VEHICLE DATA RECORDER SPECIALIST'S FACTUAL REPORT

Culver City, California

HWY18FH004

(7 pages)

NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, D.C. 20594

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Vehicle Data Recorder

Specialist's Factual Report
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1. EVENT SUMMARY

Location:	Culver City, California
Vehicle:	Tesla Model S
VIN #:	5YJSA1H13EF******
Date:	January 22, 2018
NTSB Number:	**HWY18FH004**

For a summary of the crash, refer to the Crash Summary Report in the docket for this investigation.

2. GROUP

No Group was convened.

3. DETAILS OF INVESTIGATION

The NTSB received raw data files stored within the Gateway Electronic Control Unit (ECU) of the Tesla Model S together with parametric data based on this raw data that was obtained via database query from Tesla company servers.

3.1. Tesla Driver Assistance System

The Tesla Model S comes equipped with a suite of driver assistance system (DAS) features that includes features such as adaptive cruise control (ACC), lane keeping assistance, and automatic emergency braking (AEB). The Tesla Autopilot feature fuses data obtained from optical, radar, and ultrasonic sensors on the vehicle to build an internal model of the nearby surroundings including both stationary and non-stationary objects. Using this information, together with parametric data concerning the current position[1] and motion[2] of the Tesla vehicle, Autopilot's Autosteer and Traffic-Aware Cruise Control features are designed to work together to compute the wheel torque, wheel braking, and

[1] Position information includes mapping data together with the vehicles GPS location.
[2] Motion information includes longitudinal and transverse accelerations, together with vehicle speed and direction of motion.

steering inputs required to keep the vehicle in its driving lane when cruising at a set speed on highways that have a center divider and clear lane markings.

3.2. Tesla Data Acquisition System

The Tesla Model S uses three types of sensors for measuring the relative position of objects in the nearby environment - two electromagnetic-based (radar and visible light) and one sound-based (ultrasonic). This data is used to support the Driver Assistance System. Additional sensors are integrated throughout the vehicle to monitor vehicle operation for display to the driver and to support other vehicle functions such as motor control and battery power management. Multiple CAN[3] busses are used to move data between the various electronic control units (ECU) servicing these and other automobile subsystems. Each ECU forms a 'node' on the CAN bus, and messages can be sent asynchronously from any node to any other node.[4] A central node, the Gateway (GTW) ECU, serves as a communications hub distributing messages between the various CAN busses.

3.3. Event Data Recorder Regulations

Federal regulation 49 CFR 563[5] specifies the data collection, storage, and retrievability requirements for vehicles equipped with an Event Data Recorder (EDR). The regulation does not require that vehicles be equipped with event data recorders. Equipping a vehicle with an event data recorder is completely voluntary. The regulation also specifies vehicle manufacturer requirements for providing commercially available tools and/or methods for accomplishing data retrieval from an event data recorder in the event of a crash. Since this vehicle was not equipped with an event data recorder meeting this regulation, there is no commercially available tool for data retrieval and review of the ECU data. NTSB investigators had to rely on Tesla to provide the data in engineering units using proprietary manufacturer software.

3.4. Gateway Electronic Control Unit

The Tesla Model S stores non-geo-located data on the vehicle in non-volatile[6] memory using a removable SD card installed within the Gateway ECU. This SD card is large enough to typically maintain a complete record of all stored data for the lifetime of the vehicle.

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[3] The Controller Area Network (CAN) bus is a Society of Automotive Engineers (SAE) defined data bus standard designed to allow microcontrollers and other devices to communicate without need for a host computer. This standard supports a message-based protocol (similar to the TCP-IP protocol used to support internet communications) to multiplex signals across the electrical wiring of an automobile.

[4] This is known as asynchronous communications. A node will generally add 'envelope' information including the ID of the message and error correction information along with the data being transferred. All other nodes will 'listen' to the message and respond as appropriate. Physically, communication between nodes is accomplished using a two-wire twisted pair connecting all the ECUs together.

[5] Title 49, Code of Federal Regulations Part 563 outlines the requirements covering event data for those vehicles containing an EDR.

[6] Non-volatile memory is a form of solid state memory capable of retaining stored data in the absence of external power.

One type of data acquired and stored is vehicle state information. This data is continually written to the Gateway ECU while the car is on. Typical parameters include: steering angle, accelerator pedal position, driver applied brake pedal application, vehicle speed, various Autopilot feature states, and lead vehicle distance. Some of these parameters are recorded at a 1Hz rate. Other parameters are only recorded when a change of state occurs. All parameters are timestamped with the time of arrival at the Gateway ECU using a GPS derived clock time.

Data from the SD card is episodically data-linked to Tesla servers using a virtual private network connection established via Wi-Fi, or using the 3G-cellular data capabilities of the vehicle. Camera data will only be available after it has been transferred to the Gateway ECU via CAN bus – typically after the vehicle is shut down. This process can take over 40 minutes.

In general, data stored on-board the vehicle will contain information additional to that contained on Tesla servers. Specifically, any data stored since the last auto-upload event will exist only on the vehicle itself and must be recovered by forcing an over-the-air upload, using maintenance download equipment to connect directly to the vehicle, or by removing and directly accessing the SD card within the dash-mounted electronic control panel.

3.5. Data Recovery

Data recovered from the accident vehicle and converted to engineering units by Tesla was provided to the recorder laboratory for evaluation and documentation.

3.6. Data Description

Tesla converted the data determined relevant to this crash by the NTSB into engineering units. This was accomplished by performing a database query on vehicle data stored on Tesla servers that included the information recovered from the vehicle. The result of this query yielded parametric data for 22 distinct variables, and text-based information related to 128 distinct error messages, covering the period from 7:33:36 PST to 8:39:45 PST on the day of the crash. Based on timestamps from cascading error message information, together with a change of state of several recorded crash indication parameters, the crash occurred at 8:39:39 PST. This data is included as Attachment 1 to this report. Figure 1 provides a detailed graphical depiction of this data for the entire period. All data is reported with one second precision unless otherwise noted.

In the following discussion, all ***PARAMETER NAMES*** will be given in small cap bold italics. For discrete parameters – those only taking on a finite list of possible states – the **PARAMETER STATE** will be given in small cap bold.

Certain parameters, such as ***VEHICLE SPEED***, are intended to represent a physical measurement; these are generally recorded at a set rate and referred to as *continuous* parameters. Other parameters, such as ***CRUISE STATE***, are intended to represent one of a finite number of possible states; these are generally recorded only when the state changes and are referred to as *discrete* parameters.

Figure 1 illustrates vehicle drive parameters including: ***TORQUE MOTOR*** (-***MAIN***[7] and -***SLAVE***[8]), ***BRAKE PEDAL STATE***, ***ACCEL PEDAL POSITION***, ***STEERING ANGLE***,[9] ***CRUISE SETTING,***[10] ***AUTOPILOT STATE,***[11] ***AUTOPILOT HANDS ON STATE,***[12] and ***VEHICLE SPEED***. The distance to the vehicle directly in front of the Tesla - ***LEAD VEHICLE DISTANCE*** - is also included.

Figure 2 illustrates this same information during the last 15 minutes of the accident drive.

The data depicted in figures 1 and 2 show two periods of time during the last hour of the accident drive during which Autopilot was active: from about 0800 PST to 0809 PST, and again from 0818:04 PST to the end of the recorded data.

At 0825:50 PST, the Autopilot state transitioned to **ACTIVE NORMAL**, and continued in this state until 0839:39 PST, when it transitioned to **ABORTED**. The ***LEAD VEHICLE DISTANCE*** during this time period varied from near zero to approximately 50 meters, while the ***VEHICLE SPEED*** varied from near zero to approximately 75 mph. During the last minute just prior to the crash, the ***LEAD VEHICLE DISTANCE*** remained below 10-12 meters, while the ***VEHICLE SPEED*** varied from 6 – 15 mph.

The ***AUTOPILOT HANDS ON STATE*** indicated not detected for the majority of this period, and indicated four **VISUAL WARNING**s, and one **CHIME1** warning; each followed by a brief indication that *hands-on* was detected. The last time *hands-on* was detected by the steering wheel sensor was at 8:35:58 PST – approximately four minutes prior to the crash.

The Tesla recorded flags related to a frontal crash event at 8:39:39.1 PST – approximately three seconds after the ***LEAD VEHICLE DISTANCE*** rapidly climbed from about 12 meters to a local maximum of 121 meters. The ***AUTOPILOT STATE*** also transitioned from **ACTIVE/NORMAL** to **ABORTED** at this time. The ***VEHICLE SPEED*** at the time of this transition was 30.85 mph. Recorded data stopped at 8:39:44.9 PST, after a cascade of error messages consistent with crash damage to the Tesla.

[7] Main motor torque refers to the torque on the main (rear) drive wheels.
[8] Slave motor torque refers to the torque on the slave (front) drive wheels.
[9] Positive values indicate that the steering wheel is positioned to execute a right-hand turn.
[10] Cruise control speed setting.
[11] Information indicating Autopilot activity.
[12] Information concerning driver engagement with the steering wheel; including the warning level if the system has not detected torque on the steering wheel consistent with the driver's hands being engaged after a pre-set period while Autopilot is in operation.

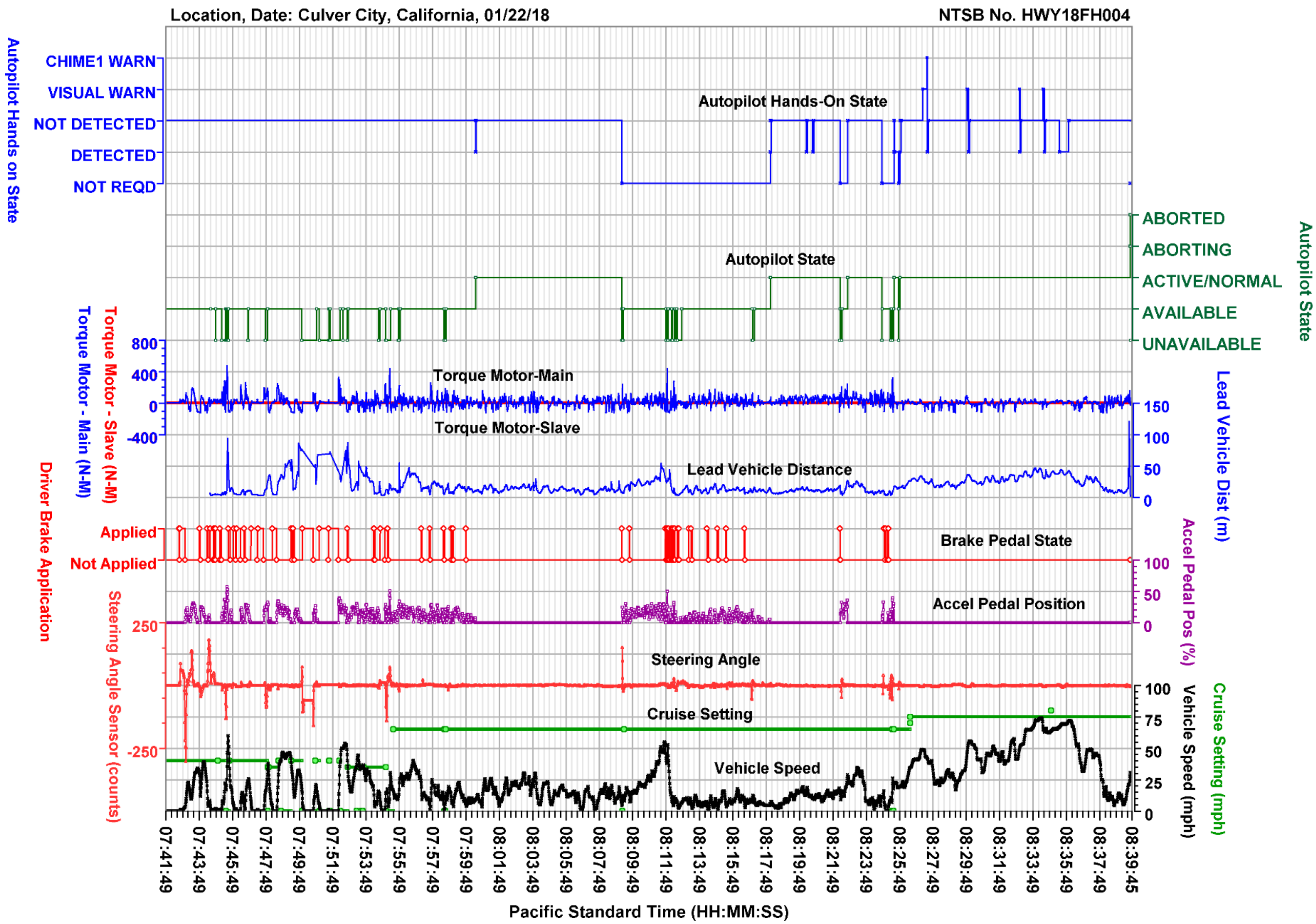

Figure 1. Vehicle drive mode information for the hour leading up to the crash.

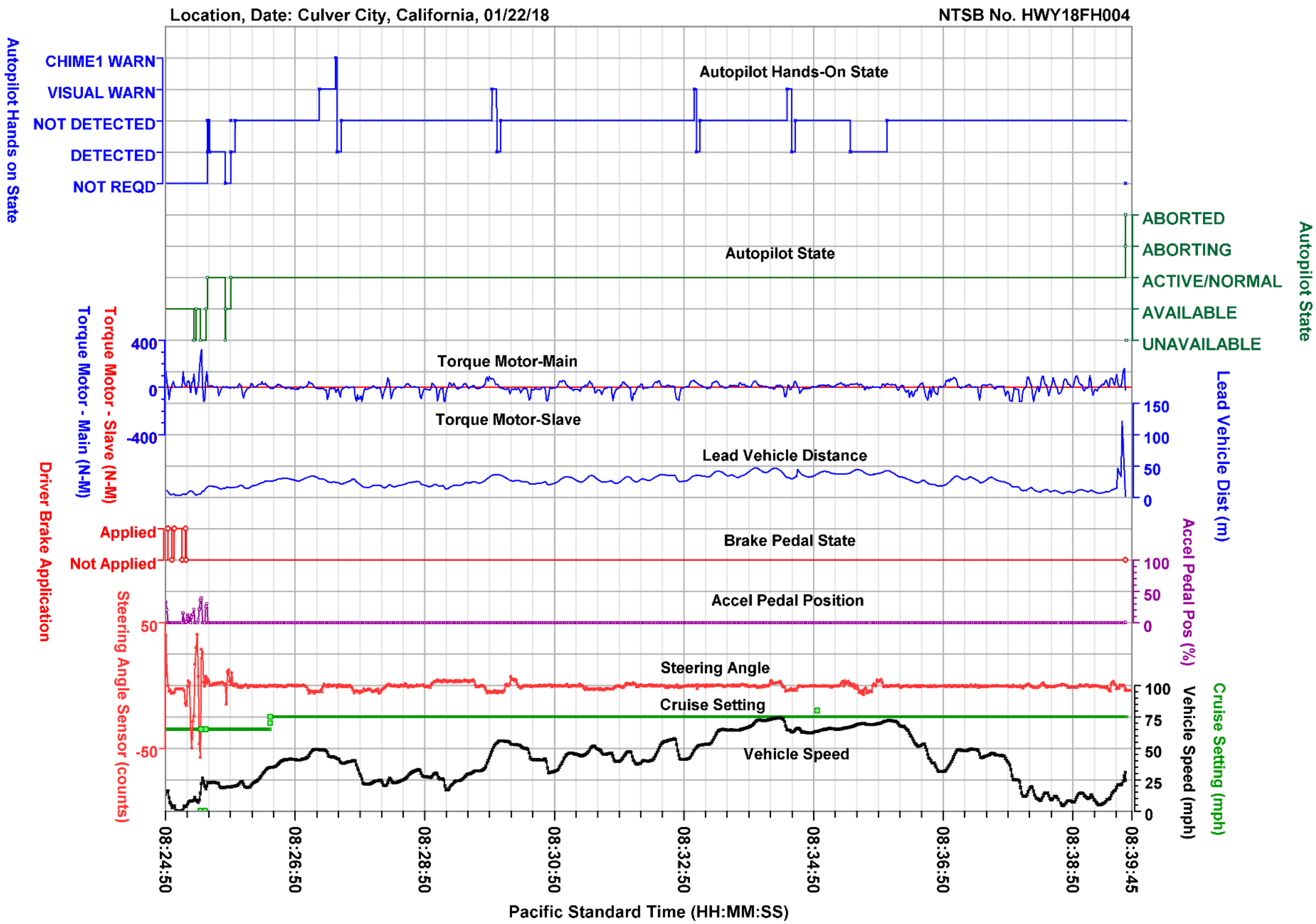

Figure 2. Vehicle drive mode information for the 15-minutes leading up to the crash.