did not detect the driver's hands on the steering wheel.[66] In fact, of the 37 minutes in which the Tesla driver operated the vehicle in the automated control mode during the crash trip, the system detected his hands on the steering wheel for only 25 seconds. Investigators found no indication in recorded vehicle data that the Tesla driver attempted to take any action (by braking or steering) to prevent crashing into the semitrailer or that he was even aware of the impending crash.

The hands-off warning interval has been under consideration elsewhere in the world, particularly in Europe. The United Nations Economic Commission for Europe adopted a new regulation pertaining to hands-off warning time in lane-keeping systems. This regulation, which is expected to go into effect in the first quarter of 2018, would require lane-keeping systems to provide an initial visual warning after 15 seconds of hands-off driving and deactivate in a controlled manner after 1 minute of hands-off driving.

To summarize the discussion of the Williston crash driver's actions before the crash, he used the Autopilot system on roadways for which it was not designed (section 2.4) and had extended periods of hands-off driving and other indications of lack of engagement/awareness before the crash (section 2.5). Both driver behaviors strongly indicate that, although the Tesla

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[64] (a) In 2005, the VTTI *100-Car Naturalistic Driving Study* was completed. The study was sponsored by NHTSA, Virginia Tech, the Virginia Department of Transportation, and the Virginia Transportation Research Council. (b) The current naturalistic driving project is the *VTTI Center for Automated Vehicle Systems Study of Level 2 Automation*.

[65] In January 2017, Volvo began recruiting volunteers to participate in this study. Additional information can be found at Volvo driving project, accessed June 19, 2017.

[66] Firmware changes to the Autopilot system issued in September 2016 shortened the alert timeframe and altered the alert sequence. The postcrash changes are discussed in appendix C.

owner's manual provided information and warnings on these subjects, the driver either did not know of or did not heed the guidance in the manual. Therefore, the NTSB concludes that the Tesla driver's pattern of use of the Autopilot system indicates an overreliance on the automation and a lack of understanding of system limitations. Also, the NTSB concludes that the Tesla driver was not attentive to the driving task, but investigators could not determine from the available evidence the reason for his inattention.

Based on the lack of response from the Tesla's driver before the impact with the truck and data indicating extended periods of hands-off driving, the NTSB further concludes that the way that the Tesla Autopilot system monitored and responded to the driver's interaction with the steering wheel was not an effective method of ensuring driver engagement. Therefore, the NTSB recommends that manufacturers of vehicles equipped with Level 2 vehicle automation systems develop applications to more effectively sense the driver's level of engagement and alert the driver when engagement is lacking while automated vehicle control systems are in use.

2.6 EDRs for Automated Vehicles

The final rule on EDRs (49 *CFR* Part 563) published in August 2006 sets forth requirements for data elements, data capture and format, data retrieval, and data crash survivability for EDRs installed in light vehicles manufactured on or after September 1, 2012.[67] The regulation does not mandate the installation of EDRs in light vehicles; rather, if the vehicle manufacturer chooses to install an EDR, the regulation defines the format and specifies the requirements for providing commercially available tools and/or the methods for retrieving data from the EDR in the event of a crash.

NHTSA estimated that as of vehicle model year 2010, about 92 percent of light vehicles had EDRs that met the regulatory standard.[68] Since then, many vehicle manufacturers have begun to design and develop automated control systems that have special data collection capabilities that do not necessarily comply with EDR requirements. Because of these innovations, the proportion of light vehicles not equipped with EDRs meeting the specifications of 49 *CFR* Part 563 has been increasing.

Vehicle manufacturers have a robust proprietary interest in capturing and maintaining their own fleet data so that the information can be used to improve the active safety systems and designs of future vehicle control systems. But even if current and future models of HAVs record the 15 data parameters defined more than a decade ago in 49 *CFR* Part 563, those data now are inadequate to comprehend even the simplest questions of who/what controlled an automated vehicle at the time of a crash.

For example, the Tesla Model S involved in this crash recorded substantial parameter data, but the methodology by which the car recorded that data did not meet, nor was it required to meet, the Part 563 definition of an EDR. As a result, the data recorded by the ECU on the Tesla could

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[67] The EDR requirements apply to "light vehicles" required to have frontal airbags—those with a gross vehicle weight rating of 3,855 kilograms (8,500 pounds) or less and an unloaded vehicle weight of 2,495 kilograms (5,500 pounds) or less.

[68] See 77 *Federal Register* 74146.

be retrieved only by Tesla; there is no commercially available tool for retrieval and review of these Tesla data. Other manufacturers of vehicles with automated systems similarly control access to the postcrash proprietary information associated with their vehicles. The NTSB concludes that, without the manufacturer's involvement, vehicle performance data associated with highly automated systems on vehicles involved in crashes cannot be independently analyzed or verified.

As more manufacturers deploy automated systems on their vehicles, to improve system safety, it will be necessary to develop detailed information about how the active safety systems performed during, and how drivers responded to, a crash sequence. Manufacturers, regulators, and crash investigators all need specific data in the event of a system malfunction or crash. Recorded data can be used to improve the automated systems and to understand situations that may not have been considered in the original designs. Further, data are needed to distinguish between automated control actions and driver control actions. All these crucial data must be reflected in the required recording parameters.

NHTSA's recently issued AV Policy recognizes the need for enhanced EDRs. The policy states that "When HAVs experience incidents or crashes, records and reports about those problems and manufacturer response actions would facilitate identification of problem causes" (NHTSA 2016). It also says that "When crashes or near crashes occur, the best source of information for learning the underlying causes will be the vehicle itself." The policy further states that—

> NHTSA believes enhanced event data recorders would be useful to allow the Agency to reconstruct the circumstances of crashes and to gain an understanding of how a vehicle involved in a crash or incident sensed and responded to its driving environment immediately before and during the crash or near crash.

NHTSA's AV Policy calls for automated vehicle control systems to be equipped with the tools needed to provide the data necessary for external safety oversight—recordkeeping/reporting and enhanced data collection tools. The NTSB also needs access to such data to perform our investigative work. The NTSB concludes that a standardized set of retrievable data is needed to enable independent assessment of automated vehicle safety and to foster automation system improvements.

The NTSB, NHTSA, the Institute of Electrical and Electronics Engineers, and the SAE have long histories of working on standards and regulations for EDRs on light vehicles, heavy vehicles, and buses.[69] Over time, the associated crash data that have been collected from state-of-the-art EDRs have provided manufacturers, researchers, and regulators with science-based means of understanding vehicle crashes. Automated vehicle control systems introduce new ways for drivers to interact with their vehicles and for vehicles to interact with the environment. Consequently, the types of crashes or near-crashes that an automated vehicle experiences may differ from those involving traditional vehicles. To understand these events, data standards different from those currently in 49 *CFR* Part 563 will be required.

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[69] The NTSB has a recommendation history concerning EDRs in the highway mode that is two decades old, beginning with Safety Recommendation H-97-18, which called for recorder requirements for light vehicles.

A technical advisory committee will be required to consider the types of data-recording requirements needed for automated vehicles that are equipped with active safety systems and automated control systems. Therefore, the NTSB recommends that the DOT define the data parameters needed to understand the automated vehicle control systems involved in a crash. The parameters must reflect the vehicle's control status and the frequency and duration of control actions to adequately characterize driver and vehicle performance before and during a crash.

NTSB investigators need effective event data to conduct valid and productive investigations involving vehicles using automated vehicle control systems. Such data are also vital to identifying emerging problems in this swiftly evolving area of highway technology. Regulators such as NHTSA will have to rely on such data when developing and conducting regulatory activities—including defect investigations—in this area. Therefore, the NTSB also recommends that NHTSA use the data parameters defined by the DOT in response to Safety Recommendation H-17-37 as a benchmark for new vehicles equipped with automated vehicle control systems so that they capture data that reflect the vehicle's control status and the frequency and duration of control actions needed to adequately characterize driver and vehicle performance before and during a crash; the captured data should be readily available to, at a minimum, NTSB investigators and NHTSA regulators.

2.7 Safety Metrics and Exposure Data for Automated Vehicles

Improved data collection could greatly enhance our ability to evaluate the safety benefits provided by automated safety systems. In assessing these relatively new systems, industry members, manufacturers, researchers, and regulators need reliable data about the availability and use of automated safety systems on vehicles in the fleet and involved in crashes. NHTSA's AV Policy includes a section on "Data Recording and Sharing." The Governors Highway Safety Association has called for including the vehicle's automation level in vehicle registration, driver licensing, and crash information systems, beginning with vehicles equipped with Level 3 automation (Hedlund 2017, p. 12). NHTSA has an opportunity to collect exposure metrics for automated vehicle control systems (such as miles driven using these systems) from manufacturers. A standard system of reporting is needed to facilitate aggregation and comparison of data across all manufacturers and fleet operators. The NTSB concludes that to determine the safety effects from the use of automated vehicle control systems and to analyze the benefit–cost outcomes of these systems, reliable information is needed on the types of systems deployed and the numbers of miles driven using them. Therefore, to evaluate the safety effects of automated vehicle control systems, the NTSB recommends that NHTSA define a standard format for reporting automated vehicle control systems data, and require manufacturers of vehicles equipped with automated vehicle control systems to report incidents, crashes, and vehicle miles operated with such systems enabled.

2.8 Connected Vehicle Technology and V2V Requirements

V2V systems transmit warnings and basic safety information (speed, position, heading, brake status, etc.) among vehicles. Intersection crashes, such as occurred in this case, are among the most frequent and fatal of crash types, accounting for 36 percent of all crashes (Choi 2010, p. v). For years, NHTSA has encouraged the development of connected vehicle technology and crash avoidance systems that could improve intersection safety. In a 2014 evaluation report, NHTSA announced plans for deploying V2V technology on heavy vehicles (Harding and others 2014, p. 10).

For V2V systems to function properly, all vehicles on the roads must be equipped with on-board communication capabilities. Also, the communication spectrum frequency for Dedicated Short Range Communication Services must be allocated to intelligent vehicle technologies.[70] In 1995, based on the investigation of a heavy truck crash that took place in Menifee, Arkansas, the NTSB recommended that the Federal Communications Commission allocate frequencies that would enhance collision warning systems (NTSB 1995).[71] A 2015 NTSB Special Investigation Report includes a summary of the many recommendations concerning crash avoidance systems that the NTSB issued to NHTSA in the years following the Menifee investigation (NTSB 2015, p. 11), including V2V systems.

In 2014, researchers categorized the precrash scenarios involving heavy trucks that could be addressed by V2V systems. Of the 37 scenarios considered, 17 were evaluated. The researchers found that a fully mature V2V system could potentially prevent about 267,000 police-reported crashes involving heavy trucks each year. The annual comprehensive costs of those crashes were estimated at $24.7 billion. Of the 17 scenarios evaluated, “straight crossing path at non-signalized intersection” (like the Williston crash) ranked second in terms of cost, accounting for over 15 percent of the total costs ($3.8 billion) (Toma and others 2014). A more recent simulation study for all types of vehicles estimated that 19–35 percent of straight crossing path intersection crashes could be prevented if both vehicles were equipped with intersection advanced driver assist systems (I-ADAS), a V2V technology designed for intersections (Scanlon, Sherony, and Gabler 2017).

In July 2016, NHTSA released a report addressing V2V for heavy vehicles (Chang 2016). That report summarized research that began in the 1990s and covered the development of systems for integrated truck and retrofit V2V systems, including real-world evaluations (Safety Pilot Model Deployment) and test track experience. The report also addressed the safety benefits provided by V2V systems. The report stated that—

> Analysis of the potential safety benefits associated with heavy-vehicle V2V systems has shown good promise based on initial results. In 2013 there were 3,964 people killed and 95,000 people injured in crashes involving at least one large truck. Based on data from police-reported crashes, 70 percent of crashes involving trucks occurred in scenarios that could potentially be addressed by V2V systems.

In early 2017, NHTSA proposed rulemaking on a new FMVSS for V2V communication technology.[72] However, NHTSA’s proposed FMVSS 150 does not address V2V applications or requirements for heavy commercial vehicles. These vehicles travel more miles than light vehicles and are over-represented in fatal crashes; consequently, the omission of heavy commercial vehicles

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[70] See 47 *CFR* Parts 90 and 95.

[71] Safety Recommendation H-95-46 to the Federal Communications Commission was classified “Closed—Acceptable Action” in 1999.

[72] See Notice of Proposed Rulemaking, “Federal Motor Vehicle Safety Standards (FMVSS); Vehicle-to-Vehicle (V2V) Communications,” published at 82 *Federal Register* 3854, January 12, 2017.

from FMVSS 150 is a missed opportunity to significantly improve highway safety. As the NTSB's response to the proposed rule stated, "Widespread use throughout the vehicle fleet—including all heavy vehicles and motorcycles—is required to capitalize on the full lifesaving benefits of V2V technology" (NTSB 2017).

Fusing V2V communication-based technology with vehicle-resident systems can enhance the safety benefits of vehicle automation systems. Such technology might have affected the outcome of the Williston crash. Increasing implementation of crash avoidance technologies is one of the NTSB's Most Wanted Transportation Safety Improvements for 2017–2018. V2V technology could address potential crash situations (that is, intersection and left turn scenarios) that are challenging for current vehicle-resident safety systems (FCW and AEB) and other automated technologies. Moreover, V2V communications will provide a complementary source of information to vehicle-resident systems, improve the reliability and accuracy of data, extend the range of threat detection, and detect crash risks that are outside of a vehicle-resident sensor's field of observation. The NTSB concludes that connected vehicle technology will be most effective when all vehicles traveling on our roadways are equipped with the technology, and that is particularly important with respect to large, heavy trucks that pose the highest risk of injury to occupants of other vehicles.

Following an investigation into a 2012 collision between a school bus and a heavy truck near Chesterfield, New Jersey, the NTSB issued Safety Recommendations H-13-30 and -31 to NHTSA, which read as follows (NTSB 2013):

> <u>H-13-30</u>
>
> Develop minimum performance standards for connected vehicle technology for all highway vehicles.
>
> <u>H-13-31</u>
>
> Once minimum performance standards for connected vehicle technology are developed, require this technology to be installed on all newly manufactured highway vehicles.

The status of these two recommendations is "Open—Initial Response Received."

It has been 4 years since the NTSB issued these recommendations. The Williston crash serves as a reminder of how the installation of V2V technology on heavy trucks could improve the safety of traffic on our nation's roadways. Because NHTSA's recent rulemaking on proposed FMVSS 150 does not address these heavy vehicles, the NTSB reiterates Safety Recommendations H-13-30 and -31.

3 Conclusions

3.1 Findings

1. No investigative evidence indicates that either driver was fatigued, that cell phone use distracted the truck driver, that the car driver was impaired by alcohol or other drugs, that any mechanical system on either vehicle failed, or that the highway design was inappropriate; consequently, these were not factors in the crash.

2. There was sufficient sight distance to afford time for either the truck driver or the car driver to have acted to prevent the crash.

3. The Tesla's automated vehicle control system was not designed to, and did not, identify the truck crossing the car's path or recognize the impending crash; consequently, the Autopilot system did not reduce the car's velocity, the forward collision warning system did not provide an alert, and the automatic emergency braking did not activate.

4. Although the results of postcrash drug testing established that the truck driver had used marijuana before the crash, his level of impairment, if any, at the time of the crash could not be determined from the available evidence.

5. If automated vehicle control systems do not automatically restrict their own operation to those conditions for which they were designed and are appropriate, the risk of driver misuse remains.

6. Because driving is an inherently visual task and a driver may touch the steering wheel without visually assessing the roadway, traffic conditions, or vehicle control system performance, monitoring steering wheel torque provides a poor surrogate means of determining the automated vehicle driver's degree of engagement with the driving task.

7. The Tesla driver's pattern of use of the Autopilot system indicates an overreliance on the automation and a lack of understanding of system limitations.

8. The Tesla driver was not attentive to the driving task, but investigators could not determine from the available evidence the reason for his inattention.

9. The way that the Tesla Autopilot system monitored and responded to the driver's interaction with the steering wheel was not an effective method of ensuring driver engagement.

10. Without the manufacturer's involvement, vehicle performance data associated with highly automated systems on vehicles involved in crashes cannot be independently analyzed or verified.

11. A standardized set of retrievable data is needed to enable independent assessment of automated vehicle safety and to foster automation system improvements.

12. To determine the safety effects from the use of automated vehicle control systems and to analyze the benefit–cost outcomes of these systems, reliable information is needed on the types of systems deployed and the numbers of miles driven using them.
13. Connected vehicle technology will be most effective when all vehicles traveling on our roadways are equipped with the technology, and that is particularly important with respect to large, heavy trucks that pose the highest risk of injury to occupants of other vehicles.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the Williston, Florida, crash was the truck driver's failure to yield the right of way to the car, combined with the car driver's inattention due to overreliance on vehicle automation, which resulted in the car driver's lack of reaction to the presence of the truck. Contributing to the car driver's overreliance on the vehicle automation was its operational design, which permitted his prolonged disengagement from the driving task and his use of the automation in ways inconsistent with guidance and warnings from the manufacturer.

4 Recommendations

4.1 New Recommendations

As a result of its investigation, the National Transportation Safety Board makes the following new safety recommendations:

To the US Department of Transportation:

> Define the data parameters needed to understand the automated vehicle control systems involved in a crash. The parameters must reflect the vehicle's control status and the frequency and duration of control actions to adequately characterize driver and vehicle performance before and during a crash. (H-17-37)

To the National Highway Traffic Safety Administration:

> Develop a method to verify that manufacturers of vehicles equipped with Level 2 vehicle automation systems incorporate system safeguards that limit the use of automated vehicle control systems to those conditions for which they were designed. (H-17-38)
>
> Use the data parameters defined by the US Department of Transportation in response to Safety Recommendation H-17-37 as a benchmark for new vehicles equipped with automated vehicle control systems so that they capture data that reflect the vehicle's control status and the frequency and duration of control actions needed to adequately characterize driver and vehicle performance before and during a crash; the captured data should be readily available to, at a minimum, National Transportation Safety Board investigators and National Highway Traffic Safety Administration regulators. (H-17-39)
>
> Define a standard format for reporting automated vehicle control systems data, and require manufacturers of vehicles equipped with automated vehicle control systems to report incidents, crashes, and vehicle miles operated with such systems enabled. (H-17-40)

To manufacturers of vehicles equipped with Level 2 vehicle automation systems (Volkswagen Group of America, BMW of North America, Nissan Group of North America, Mercedes-Benz USA, Tesla Inc., and Volvo Car USA):

> Incorporate system safeguards that limit the use of automated vehicle control systems to those conditions for which they were designed. (H-17-41)
>
> Develop applications to more effectively sense the driver's level of engagement and alert the driver when engagement is lacking while automated vehicle control systems are in use. (H-17-42)

To the Alliance of Automobile Manufacturers and to the Association of Global Automakers:

> Notify your members of the importance of incorporating system safeguards that limit the use of automated vehicle control systems to those conditions for which they were designed. (H-17-43)

4.2 Reiterated Recommendations

As a result of its investigation, the National Transportation Safety Board reiterates the following safety recommendations:

To the National Highway Traffic Safety Administration:

> Develop minimum performance standards for connected vehicle technology for all highway vehicles. (H-13-30)
>
> Once minimum performance standards for connected vehicle technology are developed, require this technology to be installed on all newly manufactured highway vehicles. (H-13-31)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

EARL F. WEENER
Member

CHRISTOPHER A. HART
Member

T. BELLA DINH-ZARR
Member

Adopted: September 12, 2017

Member Hart filed the following concurring statement on September 14, 2017.

Board Member Statement

Notation 56955: ***Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck, Near Williston, Florida, May 7, 2016 (HWY16FH018)***

Member Christopher A. Hart, Concurring

I concur with the report and its findings, probable cause, and recommendations, and I would like to add some additional comments.

Because more than 90% of motor vehicle crashes are attributed to driver error, automation in cars offers significant potential to save tens of thousands of lives every year by eventually replacing the driver. However, introducing automation into such a complex and unstructured environment will be very challenging and must be pursued thoughtfully and with considerable caution.

Early automation history in aviation includes many examples in which automation was introduced because the industry had the technological capability to do it. They learned from experience that automation "because we can" does not necessarily make the human-automation system work better. That resulted in an evolution toward "human-centric" automation, in which the objective was improving the overall performance of the human-automation system. This crash is an example of what can happen when automation is introduced "because we can" without adequate consideration of the human element.

The human element was not adequately considered in several ways. First, the owner's manual warns that the Autopilot mode, the automation mode that was being used when this crash occurred, should be used "only on highways and limited access roads." Aside from the ambiguity of this warning – route US-27A, on which this crash occurred, is arguably a highway – it fails to consider the human reality that very few owners, and even fewer non-owner drivers, read the manual. Some may look at it only twice a year, to reset the clock when daylight savings time begins and ends.

Second, even if the owner or non-owner driver reads the manual, he or she may not remember it or follow it. Moreover, many owners who are impressed with the amazing things that their car can do may experiment to find out how far they can stretch the boundaries of what it can do.

Adding to the problem is the moniker "Autopilot." In aviation, airline pilots know that even when the autopilot is controlling their airplane, the pilots still play a crucial role. Joe and Suzy Public, on the other hand, may conclude from the name "autopilot" that they need not pay any attention to the driving task because the autopilot is doing everything.

This crash demonstrates that not all owners will read and follow the owner's manual, so the automated systems must be designed to function only in circumstances for which they were designed rather than leaving that decision up to the driver.

The system that monitors and responds to lack of driver engagement also reflects inadequate consideration of the human element. First, the mere fact that the driver touches and moves the steering wheel from time to time does not necessarily indicate that the driver is engaged in the driving task. Designing the system to stop the car in the travel lane after a certain number of warnings about nonresponsiveness, as some automakers are doing, is also very troubling because stopping in a travel lane on a high-speed road greatly increases the likelihood of serious collisions.

More specifically, we have investigated many crashes on interstate highways – limited access roads – involving crashes into cars that were slowed or stopped, often for construction. Most of those crashes occurred despite the existence of numerous conspicuous warning signs in the mile or two leading up to the construction. There will be no warning signs leading up to a stopped vehicle, and without those warning signs, the likelihood of such a crash will obviously be much greater. Although it is clearly undesirable to have a car with an unresponsive driver traveling at high speed, query which is worse -- the collision of a high-speed car with an unresponsive driver into whatever happens to be in the way, or the potential chain collision of one or more high-speed cars and trucks into a stopped car. The anticipated safety benefits of automation are obviously considerable, but if there is no “graceful exit” from the scenario if something does not go as designed, query whether the entire scenario should be avoided.

In aviation, although automation has generated substantial safety, efficiency, and other benefits, we will not see airliners without pilots any time soon because no graceful exit has yet been developed from that scenario (a) if the automation encounters a situation that was not contemplated by the designer, such as in Sioux City, Iowa, in 1989, when an uncontained engine explosion resulted in the loss of all three of the airplane's hydraulic systems, or in New York City in 2009 when both of the airplane's engines were damaged beyond operability by ingesting birds; or (b) if the automation fails.

The potential benefits of automation on our streets and highways are truly phenomenal, but they must be pursued carefully and thoughtfully, and hopefully the automakers will inform the process with automation lessons learned from aviation and elsewhere.

Chairman Robert L. Sumwalt, III, joined this statement.

Appendix A. Investigation

The National Transportation Safety Board (NTSB) became aware of the Williston, Florida, crash after Tesla notified the National Highway Traffic Safety Administration (NHTSA) of the event and after NHTSA opened a defect investigation of the Tesla Autopilot and automatic emergency braking systems. Tesla sent representatives to Ocala, Florida, to assist the Florida Highway Patrol in downloading data from the vehicle. The crash occurred on May 7, 2016; the NTSB dispatched an investigative team on July 13, 2016. Due to the delayed launch, the NTSB took the case as a field investigation. Once on scene, investigators determined that a complete investigation, including crash reconstruction, could be accomplished. The NTSB established groups to investigate human performance, data recorders, motor carrier operations, traumatology, highway factors, and vehicle factors.

Parties to the investigation were Tesla Inc. and the Florida Highway Patrol.

Appendix B. Tesla's Automated Vehicle Control Systems and Subsystems

Automation System	Subsystem	Functional Description
AUTOPARK	n/a	***Autopark*** is a convenience feature that provides assistance when parking. It offers two different functionalities that differ in the level of assistance: (1) the system can provide partially autonomous parallel and perpendicular parking on demand when the driver is in the Tesla, and (2) the system can autonomously park and retrieve the Tesla from a designated parked location without a driver being in the vehicle.
SPEED ASSIST	n/a	***Speed Assist*** is a safety feature that provides a warning when the driver exceeds the speed limit. Speed limit information is derived from the camera system and the Tesla's GPS mapping information.
LANE ASSIST	Side Collision Warning	***Side Collision Warning*** is a crash avoidance system that provides a graded warning (visual warning only for least urgent, visual and auditory warning for most urgent) when another vehicle enters the Tesla's blind spot or travels too close to its side.
	Lane Departure Warning	***Lane Departure Warning*** is a crash avoidance system that provides a haptic warning when the vehicle's front wheel crosses a lane marking and the associated turn signal is not active. The haptic warning is presented as a vibration of the steering wheel. This vibration does not result in any steering corrections; it is intended only to orient the driver's attention to the lane departure.
	Autonomous Steering Intervention	***Autonomous Steering Intervention*** is a crash avoidance system that provides automated corrective steering intervention when the Tesla drifts into or close to an adjacent lane in which another vehicle is detected. The automated steering correction brings the Tesla back to the center of its own traveling lane. Concurrent to the steering correction, a visual warning is presented on the instrument panel. The system is disabled if Autosteer is activated.
(Table continues on next page)		

Automation System	Subsystem	Functional Description
FORWARD COLLISION AVOIDANCE	Forward Collision Warning (FCW)	***FCW*** is a crash avoidance system that provides a visual and auditory warning regarding a potential forward collision (rear-end crash). The visual warning appears on the Tesla's instrument panel and consists of an icon of a red vehicle in front of the Tesla vehicle icon. The auditory warning consists of a chime. The warnings remain until the driver brakes or steers away from the forward hazard.
	Automatic Emergency Braking (AEB)	***AEB*** is a crash avoidance system that automatically applies brakes when it determines that a frontal collision is unavoidable. The system is designed to mitigate the severity of the crash, although in some cases it may even prevent the collision. The braking is automatic. When the system automatically applies brakes, it also presents visual and auditory alerts. The visual warning consists of a rectangular bar in the instrument panel with lettering that reads "Emergency Braking in Progress." The auditory warning consists of a chime.
AUTOPILOT	Traffic-Aware Cruise Control (TACC)	***TACC*** is a convenience feature. After the driver activates TACC and selects a cruising speed, the system (1) maintains the set cruise speed as long as the forward area is not obstructed, (2) decelerates the Tesla when it detects a vehicle ahead and then maintains a set following distance, and (3) resumes the set cruise speed when the forward area is no longer obstructed. When necessary to maintain a set following distance, TACC applies braking force that results in deceleration of up to 0.5G. The driver can select the following distance—how closely to follow a leading vehicle. TACC has an Overtake Acceleration function that, in conjunction with Auto Lane Change, will automatically accelerate the Tesla to the set cruising speed once it is in a passing lane.
	Autosteer	***Autosteer*** is a convenience feature that automatically steers the Tesla and keeps it within the traveling lane. Autosteer can be activated only after activating TACC; Autosteer cannot operate without TACC. When Autopilot (TACC and Autosteer) is activated, the system (1) monitors the environment on the travel path, (2) maintains the set cruise velocity, (3) maintains the Tesla's position in the traveling lane, (4) brakes when it detects a slower-moving vehicle or an obstacle ahead, and (5) decelerates and follows a leading slower-moving vehicle at the predetermined following distance. Autosteer detects lane markings and the presence of other vehicles and objects ahead, to maintain the Tesla within the lane. When Autosteer is activated, an icon of a blue steering wheel appears on the instrument panel.
	Auto Lane Change	With Autosteer activated, ***Auto Lane Change*** moves the Tesla into an adjacent travel lane as indicated by an activated turn signal. Auto Lane Change can only operate in conjunction with Autosteer and when the Lane Assist system does not detect another vehicle in the blind spot.

Appendix C. Alert Timing Sequence for Tesla Autopilot Version 8

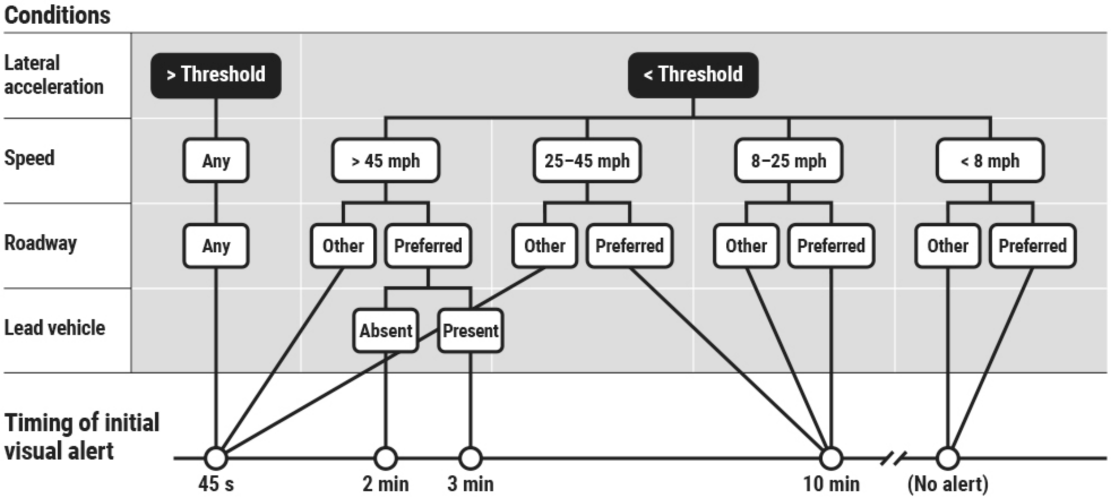

Figure C-1. Autopilot system alert timing sequence for version 8.

Since the crash, Tesla has implemented several changes to the Autopilot system, including reducing the allowed driver hands-off time. In addition, the timing of the initial visual warning is now dependent on the type of road and the speed at which the vehicle is traveling.

If the driver is driving on an unrestricted road—with a center divider or limited access—with maximum cruise speed of 90 mph, the initial visual warning for hands-off operation would occur after 3 minutes. If the driver does not place hands on the steering wheel within 15 seconds of the initial warning, an auditory warning sounds, followed by another auditory warning of greater intensity. If the driver does not place hands on the steering wheel within 5 seconds of the second auditory warning, the system initiates controlled deceleration of the vehicle. Furthermore, at that time, the system disables the use of Autopilot for the rest of that ignition cycle.

Tesla also added another constraint to Autopilot 8; Tesla referred to this as a “three strikes and you’re out” rule. If any three warnings occur during a single trip, that sequence will cause Autopilot to be disabled for the remainder of the trip.

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