VEHICLE AUTOMATION DATA SUMMARY REPORT

Culver City, CA

HWY18FH004

(8 pages)

NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF HIGHWAY SAFETY
WASHINGTON, D.C.

VEHICLE AUTOMATION DATA SUMMARY REPORT

A. CRASH INFORMATION

Location: Southbound Interstate 405 south of Washington Boulevard, Culver City, Los Angeles County, California

Vehicle1: 2014 Tesla Model S

Operator1: Private Owner

Vehicle2: 2006 Seagrave Custom Firetruck (pumper)

Operator2: Culver City Fire Department, Culver City, California

Date: January 22, 2018

Time: Approximately 8:40 a.m. PST

NTSB #: HWY18FH004

B. VEHICLE AUTOMATION DATA SUMMARY GROUP

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NTSB Office of Highway Safety
490 L'Enfant Plaza East, S.W., Washington, DC 20594

C. CRASH SUMMARY

For a summary of the crash, refer to Section C. *Crash Summary* of the Factual Report of Investigation in the docket for this investigation.

D. DETAILS OF THE REPORT

The Vehicle Automation Data Summary report describes data pertaining to the operation of Tesla vehicle prior to the crash with focus on Autopilot operation and driver's engagement with the vehicle.

1. 2014 Tesla Model S

1.1. General Information

According to Tesla, at the time of the crash the crash vehicle was operating Hardware Version 1 and was running firmware version 17.50.97-3bd9f6d082U (SX). The firmware was installed using wireless connectivity on December 28, 2017. The vehicle was equipped with

multiple collision avoidance and driver assist systems. The functionality of these systems was afforded by a radar, a camera and multiple ultrasonic sensors. For additional description of these systems, see the Combined Chairman Factual and Data Group Chairman Factual reports. Among other systems, the crash-involved Tesla was equipped with the following systems:

- Speed Assist
  - *Provides a warning when driver exceeds the speed limit*
- Lane Assist
  - Side Collision Warning
  - Lane Departure Warning
  - Automatic Steering Intervention
- Forward Collision Avoidance
  - Forward Collision Warning (FCW)
  - Automatic Emergency Braking (AEB)
- Highway Convenience Features - *component of Autopilot Technology Package*
  - Traffic-Aware Cruise Control (TACC)
    - *TACC is a convenience feature; it is an adaptive cruise control system that maintains the set cruise speed, applies brakes when approaching a slower moving lead vehicle to preserve a time-based following distance, or accelerates to the set cruising speed when forward area is no longer obstructed.*
  - Autosteer
    - *Tesla's Autosteer is a convenience feature that automatically steers the vehicle to keep it within its traveling lane. Autosteer can be engaged only after activating TAAC; Autosteer cannot operate without TACC.*
  - Auto Lane Change

Most of this report describes data pertaining to the operation of Autopilot (Autosteer + TACC) and driver's engagement with the system as detected through monitoring of driver-applied steering wheel torque.

When Autosteer is engaged, Tesla's automation system monitors driver-applied changes to the steering wheel torque (i.e., driver's hands on the steering wheel). If the system does not detect driver-applied steering wheel torque for a prolonged period, it provides a series of warnings to the driver, starting with a visual alert. The latency of the visual warning is dependent on several factors, including (1) the speed of the Tesla, (2) presence of a vehicle ahead of the Tesla, and (3) lateral acceleration, (4) the type of roadway on which the vehicle is traveling, (5) detection of errors in the system which would prompt an immediate warning, (6) application of pedals by a driver, and (7) miscellaneous factors such as presence of a construction flag.

Tesla provided the logic detailing the conditions that affected the timing of the initial alert on the Autopilot system installed on the crash-involved vehicle.[1] The crash occurred on Interstate 405, which as a divided roadway was considered a preferred roadway type.

[1] The crash-involved Tesla was installed with Hardware Version 1.0, and the timings of the warnings for hands-off operation of Autopilot are based on that hardware version. Currently, newer Tesla vehicles are equipped with

- When traveling on a divided roadway at a speed greater than 45 mph and with the lateral acceleration below a fixed threshold[2]:
    - If a lead vehicle is present ahead of the Tesla, the system would issue a visual warning after 3 minutes of not detecting driver-applied torque on the steering wheel.
    - If lead vehicle is not present ahead of the Tesla, the system would issue a visual warning after 2 minutes of not detecting driver-applied torque on the steering wheel.
- When traveling on a divided roadway at a speed up to 25 mph, and with the lateral acceleration below a fixed threshold:
    - The system does not present a warning for hands-off operation of Autopilot system.

If the system does not detect driver-applied torque on the steering wheel after the initiated of the visual warning, the system presents the first auditory warning 15 seconds after the visual warning. If driver-applied torque on the steering wheel is still not detected, the system presents second auditory warning 10 seconds after the first auditory warning. If driver-applied torque on the steering wheel is still not detected, 5 seconds later the system applies third auditory warning and begins to decelerate the vehicle.

When the system detects driver-applied torque on the steering wheel during Autopilot operation, it cancels the progression of any warnings (if they occurred) and it resets the hands-off count. The count starts again when the driver-applied torque on the steering wheel is no longer detected.

1.2. Autopilot Activation and Warnings for Hands-Off Operation

Tesla wirelessly downloaded the recorder/ Autopilot data from the crash-involved vehicle postcrash; this data was provided to NTSB investigators.[3] The vehicle data shows that the ignition cycle that preceded the crash (the duration of the operation since the last start of the vehicle's engine) lasted 66 minutes and 9 seconds. The Autopilot was engaged for a total of 29 minutes

Hardware Version 2.0, 2.5 or 3.0 which have different sensors and different detection capabilities than Hardware Version 1.0. Additionally, the timings of the warnings for the hands-off operation of Autopilot have been changed. In the Hardware 2.0 or later versions with the current firmware, the hands-off warnings are also presented when traveling at speeds under 25 mph, as well as being presented earlier when traveling at higher speeds. Hardware Version 2.0 and 3.0 were introduced on new vehicles in October 2016, and the first quarter of 2019, respectively.

[2] The timing logic presented in this report are based on these factors: (1) a divided roadway, (2) lateral acceleration is below the fixed threshold, (3) no construction zone (specifically, a flagger is not present), (4) that the driver did not apply an accelerator pedal during Autopilot operation, (5) the system did not detect any errors.

[3] The vehicle data is included as an attachment to this report and can be found on the NTBS public docket for this investigation (HWY18FH004). The file has been modified by NTBS investigators to provide a more descriptive names of the variables; additionally, the variable describing relevant events has also been modified using colloquial language.

during the last ignition cycle (see figure 1). The driver operated the Tesla manually for the first 26 minutes and 48 seconds.

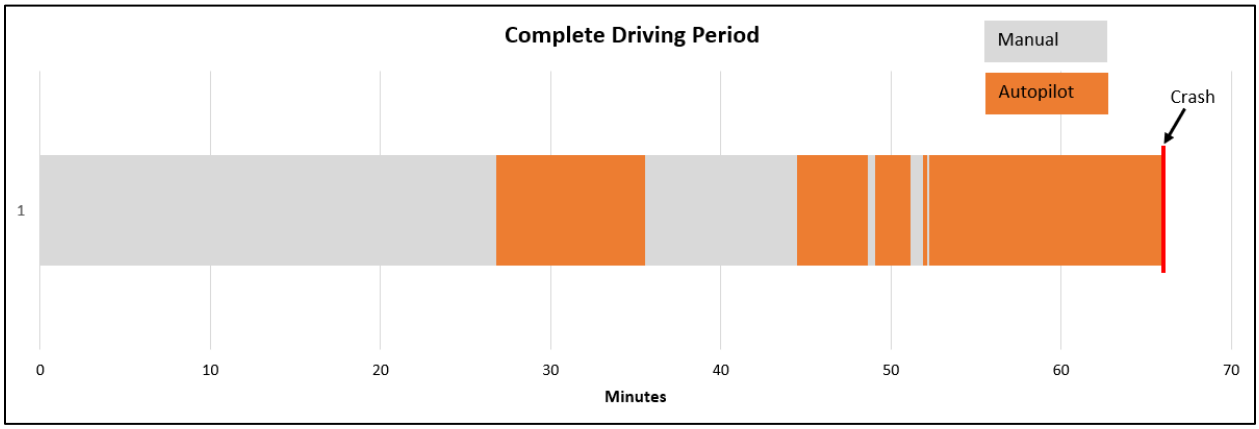

Figure 1. Depiction of manual and Autopilot controlled operation of the Tesla during the crash trip.

For the majority of the time that Autopilot was engaged, the system did not detect driver-applied steering wheel torque. The system detected driver's hands on the steering wheel for only 78 seconds out of 29 minutes and 4 seconds during which the Autopilot was active (see figure 2).

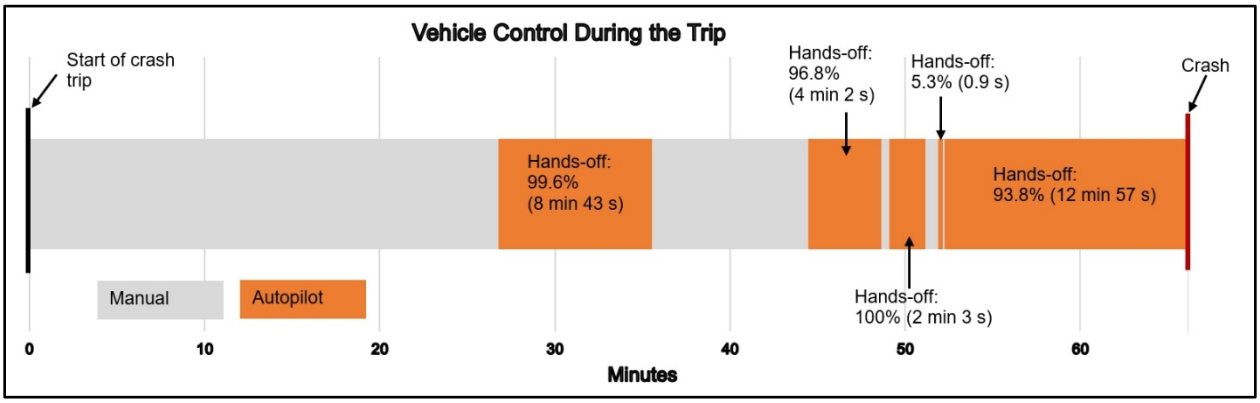

Figure 2. Depiction of manual and Autopilot controlled operation of the Tesla, along with detection of driver-applied steering wheel torque.

The driver had Autopilot engaged continuously for the final 13 minutes and 48 seconds of the crash trip, including the time of the crash. During this last Autopilot segment, the system issued several alerts regarding hands-free operation of Autopilot (see figure 3). During this segment:

- The system detected driver-applied steering wheel torque for a total of 51 seconds.
- The system presented a visual alert regarding hands-off operation of the Autopilot on 4 separate occasions.
- The system presented a first level auditory warning on one occasion; it occurred following the first visual alert.

- The longest period during which the system did not detect driver-applied steering wheel torque was 3 minutes and 41 seconds.

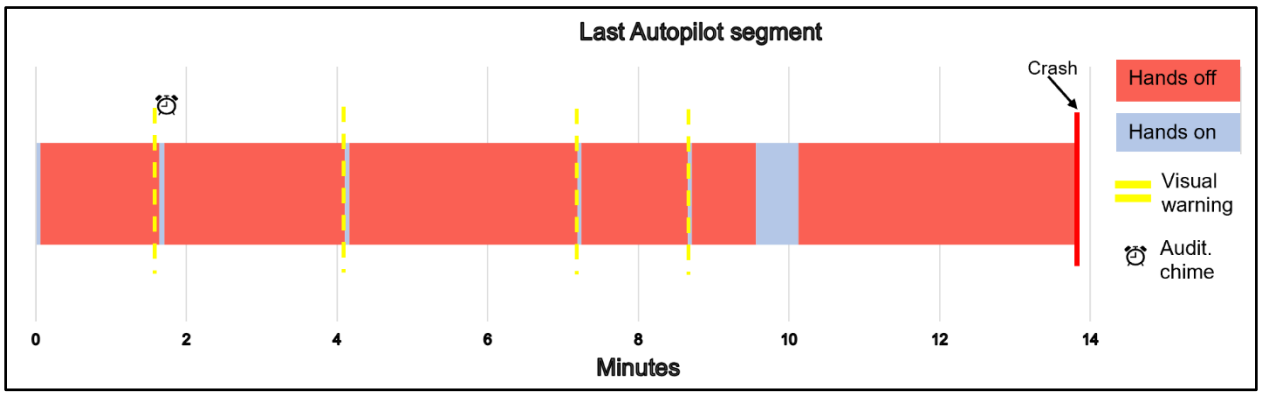

Figure 3. Depiction of the last Autopilot segment of the crash trip, including the warnings for hands-free operation.

During the last 3 minutes and 41 seconds leading up to the crash, the system did not detect driver-applied steering wheel torque. During this period, the speed of the Tesla dropped below 25 mph (see figure 4). Based on Tesla's logic for activation of a visual alert for hands-off operation, the system does not provide a warning for hands-off operation when traveling below 25 mph.

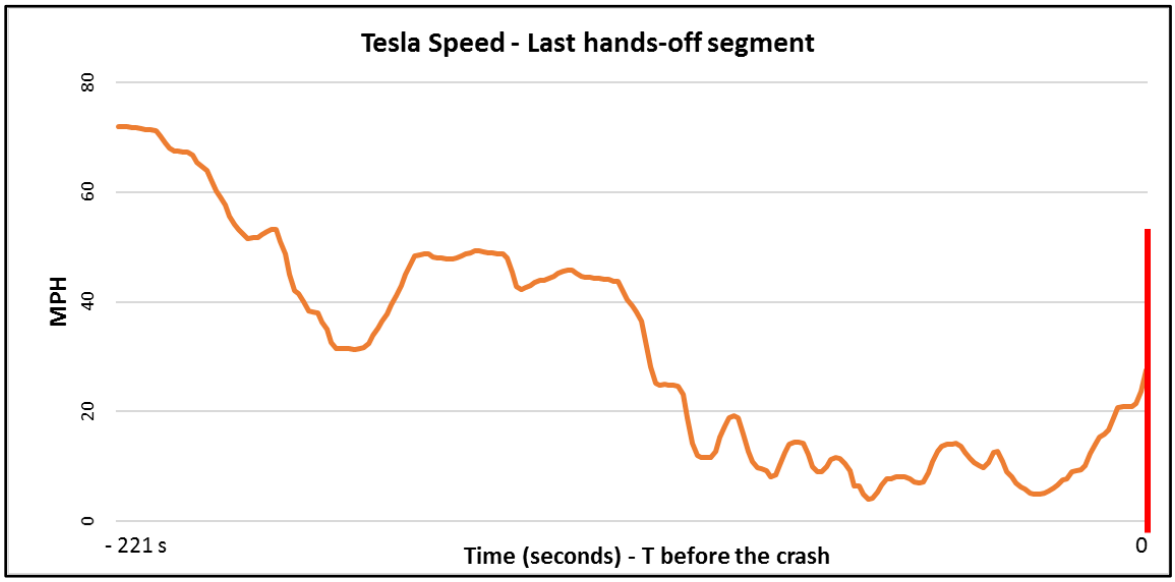

Figure 4. The velocity of the Tesla for the last segment of Autopilot operation during which the system did not detect driver-applied steering wheel torque.

1.3. Lead Vehicle Following and Collision Warning

Data show that for the most of the operation of the Autopilot, the system detected and followed a vehicle traveling ahead of the Tesla in the same lane of travel. When TACC is engaged, the system adjusts the speed of Tesla by accelerating and decelerating (modifying throttle and/ or

braking) to maintain a constant time-based distance with the lead vehicle. The following distance is dependent on the vehicle speed; the distance increases as the velocity increases. For example, for about a minute and a half prior to the crash (excluding the last 8 seconds) the speed of the Tesla ranged between 4-25 mph, and the following distance ranged between 6-16.5 meters (see figure 5).

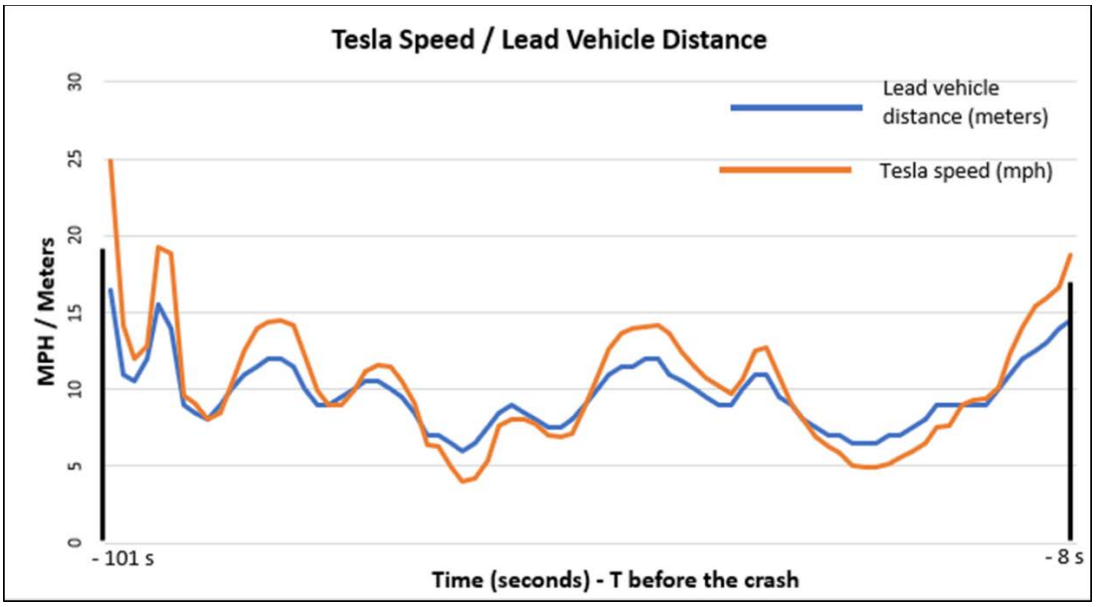

Figure 5. Tesla's speed and the distance at which it followed a lead vehicle leading up to the crash.

The Tesla was following a lead vehicle for an extended period at a relatively consistent speed and the following distance. Data indicates that for a period of 4-7 seconds before the crash, as the Tesla was traveling at a consistent speed of about 21 mph, the lead vehicle was slowing (i.e., the following distance was reducing). That lead vehicle changed lanes 3-4 seconds before the crash. The movement of this lead vehicle is deduced from data which shows that the following distance of 33 meters at 4.1 seconds before the crash dramatically increased to 120 meters one second later; the 120 meter is a default value indicating that the system *has not* detected a vehicle in front. See figure 6 for the relevant metrics and the movements the Tesla and the lead vehicles prior to the crash.

As the system no longer detected a lead vehicle 3-4 seconds before the crash, Autopilot started accelerating the Tesla toward the TACC-set cruise speed of 80 mph which the driver set nearly 5 minutes before the crash.[4] At the time of impact, the Tesla was traveling at the speed of 30.9 mph.

Data shows that about 490 msec before the crash, the system detected a stationary object in path of the Tesla. At that time, the forward collision warning was activated; the system presented a visual and auditory warning. Data also shows that the AEB did not engage and that there was no

[4] For the entire final trip, the driver had set the lead vehicle following distance to setting "3". According to Tesla, this setting is based on the time-based distance to the lead vehicle (approximately 3 seconds for the "3" setting) and an additional distance (about 5 meters) for stopping.

driver-applied braking of steering prior to the crash. According to Tesla, the AEB was active at the time of the crash, and considering that the stopped fire truck was detected about half a second before impact, there likely was not sufficient time to activate the AEB.

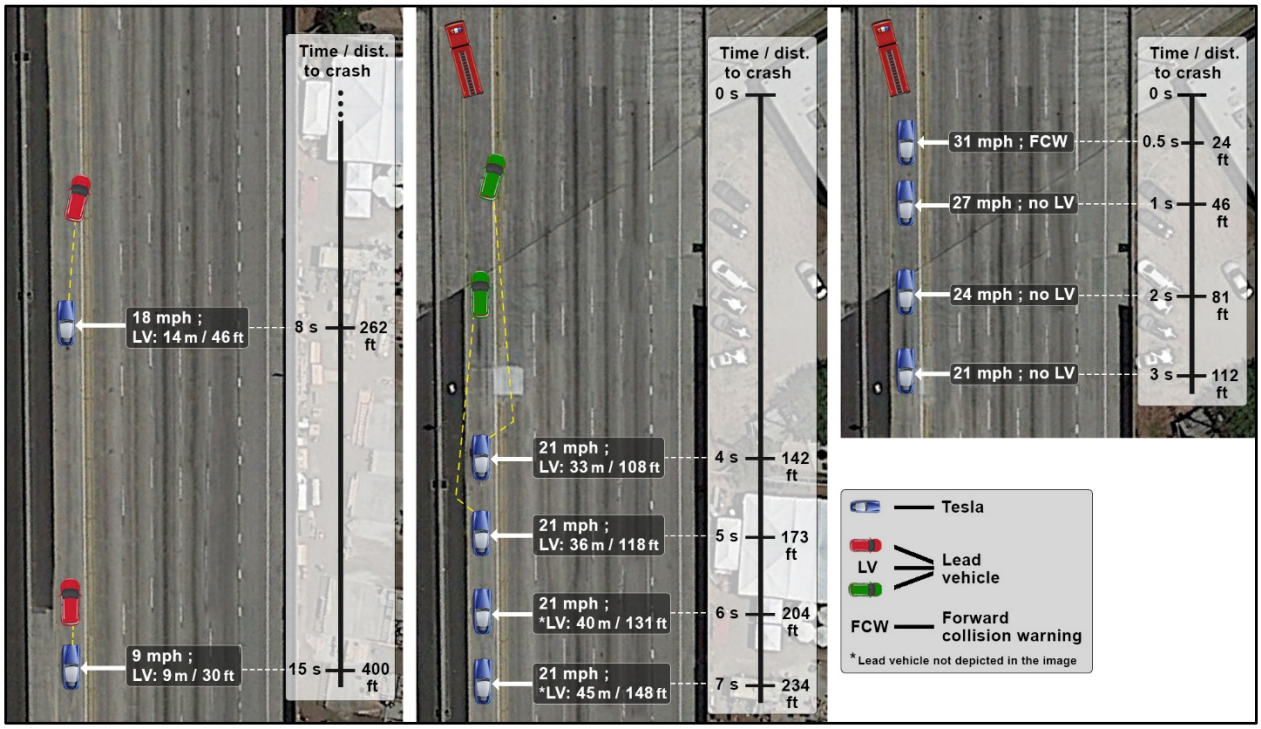

Figure 6. Depiction of movement of Tesla (blue vehicle) and vehicles traveling ahead of Tesla in same lane (lead vehicle). Images show approximate position of vehicles, Tesla speed, and distance to closest lead vehicle. Separate time intervals prior to crash are shown in each image: 15 to 8 seconds (left image), 7 to 4 seconds (middle image), and last 3 seconds (right image) before the crash.

E. DOCKET MATERIAL

The following attachments are included in the docket for this investigation:

Attachment 1: Tesla data.

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