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Special Crash Investigations: On-Site Automated Driver Assistance System Crash Investigation of the 2015 Tesla Model S 70D

DISCLAIMER

The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points are coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics in order to determine the pre-crash, crash, and post-crash movements of involved vehicles and occupants.

Because each crash is a unique sequence of events, generalized conclusions cannot be made concerning the crashworthiness performance of the involved vehicles or their safety systems.

This report and associated case data are based on information available to the Special Crash Investigation team on the date this report was written and submitted.

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15. Supplementary Note

An investigation of the fatality of a 40-year-old male driver of a 2015 Tesla Model S 70D.

16. Abstract

This on-site investigation concerned the fatal underride crash of a 2015 Tesla Model S 70D sedan with the right plane of a 2003 Utility Trailers Incorporated (UTI) semi-trailer that was pulled by a 2014 Freightliner Cascadia conventional truck tractor. The 40-year-old belted male driver of the Tesla sustained fatal injuries and was pronounced deceased at the crash site. At the time of the crash, the driver was operating the Tesla with an Advanced Driver Assistance System (ADAS) enabled. The crash occurred when the Freightliner turned left across the travel path of the Tesla, and the Tesla underrode the mid-aspect of the semi-trailer. After traveling completely under the semi-trailer, the Tesla departed the roadway and impacted other objects before coming to final rest. The air bags in the Tesla deployed during the crash sequence.

The Tesla's ADAS technologies were provided as supplemental emergency collision warning, mitigation, and avoidance aides. Their use still required the full and continual attention of the driver to monitor the traffic environment, maintain ultimate control of the vehicle, and remain prepared to take evasive action. The ADAS technologies were not capable of performing in every collision situation, and their limitations made it difficult for the system to recognize this specific crash due to the cross- path configuration of the involved vehicles' trajectories and the overall physical characteristics of the intersection/roadway. The Tesla's ADAS technologies were functional at the time of the crash, and although they did not respond to an impending crash event, the SCI investigator was unable to identify any performance anomalies. It was also determined that the Tesla's driver would have had a clear and unobstructed view of both the intersection and turning tractor-trailer but made no attempt to avoid the crash, despite sufficient time to do so.

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LOCATION: FLORIDA
CRASH DATE: MAY 2016

BACKGROUND

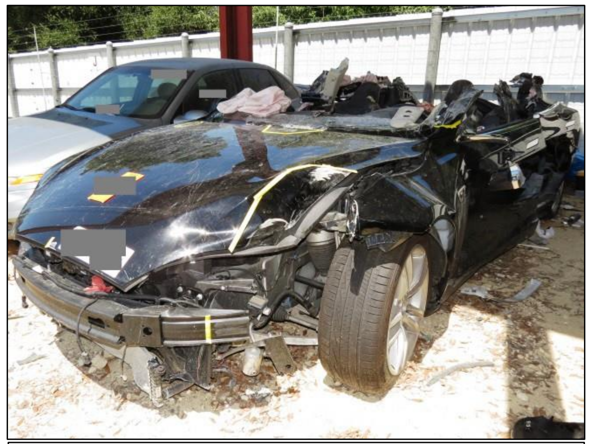


Figure 1: Left front oblique view of the 2015 Tesla Model S 70D at the time of the SCI vehicle inspection.

This on-site investigation concerned the fatal underride crash of a 2015 Tesla Model S 70D sedan (**Figure 1**) with the right plane of a 2003 Utility Trailers Inc. (UTI) semi-trailer that was pulled by a 2014 Freightliner Cascadia conventional truck tractor. The 40-year-old belted male driver of the Tesla sustained fatal injuries and was pronounced deceased at the crash site. At the time of the crash, the driver was operating the Tesla with an Advanced Driver Assistance System (ADAS) enabled. The crash occurred when the Freightliner turned left across the travel path of the Tesla, and the Tesla underrode the mid-aspect of the semi-trailer. After traveling completely under the semi-trailer, the Tesla departed the roadway and impacted other objects before coming to final rest. The air bags in the Tesla deployed during the crash.

The crash was reported by the manufacturer of the Tesla to the National Highway Traffic Safety Administration's Office of Defects Investigation (ODI), which notified the Crash Investigation Division (CID). The CID forwarded the notification to the Special Crash Investigations (SCI) team and assigned the crash for on-site investigation on June 21, 2016. The SCI team located the vehicle at a salvage facility and established cooperation for inspection. The on-site portion of this investigation occurred on June 22 and 23, 2016, and involved inspections of the Tesla, the UTI semi-trailer, and the crash site. The Tesla was not equipped with an event data recorder (EDR) supported by the Bosch Crash Data Retrieval (CDR) software/tool, and as such, no data could be imaged from the Tesla by the SCI investigator during inspection. However, vehicle data logs, which recorded pre-crash operational parameters and diagnostic data, were removed from the vehicle by a Tesla representative prior to SCI crash notification. A translated copy of that data was later provided to the SCI investigator for analysis. Secondary documentation of the crash site was performed by the SCI investigator on December 1, 2016. At that time, a visibility study of the crash site and intersection was conducted using a single-unit heavy truck and 4-door sedan as exemplary vehicles.

The Tesla's ADAS technologies were provided as supplemental emergency collision warning, mitigation, and avoidance aides. Their use still required the full and continual attention of the driver to monitor the traffic environment, maintain ultimate control of the vehicle, and remain prepared to take evasive action. The ADAS technologies were not capable of performing in every collision situation, and their limitations made it difficult for the system to recognize this specific crash due to the cross-path configuration of the involved vehicles' trajectories and the overall physical characteristics of the intersection/roadway. Based on the Tesla's data logs, the Tesla's ADAS technologies were functional at the time of the crash. Although they did not respond to an impending crash event, the SCI investigator was unable to identify any performance anomalies. It was also determined that the Tesla's driver had a clear and unobstructed view of both the intersection and turning tractor-trailer but made no attempt to avoid the crash, despite sufficient time to do so.

SUMMARY

Crash Site

The crash occurred at a four-leg intersection on an east/west divided roadway during afternoon hours. According to the National Weather Service, conditions in this rural area at the time of the crash included clear skies with a temperature of 27.2 °C (81 °F), 26-percent relative humidity, and 13 km/h (8 mph) northwesterly winds. Asphalt roadway surfaces were dry. The physical environment of the roadway was documented during the SCI crash site inspection using a Nikon Nivo 5.M+ total station. The eastbound roadway consisted of two travel lanes, divided from the westbound lanes by a 22.8 m (74.8 ft) wide grass median. A two-lane local roadway, oriented north/south across the divided roadway, formed the intersection. A median crossover supported the intersection and the traffic turning in multiple directions. On approach to the intersection, both portions of the roadway featured a third left-turn-only lane. All travel lanes were approximately 3.5 m (11.5 ft) wide. They were delineated by broken white lane lines, a single solid-white fog line, and a single solid-yellow median line. Outboard shoulders that were 1.8 m (5.9 ft) wide supported the travel lanes in both directions, with inboard shoulders that measured 0.5 m (1.6 ft) wide. Speed was regulated by a posted limit of 105 km/h (65 mph).

A review of historical data[1] concerning this intersection revealed that there were 11 traffic incidents reported from January 1, 2012, to December 31, 2016. Three were within a 0.4 km (0.25 mi) radius, but did not occur at or in the intersection. Of the remaining 8 incidents, 7 involved injury or fatality. The SCI investigator used this information to obtain police crash reports (PARs) for the 7 injury/fatality incidents. Including the subject crash, there were 7 vehicle occupant injuries and 2 vehicle occupant fatalities. The fatality incidents included the subject crash and another crash that occurred afterward. That crash involved a vehicle that entered the intersection from the local roadway and was struck on the driver's side by an oncoming vehicle.

[1] Geo-location Search, Florida's Integrated Report Exchange System (FIRES), July 28, 2017. Available at http://firesportal.com/Pages/Public/PublicSearchMap.aspx?Id=19&CL=1

For the Tesla's eastbound trajectory, the roadway was level for approximately 1 km (0.6 mi) and transitioned into an approximate 2.5 percent downgrade on approach to the intersection (**Figure 2**). The perceived crest of this transition was located 225 m (740 ft) west of the intersection. The roadway was level in the westbound trajectory of the Freightliner (**Figure 3**).

Figure 2: Eastbound trajectory view of the roadway and intersection for the Tesla's pre-crash travel.

Figure 3: West-facing view of the Freightliner's pre-crash trajectory on approach to the intersection.

Southeast of the intersection, a chain-link fence enclosed an expansive grass area. The fence paralleled the south roadway edge at a distance of 18 m (58.4 ft), beginning 51 m (167.3 ft) east of the south intersecting roadway. Between the roadway and the fence was an open, depressed grass swale. At a distance of approximately 230 m (755 ft) from the south intersecting roadway, the fence turned 90 degrees south and bordered a residential property line. The residence was served by a sand/gravel-surfaced driveway that began approximately 267 m (876 ft) east of the intersection. A wooden utility pole at the residence was located 34.5 m (113.2 ft) south of the south roadway edge. **Figure 4** depicts the chain-link fence and expansive grass area, while **Figure 5** depicts the utility pole, driveway, and yard of the residence. A Primary Impact Crash Diagram and Subsequent Impacts Crash Diagram are included at the end of this report.

Figure 4: East-facing view of the south roadside and grass area surrounded by the chain-link fence.

Figure 5: Northeast-facing view of the wooden utility pole (*replaced*) and driveway of the private residence.

Pre-Crash

On the day of the crash, the 40-year-old male driver was traveling eastbound on the divided roadway. Data from the Tesla indicated that the vehicle had been in operation for approximately 40.8 minutes, and the optional Autopilot Technology Package[2] was enabled by the driver. The Tesla's equipped ADAS technologies, including Autopilot, are described in detail on **Page 21** of this report. The autopilot system had been activated three times during the current driving cycle, and was last activated approximately 6.2 minutes prior to the crash. This occurred about 10.8 km (6.7 mi) prior to the crash, which correlated to shortly after the Tesla completed a right turn in a small town located west of the crash site. Following this Autopilot activation, the Tesla operated in restricted speed mode for about 1.4 km (0.9 mi) before it reached the town limits and the beginning of the divided roadway. At that point, approximately 5 minutes and 9.5 km (5.9 mi) prior to the crash, the driver set the cruise control speed to 105 km/h (65 mph). He adjusted the cruise speed upward three more times over the following three minutes. The last recorded action by the driver prior to the impact was the final speed increase to 119 km/h (74 mph), which occurred approximately 112 seconds prior to the crash.

During the course of this investigation, allegations that the driver of the Tesla was watching video entertainment at the time of the crash surfaced. An aftermarket laptop computer mount was observed to be installed in the front right seat position during the SCI vehicle inspection. This mount was fully adjustable, and enabled the driver to operate a laptop computer from the driver's seat position by reaching over the center console. Also, an Asus personal laptop computer was found in the Tesla, and was dimensionally compatible with the mount. Contrary to news media reports, no portable DVD player was found in the Tesla during the police or SCI vehicle inspections. While the Asus laptop computer was equipped with an optical disc drive, there were no polymer disc cases, compact discs, or any other evidence of home videos or movies found in the Tesla. Due to the fatal outcome of the driver and the inoperability of the electronics found in the Tesla during the SCI inspection, distraction of the driver by video entertainment relative to the crash remains unknown. The aftermarket mount and various electronics found in the Tesla are described on **Page 17** of this report.

Another allegation was that the Tesla passed a non-involved vehicle at high speed approximately 1.6 km (1.0 mi) west of the crash location. This allegation was reported by the driver of the non-involved vehicle, who came upon the crash and alleged to the investigating law enforcement agency that the Tesla passed her while she was operating her vehicle at 137 km/h (85 mph). However, the Tesla's data logs indicated that the cruise control had been set by the Tesla driver at 119 km/h (74 mph) and the vehicle was traveling for nearly 2 minutes at a consistent speeds of 118.9-119.3 km/h (73.9-74.1 mph). Prior samples in the data report were at lower speeds. This data refuted the non-involved vehicle driver's allegations.

[2] Model S Owner's Manual, Version 7, page 67, About Driver Assistance, Tesla, July 2016. Retrieved from www.tesla.com/sites/default/files/model_s_owners_manual_north_america_en_us.pdf

Regardless of the Tesla driver's engagement with the driving task, his level of distraction, or his travel speed, the Tesla was eastbound in the right lane. Meanwhile, the Freightliner was westbound on approach to the intersection. It was hauling a 16.1 m (53.0 ft) refrigerated semi-trailer laden with 16 pallets of produce equivalent to 9,072 kg (20,000 lb). Its 62-year-old male owner/operator merged into the left-turn-only lane with the intention of turning left at the intersection and proceeding south. He reduced and maintained speed control of the Freightliner truck tractor and UTI semi-trailer as he entered the median crossover.

During an initial SCI interview, the driver of the Freightliner did not provide pre-crash specifics and reported that he did not see the Tesla prior to the crash. A review of multiple news media reports published both before and after the initial SCI interview of the Freightliner driver revealed that his statements regarding the pre-crash circumstances of his operation of the truck tractor and his observance of oncoming traffic varied significantly. It should be noted that the driver had refused to provide a formal statement to the investigating law enforcement agency following the crash. Then, during a second SCI interview, the driver stated that he had brought the Freightliner to a complete stop in the median crossover and waited for an eastbound non-contact vehicle to pass. He further stated that he had momentarily observed that there were no vehicles in his sight line approaching the intersection from the west, and subsequently accelerated the Freightliner. During initial acceleration, he then detected the Tesla as it crested the transition into the downgrade approach to the intersection. He stated that he had perceived there was sufficient time for him to complete the left turn, based on the distance to the approaching Tesla in comparison to the time that it had taken for previous traffic to pass from the crest through the intersection.

Data from the Tesla indicated that there were no lead vehicles in its approximate 204.6 m (671.3 ft) line of detection. However, the term "lead" was presumably indicative of a vehicle directly in the same travel path as the Tesla, and not in adjacent lanes. Therefore, the vehicle that the Freightliner driver claimed to have waited for was likely either traveling in the left (inboard) lane, was beyond the distance of detection capability for the Tesla, or did not exist. The Tesla's data indicated that the only presence of a lead vehicle occurred from 2 minutes, 8 seconds prior to the crash until 1 minute, 38 seconds prior to the crash. Based on the reported lead distance, this unknown vehicle was traveling approximately 18 km/h (11 mph) faster than the Tesla. No other lead vehicles were detected by the Tesla prior to or leading up to the crash.

The Freightliner driver continued to accelerate the truck tractor and semi-trailer from the median crossover and began to cross over the eastbound lanes of the divided roadway. Given the time of day and position of the sun in relation to the horizon, the SCI investigation determined that visibility of the intersection and oncoming eastbound traffic on behalf of the Freightliner's driver would have been clear and unobstructed. This determination was supported by the observations of the SCI investigator and the data collected during the visibility study of the intersection, as detailed on **Page 19** of this report.

According to SCI documentation of the crash site, the distance along the arcing travel path from the westbound left turn-only lane to the southbound local roadway measured 58 m (190 ft). This was the total travel distance required for a vehicle of similar length to the Freightliner truck tractor with semi-trailer to turn from the westbound lanes through the median crossover, across both eastbound lanes, and entirely clear the intersection. The SCI investigator observed that the broad width of the median crossover allowed traffic intending to complete the left turn to proceed into the crossover prior to yielding to oncoming traffic. Assuming that the Freightliner followed this common travel path, the total distance required to complete the turn and clear the intersection was shortened to approximately 36 m (118 ft). The underride impact was located in the right eastbound lane in the intersection. Therefore, the Freightliner had traveled approximately 25 m (72 ft) through the turn when the crash occurred.

At a speed from 16 km/h (10 mph) to 24 km/h (15 mph), a vehicle would require 4.9 to 3.2 seconds, respectively, to complete the turn. However, the Freightliner driver reported that he stopped, waited for traffic to clear, and then accelerated. The SCI investigator ultimately concluded that the time required to accelerate the tractor-trailer from the median crossover to the point of impact was at least 6.3 seconds. This was calculated based on the assumption that the Freightliner accelerated at 0.11 G [equivalent to a rate of 1.08 m/s^2 (3.54 ft/s^2)], a value derived from research studies that evaluated the average acceleration of laden heavy trucks from a stopped position. See the ***Truck Tractor Speed Reconstruction***, included as **Attachment A**, for further detail regarding the speed reconstruction of the Freightliner/UTI semi-trailer.

At ground level, the distance between the topographical hillcrest and the area of impact measured approximately 225 m (740 ft). This equated to 7.7 seconds of travel time for a vehicle traveling at the 105 km/h (65 mph) speed limit. At the Tesla's average pre-crash speed of 119 km/h (74 mph), it would have traveled the distance from the hillcrest to the west aspect of the intersection in approximately 6.8 seconds. This coincided, within 0.5 seconds, to the calculated time required for the truck tractor and semi-trailer to accelerate from the median crossover and reach its at-impact positioning. The SCI investigator noted that the line of sight from the hillcrest to the intersection was clear and unobstructed. The afternoon positioning of the sun at the time of the crash was opposite the Tesla driver's heading angle, and therefore provided illumination of the objects in the Tesla's trajectory. Despite clear visibility, there was no physical evidence of any avoidance action by either driver prior to impact.

Crash

The front plane of the Tesla underrode the mid-aspect of the semi-trailer in the intersection, and the first crash event occurred as the base of the windshield and both A-pillars of the Tesla impacted and engaged the sill/frame of the semi-trailer's right plane/undercarriage. Directions of force were in the 12 o'clock sector for the Tesla and the 3 o'clock sector for the UTI semi-trailer. The Tesla maintained its momentum and completely underrode the semi-trailer, which sheared the entire greenhouse and roof structure from the Tesla.

During the underride impact, the driver's face and head contacted multiple intruding components. These contacts produced fatal injuries to the driver. Intruding components and the semi-trailer also contacted and deformed both front row seatbacks and all of the Tesla's structural pillars. The sheared roof and tailgate/hatch of the Tesla were captured by the right plane of the semi-trailer as the vehicle continued beneath it, and became deposited in the roadway at the location of the impact. A portion of the tailgate/hatch of the Tesla became folded over and was then dragged behind the vehicle as it maintained its momentum.

The Tesla exited from beneath the semi-trailer and coasted along the eastbound portion of the divided roadway. Without driver input, the Tesla drifted right and ultimately departed the right (south) roadway edge. It continued through the roadside swale and struck the wire fence (Event 2) approximately 193 m (633 ft) east of the intersection. Due to the flexible nature of the fence with respect to the mass and momentum of a vehicle, the Tesla displaced and penetrated through the fence as it maintained an errant trajectory into the expansive grass area. The Tesla traveled through the grass and then struck the fence a second time (Event 3) at the residential property line. Similarly, the Tesla again displaced and penetrated through the fence without alteration of its errant trajectory.

The fourth crash event then occurred as the left front corner of the Tesla struck the wooden utility pole in the yard of the residence. This impact was in the 12 o'clock sector for the Tesla. Crash forces sheared the wooden pole at ground level and induced a counter-clockwise rotation to the Tesla. The Tesla yawed counter-clockwise across the private driveway and into the front lawn, evidenced by arcing tire marks though the soft soil/sand surface.

Figure 6 depicts a look-back view from the residential property toward the utility pole and fence. The Tesla's tire marks are highlighted in the image using evidence-marking cones. The wooden utility pole had been replaced at the time of the SCI inspection. In the top left corner of the image, the intersection (location of initial impact) can be seen in the distance. The Tesla came to an uncontrolled rest in the front lawn of the residence, facing northeast. This final rest position was centered 29.9 m (98.1 ft) south of the roadway edge and 256.7 m (842.2 ft) east of the intersecting local road. In a straight-line trajectory, the location of the Tesla's center of mass (COM) at final rest was 270.2 m (886.5 ft) from the initial point of impact with the UTI semi-trailer.

Figure 6: West-facing view of the Tesla's yawing tire marks through the lawn of the residence and the location of the impacted utility pole (replaced). The intersection is visible in the distance in the upper left corner.

Post-Crash

The local emergency dispatch center received multiple communications reporting the crash and dispatched local law enforcement, fire department, and emergency medical services (EMS) to the crash scene. First-arriving units identified the unresponsive driver restrained in the Tesla, absent of life signs and obviously deceased. His body was later removed from the vehicle by the medical examiner.

The driver of the Freightliner exited his vehicle without assistance. He denied injury at the crash scene and was not medically treated or transported. However, as part of the law enforcement's routine investigation of the crash, the Freightliner driver was subjected to a blood draw by EMS personnel at the scene. The resulting substance screen ultimately tested positive for cannabis. As of the date of this technical report, the Freightliner driver had not been criminally charged in conjunction to the substance test results.

Both the Tesla and the Freightliner were removed from the crash scene and held in impound by the investigating law enforcement agency. Following completion of their investigation, the Tesla was released to its insurer. It was then transferred to the salvage facility where it was located for this SCI investigation. The Freightliner and UTI semi-trailer were returned to the owner, who traded the semi-trailer to a dealer for replacement. The UTI semi-trailer remained with that dealer at the time of the on-site SCI investigation.

2015 TESLA MODEL S 70D

Description

A placard found in the left front door frame identified the 2015 Tesla Model S 70D by the Vehicle Identification Number (VIN) 5YJSA1S26FFxxxxxx. The placard stated that the vehicle was manufactured in June 2015. It also declared that the Tesla's gross vehicle weight rating was 2,600 kg (5,732 lb) and had respective front and rear gross axle weight ratings of (1,276 kg 2,813 lb) and 1,500 kg (3,307 lb). The manufacturer's placard also identified that the recommended tire sizes/cold tire pressures for the Tesla were P245/45R19 at 310 kPa (45 PSI) for all tires.

The SCI investigator observed that the Tesla (**Figure 7**) was a four-door hatchback sedan, constructed on an aluminum chassis with aluminum and carbon fiber body paneling. At the time of the SCI inspection, the Tesla was equipped with a Goodyear Eagle RS-A2 tire at the left front position and Michelin Primacy Radial X tires at the left rear, right front, and right rear axle positions. All four tires were of the recommended size, and were mounted on the originally equipped aluminum-alloy wheels.

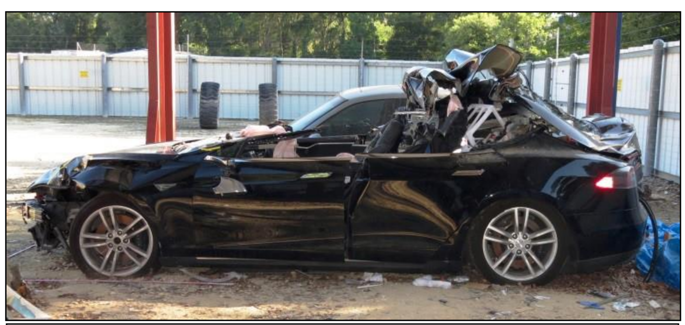


Figure 7: Left plane view of the 2015 Tesla Model S 70D sedan.

Specific tire data from the Tesla at the time of the SCI inspection is summarized in **Table 1**.

Position	Tire Identification Number (TIN)	Measured Pressure	Measured Tread Depth	Restricted	Damage
LF	M67V JE1R 1615	Tire Flat	3 mm (4/32 in)	No	None visible
LR	B9YP 005X 2315	276 kPa (40 PSI)	3 mm (4/32 in)	No	None
RR	B9YP 005X 2315	290 kPa (42 PSI)	3 mm (4/32 in)	No	None
RF	B9YP 005X 2315	290 kPa (42 PSI)	2 mm (3/32 in)	No	None

Table 1: 2015 Tesla Model S 70D tire data.

According to literature widely published by the Tesla's manufacturer,[3] the Model S was built on an all-wheel drive platform and was equipped with a pair of 257-horsepower electric motors. Its power was derived from a lithium-ion battery pack located under the floor of the vehicle between the front and rear axles (refer to **Page 16**). Manufacturer specifications[4] stated that the Tesla had a 296 cm (116.5 in) wheelbase and a curb weight of 2,108 kg (4,647 lb).

The SCI investigator observed that the 2015 Tesla Model S was configured for the seating of up to five occupants. The driver and front right seats were leather-surfaced, forward-facing bucket seats with integral head restraints. Both featured electronic seat track and seatback recline adjustments. At the time of the SCI inspection, the driver's seat appeared to be adjusted to its rearmost track position. A center console with armrest and storage space was located between the two front seats. The instrument panel featured a vertically oriented 43 cm (17 in) touchscreen, which controlled numerous vehicle operations and equipment.[5] The second row consisted of a leather-surfaced three-passenger bench seat with split folding backs (left side wide) that featured integral head restraints. All seat positions were equipped with 3-point lap and shoulder safety belt systems for manual restraint. Supplemental restraint was provided by front safety belt pretensioners, a frontal air bag system, front knee air bags, front seat-mounted, side-impact air bags, and inflatable curtain air bags. The 2015 Tesla Model S 70D received a 5-star rating[6] in NHTSA's New Car Assessment Program for the side and rollover crash tests.

According to a commercially available vehicle history report[7] based on the vehicle's VIN, the Tesla had only one reported owner in its lifetime. The diagnostic log data provided to the SCI investigator reported that the Tesla's odometer reading at the time of the crash was approximately 76,761 km (47,697 mi).

[3] Model S Premium Electric Sedan (brochure), Page 3, TESLA, July 28, 2017; website: www.tesla.com/sites/default/files/tesla-model-s.pdf
[4] Support: Model S Specifications, TESLA, July 28, 2017; website: www.tesla.com/support/model-s-specifications
[5] Model S Premium Electric Sedan (brochure), Page 11, TESLA, July 28, 2017; website: www.tesla.com/sites/default/files/tesla-model-s.pdf
[6] 2015 Tesla Model S 70D, Safety Ratings; National Highway Traffic Safety Administration, July 28, 2017; website: www.nhtsa.gov/vehicle/2015/TESLA/MODEL%252520S%25252070D/5%252520HB/AWD
[7] CARFAX Vehicle History Report, 2015 Tesla Model s 70D, VIN: 5YJSA1S26FFxxxxxx, June 17, 2016

Exterior Damage

The Tesla sustained damage on all planes associative to the events of the crash. Direct contact from the first event underride impact with the UTI semi-trailer began on the rear of the Tesla's hood at the center aspect, immediately forward of the base of the windshield. Damage on the left A-pillar began 6 cm (2.4 in) above the beltline, while the damage at the right A-pillar began 14 cm (5.5 in) above the beltline. These locations correlated to the bottom edge of the semi-trailer's sill and undercarriage. The entire roof structure and corresponding components of the Tesla from the beltline upward were sheared from the vehicle. The height above ground level of the impact damage measured 93 cm (36.6 in) on the left plane and 103 cm (40.6 in) on the right plane. The Collision Deformation Classification (CDC) assigned for the Event 1 underride damage profile was 12FDGW9.

No WinSMASH calculations could be performed due to the impact type that was outside of the model's scope. However, diagnostic log data from the Tesla indicated that an approximate 16 km/h (10 mph) reduction in vehicle speed resulted from the impact. **Figure 8** depicts the height of damage to the Tesla from the Event 1 underride impact.

Figure 8: Height of the damage pattern as viewed from the left plane Tesla.

Figure 9: Height of the damage patterns to the Tesla's right A-pillar.

Damage associated with the second and third event impacts with the wire fence was distributed across the front plane of the Tesla. Numerous abrasions and scratches were observed on the hood. An area of heavy abrasions was also observed on the lower aspect of the right A-pillar, where the fence wire was directed to the right of the Tesla and deflected beneath the right side mirror. This damage pattern was distinguishable from the first event damage by a void in the damage to the right A-pillar (**Figure 9**). There was no discernable deformation to the Tesla from either the second or third event impacts with the fence. The CDC for both events was 12FDEW1. These events were beyond the scope of the WinSMASH program.

The fourth crash event with the wood utility pole involved the front left corner of the Tesla. Direct contact damage began 65 cm (25.6 in) left of center and extended 26 cm (10.2 in) to the left front corner.

The combined direct and induced damage width (Field-L) measured 140 cm (55.1 in) across the front bumper beam's entire width. A residual crush profile was documented using a Nikon Nivo 5.M+ total station mapping system, which produced the following resultant measurements: C1 = 12 cm (4.7 in), C2 = 5 cm (2.0 in), C3 = 1 cm (0.4 in), and C4 - C6 = 0. Maximum crush was located at the left bumper corner (**Figure 10**). The left wheelbase was reduced 8 cm (3.1 in). The CDC assigned to the Tesla for the utility pole impact was 12FLEE2.

Figure 10: Overhead view of the Event 4 damage profile to the Tesla.

Crash forces sheared the utility pole at ground level and induced counter-clockwise rotation to the Tesla. The barrier algorithm of the WinSMASH model was used to calculate a borderline reconstruction of the crash event for analysis purposes. The total calculated delta V of the Tesla for the utility pole impact was 12 km/h (7 mph). Longitudinal and lateral components of the calculated delta-V were -12 km/h (-7 mph) and 0 mph, respectively. Based on SCI expertise, these reconstruction calculation results appeared reasonable.

Event Data Recorder

The 2015 Tesla Model S 70D was equipped with an air bag control module (ACM) that monitored and controlled the vehicle's active restraint systems (air bags and safety belt pretensioners). The ACM was not equipped with an EDR supported by the Bosch CDR software/tool. Therefore, no data could be imaged from the vehicle by the SCI investigator during the vehicle inspection. However, vehicle performance data were recorded in the vehicle's central computer, and a Gateway electronic control unit (ECU) continually wrote data to a diagnostic log while the vehicle was turned on. The diagnostic log file contained a subset of the messages received by the Gateway ECU and was stored on an SD memory card located in the Gateway.

Dependent upon the data element, the Gateway ECU wrote data to the log file continuously, at regular sampling intervals and/or intermittently, in response to changes in state, events, or alerts. The diagnostic log data could be retrieved from the vehicle telematically (through secure over-the-air communication) by the manufacturer or downloaded via physical connection by a technician with a valid vehicle-specific key. When those options were unavailable, such as due to collision damage, the data could be retrieved directly from the SD memory card by disassembling the vehicle's instrument stack and removing it from the ECU. Regardless of the retrieval method, the data log files were interpreted by the manufacturer using a proprietary method. The Tesla's SD memory card and diagnostic log data were removed by a Tesla representative prior to notification of the crash to SCI. A copy of the data was later provided to the SCI investigator for analysis purposes.

The Tesla's data was presented in a proprietary format and organized as a spreadsheet. Data contained multiple samples of several operational parameters, including vehicle speed, accelerator pedal position, brake status, steering wheel angle, cruise control state, lead vehicle presence and distance, front and rear motor torque, and vehicle odometer readings. Certain data were sampled in one-second intervals. The reported odometer reading at the time of the crash was 76,761.4 km (47,697.34 mi). Over a 6-minute interval leading up to the crash, the Tesla was traveling with the cruise control engaged at 119 km/h (74 mph). Autopilot was indicated "active." The vehicle's operational parameters were approximately constant over a nearly 2-minute time period leading up to the apparent time of the crash. A partial 10-second listing of the recorded pre-crash data is summarized in **Table 2**.

Time (seconds)	Vehicle Speed	Accelerator Pedal Position (percentage)	Brake Status	Steering Wheel Angle (degrees)
-10	119.3 km/h (74.1 mph)	0	Off	0.0
-9	119.3 km/h (74.1 mph)	0	Off	0.2
-8	119.3 km/h (74.1 mph)	0	Off	0.8
-7	119.3 km/h (74.1 mph)	0	Off	-0.3
-6	119.3 km/h (74.1 mph)	0	Off	0.4
-5	119.2 km/h (74.05 mph)	0	Off	-0.1
-4	119.2 km/h (74.05 mph)	0	Off	-0.2
-3	119.0 km/h (73.95 mph)	0	Off	-0.4
-2	119.0 km/h (73.95 mph)	0	Off	-0.5
-1	118.9 km/h (73.9 mph)	0	Off	-0.9

Table 2: Pre-crash data reported by the 2015 Tesla Model S 70D.

Multiple alerts indicative of a crash event were recorded. Aside from the distinct crash recognition flag, these included inverter faults and other operational warnings, driver's door open indication (likely due to B-pillar deformation), and power supply warnings. Over an approximate 2-second time interval, the reported vehicle speed decreased from 119.0 km/h (73.95 mph) to 102.9 km/h (63.95 mph). It was apparent that this data coincided to the underride impact with the semi-trailer (SCI Event 1). The vehicle then appeared to coast over an approximate 7-second interval, where its speed gradually decreased from 102.9 km/h (63.95 mph) to 87.1 km/h (54.15 mph). The next reported data sample included additional vehicle alerts consistent with a different collision, and included activation of the air bag warning lamp. Over the following 2-second time interval, the reported speed of the Tesla decreased from 78.09 km/h (49.05 mph) to 64.3 km/h (39.95 mph). It was apparent that this data coincided to the occurrence of the utility pole impact (SCI Event 4). Following this change in vehicle speed, the vehicle quickly decelerated and came to rest.

An analysis of the data revealed that an approximate 9-second interval was present between the two apparent distinct crash events. A time-distance analysis of the vehicle's reported speeds equated to an average speed of 96.5 km/h (59.98 mph), which revealed that the Tesla would have traveled approximately 241 m (790.7 ft) during this 9-second time interval.

In comparison to the SCI documentation of the crash site, this was equivalent to the distance from the location of the underride impact (SCI Event 1) in a near straight-line trajectory to the location of the impacted utility pole. This confirmed the SCI reconstruction of the crash events relative to the recorded data. It should be noted that the Tesla's data available to the SCI investigator did not contain any acceleration, vehicle velocity change (delta V), roll angle, or vehicle stability data.

Interior Damage

The interior of the Tesla was inspected for crash-related damage and occupant contact. Crash-related damage included the deployment of multiple supplemental restraint systems, as well as deformation and intrusion into the occupant compartment.

The entire roof structure of the Tesla was sheared from the vehicle during the underride impact. From essentially the beltline level and above, all components were separated and/or deformed and were directly contacted by the sill and undercarriage of the UTI semi-trailer. Both front row head restraints and the upper aspects of both front seat backs had multiple cuts and abrasions to their forward surfaces. The seatbacks were both deformed rearward (**Figure 11**) from engagement with the semi-trailer. None of the second row seats were damaged, as they were folded completely down to allow room for cargo carried in the vehicle at the time of the crash. Blood and body fluid splatter from the driver covered nearly every surface and component in the Tesla's interior. Deformation to both B-pillars separated the latch/striker of the front doors and prevented the opening of the rear doors. However, all doors remained closed during the crash. All glazing was fractured and/or disintegrated during the crash.

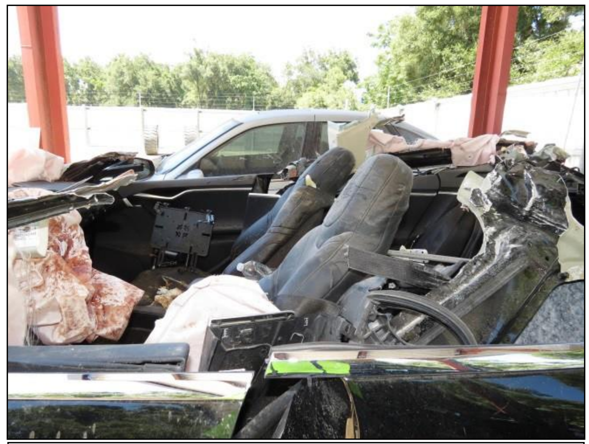


Figure 11: View of the Tesla and the sheared greenhouse, with rearward deformation to both front seats.

Manual Restraint Systems

The Tesla was equipped with 3-point lap and shoulder safety belt systems for all five seating positions. Both the driver's and front right occupant's safety belt systems utilized continuous-loop webbing with cinching latch plates. They were fixed height at their respective D-ring locations. The driver's safety belt system retracted onto an emergency locking retractor (ELR), while the front right safety belt used an ELR/automatic locking retractor (ALR). Both were equipped with lower anchor and retractor pretensioners. At the time of the SCI inspection, the webbing of the driver's safety belt system was locked in position as a result of pretensioner actuation.

Figure 12: The Tesla driver's 3-point lap and shoulder safety belt system.

The driver's cinching latch plate remained engaged in the buckle, and the webbing was cut 9 cm (3.5 in) above the lower anchor and 25 cm (9.8 in) below the D-ring. There was 69 cm (27.2 in) of webbing from the shoulder cut point to the latch plate, with an additional 45 cm (17.7 in) of webbing from the latch plate to the lap portion cut point (**Figure 12**). This represented 148 cm (58.3 in) of total webbing exposed. Based on exemplar measurements, the length of exposed webbing for the driver's position when the safety belt system was stowed was 70 cm (27.6 in). The length of exposed webbing observed in the Tesla correlated to the use of the safety belt system by the driver at the time of the crash.

Supplemental Restraint Systems

The Tesla was equipped with multiple inflatable supplemental restraint systems to provide occupant protection. The first was a Certified Advanced 208-Compliant (CAC) frontal air bag system, which consisted of dual-stage frontal air bags in the steering wheel and top instrument panel. The CAC system incorporated safety belt buckle switch sensors and seat track positioning sensors. Additional frontal protection incorporated lower instrument panel-mounted knee air bags for the driver and front right occupant positions. Both front row seat positions were further equipped with outboard seat-mounted side impact air bags. Finally, side impact IC air bags provided protection from the roof side rails to the beltline for the outboard aspect of both the front row and second row seat positions. Both frontal, both knee, and the driver's seat-mounted side impact air bags deployed in the crash. Due to vehicle damage and a lack of EDR data, the deployment status of the IC air bag systems could not be determined. The front right seat-mounted air bag did not deploy in the multiple event crash.

Figure 13: Deployed driver's frontal air bag covered in blood evidence within the Tesla.

The driver's frontal air bag deployed from the steering wheel hub-mounted module through the star-configured cover flaps without damage. In its deflated state, it measured 68 cm (26.8 in) in overall diameter. It was internally tethered and extruded a maximum of approximately 25 cm (9.8 in) rearward at its center aspect. A pair of 3 cm (1.2 in) diameter vent ports was located on the back side of the air bag, one each at the 10 o'clock and 2 o'clock positions. Nomenclature stamped on the driver's frontal air bag included "2482709 AD" and "06 08 15." The driver's frontal air bag was almost entirely covered in blood (**Figure 13**).

Figure 14: The Tesla driver's deployed knee air bag at the time of the SCI vehicle inspection.

The driver's knee air bag (**Figure 14**) deployed from the left lower instrument panel, beneath the steering column and bolster panel. It measured 60 cm (23.6 in) in overall width and 35 cm (13.8 in) in overall height in its deflated state. The air bag was pleated for expansion, but was not vented. Nomenclature included "2457461 AE," "512365478," and "05 06 15 MV." Although there was no discernable occupant contact to the face of the driver's knee air bag, there were several droplets of blood on its right aspect.

Figure 15: Deployed driver's seat-mounted side impact, frontal, and knee air bags within the Tesla.

The driver's seat-mounted side-impact air bag deployed through 52 cm (20.5 in) of stitching on the leading outboard aspect of the seatback (**Figure 15**). The air bag consisted of two primary fill portions, the upper portion of which measured approximately 24x42 cm (9.4x16.5 in) and the lower portion of which measured approximately 18x30 cm (7.1x11.8 in) in width by height, respectively. There were no visible vents. An 18 cm (7.1 in) vertically-oriented cut was observed to the forward lower aspect of the upper fill portion of the air bag. The origins of this cut remain unknown. The air bag was covered with blood on both sides.

Figure 16: The Tesla passenger's deployed frontal air bag at the time of the SCI vehicle inspection.

The passenger's frontal air bag deployed from the top instrument panel through the H-configuration cover flaps without damage. In its deflated state, the air bag measured approximately 60 cm (23.6 in) wide and 70 cm (27.6 in) tall, and extruded a maximum of approximately 35 cm (13.8 in) rearward at its center aspect. Internal tethers were affixed to the air bag's face. The front right passenger's frontal air bag had an area of abrasions and small cuts to its top aspect. It is possible that this damage was sustained post-crash as components of the Tesla were placed inside the vehicle and removed by various parties. There was also blood splatter from the driver on the left aspect of the deployed air bag's face (**Figure 16**).

The front right passenger's knee air bag deployed from the right lower instrument panel. It was dimensionally similar to the driver's knee air bag. Nomenclature stamped on the front right passenger's knee air bag included "2476450 AB," "513339455," and "27 05 15 MV." Although there was no discernable occupant contact to the face of the air bag, there was an area of blood on its left aspect. **Figure 17** depicts the passenger's knee air bag.

Figure 17: Left aspect of the deployed passenger knee air bag within the Tesla.

Lithium-Ion Battery

<u>Pre-Crash Condition</u>

The power of the Tesla Model S 70D was provided by a high-voltage lithium-ion battery, which was contained in an undercarriage-mounted pack. According to the vehicle's manufacturer[8], it produced the equivalent of 70 kWh and provided for a projected vehicle travel range of 386 km (240 mi) at an average speed of 89 km/h (55 mph). The battery pack was bolted to the undercarriage of the Tesla, and occupied the full-length area of the wheelbase and the full-width of the vehicle. Based on prior SCI joint-investigations with the vehicle's manufacturer, the SCI investigator was aware that the Tesla's battery pack was comprised of 6,216 cells of proprietary chemistry, distributed equally in 14 modules that were positioned in opposing rows of seven. Each module contained 444 cells, with the cells oriented vertically in seven distinct rows. Firewalls separated the modules to prevent damage to an adjacent module in the event of a cell or module issue/problem. Each row of 7 modules was designed to vent laterally out the sides of the vehicle in the event of a fire.

The battery pack was protected on its underside by a bottom tray. Manufacturer literature described this tray as being manufactured of armor-rated aluminum. Based on prior SCI investigations and previous SCI inspections of similar Tesla Model S vehicles, the tray measured 157 cm (62 in) in overall width, 253 cm (99.5 in) in overall length, and was approximately 6 mm (0.25 in) thick. Several skids were welded to the bottom of the aluminum battery tray, designed to protect both it and the internal lithium-ion battery modules from damage by exterior objects/impacts. The skids were I-shaped rails positioned in five rows of two along the length of the tray. There was no pre-existing damage to this vehicle's battery pack. Years prior to this crash, there were a few documented incidents involving objects striking the undercarriage of earlier Model S vehicles. These incidents resulted in fires in the lithium-ion battery pack. In response, the Tesla's manufacturer implemented a modification to the Model S line of vehicles that consisted of a titanium shield and aluminum deflector plates.

[8] Model S Premium Electric Sedan (brochure), Page 13, TESLA, July 28, 2017. Retrieved from www.tesla.com/sites/default/files/tesla-model-s.pdf

These components were mounted to the vehicle undercarriage between the left front and right front axle positions, at the forward aspect of the electric motor support frame and the forward aspect of the lithium-ion battery pack. The manufacturer had made this change effective for all Model S vehicles produced after March 6, 2014, and provided retrofit for all previously manufactured vehicles. That equipment was installed on the involved Tesla during initial manufacturing as standard equipment, preceding the owner's purchase.

Crash-Related Damage and Post-Crash Condition

Due to the severe damage to the Tesla and its location in the vehicle salvage facility, the SCI investigator had no means by which to raise the vehicle for inspection of the lithium ion battery pack or the vehicle's undercarriage. However, none of the crash events involved the Tesla's undercarriage or its battery pack. There was no evidence of any malfunction or damage to the battery pack in relation to the focus crash. During the SCI vehicle inspection, no evidence suggestive of compromise to the battery pack could be detected by the SCI investigator.

NHTSA Recalls and Investigations

A search for safety recalls based on the Tesla's VIN revealed that there were no active Recalls[9] concerning this specific 2015 Tesla Model S 70D.

Electronic Equipment Found in the Tesla

Multiple electronics were found in the Tesla during the SCI vehicle inspection. Most were computer networking hardware and components, relative to the driver's IT employment. Electronics of specific interest to the SCI inspection were a Samsung S22E310H monitor, an unidentified model Samsung cellular telephone, an Asus X551MAV-EB01-B(S) personal laptop computer with Mobotron mounting system, and the Tesla's console-mounted computer/display. The Samsung S22E310H monitor was a 55 cm (21.5 in) high-definition LED computer monitor. Although largely undamaged, there were a few blood droplets on both the front and back of the monitor. It is probable that this monitor was stowed in the second row or cargo area of the Tesla at the time of the crash.

The model of the Samsung cellular telephone could not be identified. Both the front and back surfaces were fractured, and the top right corner was deformed rearward (**Figure 18**). It was non-functional due to damage. Accompanying the device was a suction-cup mount, the stalk of which was fractured and the portion that would have held the device was missing. It is unknown if the mount was attached to the Tesla's windshield at the time of the crash.

Figure 18: View of the backside of the cellular telephone and the deformed top left corner.

[9]Safety Issues & Recalls, National Highway Traffic Safety Administration, July 28, 2017. Retrieved from www.nhtsa.gov/recalls

Figure 19: The Asus X551MAV-EB01-B(S) personal laptop computer found within the Tesla.

The Asus X551MAV-EB01-B(S) was a 40 cm (15.6 in) personal laptop computer (**Figure 19**). It was manufactured in December 2014, and was equipped with a 500 GB hard drive and an optical disc drive. The laptop's LCD was fractured, and the overall body was deformed. The deformation to the screen portion was such that the center aspect was deflected inward, and the outer edges were deflected upward. There were multiple scrapes and abrasions to the laptop's casement. The laptop was non-functional due to damage.

Figure 20: The Mobotron MS-526 stand/holder installed within the Tesla.

Also found in the vehicle was a Mobotron MS-526 heavy-duty laptop computer mount stand holder, attached to the right side of the front row right position's seat frame (**Figure 20**). The mount was fully adjustable, with telescopic height, swing arm, and cradle adjustments. The purpose of the mount was to allow an individual to operate a computer from the driver's seat position in a comfortable orientation while the vehicle is parked by reaching over the center console. Such mounts avoid the difficulty an individual would experience if they attempted to use a computer in the driver's seat position, where the steering wheel prevents comfortable positioning of a laptop. At the time of the SCI vehicle inspection, all adjustments were loose and the mount freely moved in all directions. No conclusions could be drawn concerning its pre-crash positioning and adjustments.

The SCI investigator noted that the location of the mount was on the outboard aspect of the front row right seat frame, rather than on the inboard aspect, which prevented adjustment of the mount's cradle over the center console or into the driver's seat position. It also prevented any individuals from sitting in the Tesla's front row right seat position. Although commonly used in fleet vehicles, it should be noted that similar mounts are also frequently installed in emergency services vehicles, such as law enforcement cruisers. In most cases, these mounts are typically installed on the inboard aspect of the right front seat, adjacent to the center console, in order to allow the emergency services official or employee to easily operate the cradled laptop from the driver's position during their shift.

The Mobotron mount installed in the Tesla was observed to be dimensionally compatible with the Asus laptop. There was no apparent damage to the mount, other than the deflection of a few of the cradle's adjustments. Based on the observations of the SCI investigator, it is probable that the Asus laptop was secured in the Mobotron mount at the time of the crash.

The final noteworthy electronic component found in the Tesla was the vehicle's on-board computer and display (**Figure 21**). The SCI investigator observed that the entire display and computer had been removed from the instrument panel prior to the SCI vehicle inspection. The SCI investigator later learned that the display and computer had been removed by the Tesla manufacturer's representative during a joint inspection with the investigating law enforcement agency, prior to SCI involvement. The computer display had been dismantled by the technician in order to retrieve the SD memory card that was located on one of the circuit boards. A review of images supplied by the police investigator relative to the images taken at the time of the SCI inspection indicated that a small circuit board measuring approximately 10 x 10 cm (4 x 4 in) also appeared to have been removed by the technician, and was not with the vehicle at the time of the SCI inspection.

Figure 21: View of the Tesla's center instrument panel at the time of the SCI inspection.

Crash Site Visibility Study

The SCI investigator returned to the crash site on December 1, 2016, to conduct a visibility study of the intersection and crash site. A rental sedan and a rental single-unit truck served as exemplar vehicles for reconstruction purposes during the SCI visibility study. The rental vehicles included a 2017 Buick Verano and a 2015 International 4300. The visibility study of the crash site sought to determine distances for visibility of the involved vehicles based on the positioning and location of the opposing vehicle, with respect to the intersection and crash site.

The 2017 Buick Verano had an overall length of 467 cm (184.0 in) and an overall height of 147 cm (58.0 in), which was dimensionally similar to the 2015 Tesla Model S. The exemplar driver's eye height in the Buick was 119 cm (47.0 in), and was in the 112-127 cm (44.0-50.0 in) likely range of the eye height of a driver in the 2015 Tesla Model S. The 2015 International 4300 was similar in size to the 2014 Freightliner Cascadia and 2003 UTI semi-trailer as viewed from the Tesla driver's oncoming perspective, with an overall length of 11.0 m (36.3 ft) and overall height of 3.8 m (12.6 ft). Furthermore, the 244 cm (96.1 in) eye height of the exemplar driver was in the 240-250 cm (94-98 in) likely eye height range of a driver in the 2014 Freightliner Cascadia.

Figure 22: Front left oblique view of the 2017 Buick Verano four door sedan.

Figure 23: Front left oblique view of the 2015 International 4300 single-unit straight truck.

The exemplar Buick and International are depicted in **Figures 22** and **23**, respectively. Note the target location markings on the vehicles, which were used to measure vehicle positions and calculate distances for the visibility study. A first set of data points (1A-1E) was gathered using the International 4300 positioned stationary at the end of the left turn lane at the intersection. A second set of data points (2A-2E) was then collected with the International 4300 positioned in the median crossover, as if in preparation for the execution of the left turn. Under both conditions, the Buick was operated eastbound in the south shoulder on approach to the intersection. An exemplar driver in each vehicle observed the opposing vehicle and identified when the described points of interest occurred. The Buick's position was marked for each point, and then documented using a Nikon Nivo 5.M+ total station. The distances presented in **Table 3** were calculated using the total station documented target locations on the windshield header of the Buick and on the cargo box of the International, adjacent to/above the respective driver's positions. A 61 cm (24 in) collapsible orange traffic cone was used as the object for documentation of data points AA and BB.

Data Point	Description	Distance from Buick to: International	Distance from Buick to: P.O.I.
1-A	Buick driver began to see International	432 m (1,417 ft)	417 m (1,368 ft)
1-B	International driver began to see Buick	398 m (1,306 ft)	382 m (1,253 ft)
1-C	International driver saw all of Buick	343 m (1,125 ft)	327 m (1,073 ft)
1-D	Buick driver saw all of International	302 m (991 ft)	286 m (938 ft)
1-E	Buick driver saw all of International and intersection	257 m (843 ft)	241 m (791 ft)
2-A	Buick driver began to see International	442 m (1,450 ft)	441 m (1,447 ft)
2-B	International driver began to see Buick	406 m (1,332 ft)	406 m (1,332 ft)
2-C	International driver saw all of Buick	362 m (1,188 ft)	361 m (1,184 ft)
2-D	Buick driver saw all of International	293 m (961 ft)	292 m (958 ft)
2-E	Buick driver saw all of International and intersection	247 m (810 ft)	246 m (807 ft)
AA	Buick driver began to see a 61 cm (24 in) tall object	N/A	327 m (1,073 ft)
BB	Buick driver saw all of a 61 cm (24 in) tall object	N/A	278 m (912 ft)

Table 3: Documented line of sight distances for the Buick and International during the SCI visibility study.

Based on the data collected during the SCI visibility study, the Tesla driver would have been able to see the Freightliner truck and UTI semi-trailer in the median crossover at a distance of at least 240 m (787 ft) from the point of impact. At the reported pre-crash speed of the Tesla, which was equivalent to 33.1 m/s (108.6 ft/s), its driver would have had unobstructed visibility of the truck and intersection for approximately 7.25 seconds before impact. For a vehicle traveling at the posted limit of 89 km/h (65 mph), the time of complete visibility of the International and intersection was approximately 8.25 seconds. The findings of the SCI study indicated that visibility for traffic at the intersection and along the roadway likely were not contributing factors to the crash. This supported evidence gathered during the SCI investigation and suggested that the Tesla's driver may have been distracted prior to the crash.

Crash Avoidance Systems and Advanced Driver Assistance Systems Discussion

The Tesla was equipped with advanced driver assistance technologies that incorporated operational and crash avoidance (CA) systems to improve vehicle safety performance and mitigate potential involvement in crash events. Specific components of the Tesla's safety and CA equipment included the optional Autopilot Technology Package, which included Traffic Aware Cruise Control (TACC), Autosteer (automatic lane centering and changing), Autopark, lane assist, collision avoidance assist, and speed assist.

The lane assist feature incorporated lane departure warning (LDW) with lane keeping and side collision warning (SCW), while the collision avoidance assist incorporated forward collision warning (FCW) and automatic emergency braking (AEB). Other features of the safety and CA equipment included daytime running lights, electronic stability control (ESC), electronic traction control (ETC), and blind spot detection (BSD).

The Autopilot Technology Package was made incrementally available by the manufacturer through software upgrades. Its primary function was to enable automated control of the vehicle's brakes, motors, and steering. The foremost technologies of the Autopilot system were the Autosteer and TACC capabilities. When both were enabled, the vehicle was said to be operating in Autopilot mode. Autosteer enabled the Tesla to maintain its travel lane and steer the vehicle in the lane. In conjunction with the TACC system, the Tesla could maintain highway-speed travel in traffic without driver input.

The TACC system detected the speed of other vehicles/objects in its travel path using information from the forward-looking camera and radar sensor. When no other vehicles/objects were in front of the Tesla, TACC maintained the speed selected by the driver. When a lead vehicle/object was detected that was traveling slower than the Tesla's set speed, TACC could adjust the Tesla's speed accordingly by controlling motor torques in order to maintain selected time-based distance from the lead vehicle/object. When the travel path was clear, the Tesla could accelerate and/or maintain its speed. This allowed the Autopilot to even be used in stop-and-go traffic under ideal circumstances.

GPS technology and digital mapping enabled the TACC system to recognize geography of the roadway and posted speed limits in the area in order to assist the driver in maintaining safe travel speeds. The Autosteer system used information from a forward- looking camera, radar sensor, and ultrasonic sensors to detect lane markings and the presence of vehicles/objects. It was capable of providing automated lane-centering steering control based on the lane markings and the vehicles/objects directly in front of the Tesla (if present). It also had the ability to change lanes by activating the turn signal indicator. Autosteer was only available when TACC was enabled.

The Tesla's FCW system incorporated a combination of cameras, sensors, and/or radar to detect vehicles/objects in the travel path and alert the driver of the potential for a crash event. An additional feature of AEB made the Tesla capable of applying the brakes when an impending crash event became imminent , and the driver neglected to respond to the warnings. The BSD system functioned by alerting the driver if a vehicle/object was in the blind spot areas at the rear corners of the Tesla, in order to prevent the driver from changing lanes or merging when another vehicle/object was in close proximity. Finally, the LDW system alerted the driver if the vehicle began to drift from its travel lane.

According to the vehicle's manufacturer, this specific 2015 Tesla Model S was using the most recent vehicle firmware, version 7.1 (2.17.37), at the time of the crash. This firmware update was received telematically by the vehicle in April 2016. The first update, which activated the Autosteer feature and enabled operation of the Tesla in Autosteer mode, was received telematically by the vehicle in October 2015. The vehicle's odometer reading at the time of the October 2015 update was approximately 24,353 km (15,132 mi). Based on the odometer reading at the time of the crash, the vehicle had traveled approximately 52,408 km (32,565 mi) after receiving the update leading up to the crash. The vehicle's manufacturer reported that, based on the Tesla's diagnostic log data, 42,448 km (26,376 mi) of the distance traveled since the October 2015 update (equivalent to 81%) was operated with Autopilot mode activated.

According to manufacturer literature, the Autopilot system was designed for use only on limited access divided roadways with prominent lane markings, during times of clear atmospheric weather conditions. With Autopilot turned on, and under these appropriate conditions, the Tesla had the capability to operate at highway speeds and travel without requiring input from the driver. However, the technology was not intended to entirely replace the human driver or remove the driver from the driving task. The vehicle was capable of monitoring driver engagement through interactions with the steering wheel, turn signal, and TACC speed-setting stalk. Drivers were required to maintain contact of their hands on the steering wheel and remain alert and in control of the vehicle at all times. To ensure this, an escalating series of warnings was presented when driver engagement was not detected for a period of time, which varied dependent upon road class, vehicle speed, roadway curvature, and traffic conditions.

The warnings began with a visual alert indicating that hands on the steering wheel were required. If the driver did not respond to the visual warning, an audible chime was sounded after 15 seconds. A more pronounced chime was initiated if the driver did not respond after another 10 seconds. If the driver did not respond to the third alert stage in 5 seconds, the system gradually slowed the vehicle while maintaining position in the lane. Once the driver's hands were detected on the steering wheel, the warnings were suspended and the Autopilot operation resumed.

Figure 24: View of the Tesla's computer and empty SD memory card slot at the time of the SCI inspection.

Data concerning the Tesla's operation and other parameters were monitored and recorded to a SD memory card that was located in a computer board that was affixed to the rear of the vehicle's console-mounted display. This card was removed by the Tesla manufacturer's representative prior to notification of the crash to SCI. The SCI investigator had no means by which to image or obtain any data from the Tesla during the inspection. **Figure 24** depicts the Tesla's onboard computer and empty SD card slot at the time of the SCI inspection. A copy of the data from the SD card was provided by the vehicle's manufacturer to ODI, who shared an electronic copy of the data with the SCI investigator for analysis purposes.

A review of the data revealed three distinct vehicle operation cycles (termed drive rail cycles) that occurred on the date of the crash. Specific time and distance duration data identified the separate operational cycles. The operational trip summary data included specifics concerning the driver's use of the Autopilot mode. His level of engagement with the system was also documented through counters of escalating warning activations. **Table 4** on **Page 24** provides a summary of the operational data on the date of the crash. **Table 5** on **Page 24** provides a summary of the Autopilot activation for the crash cycle.

Crash Date Drive Rail Cycle Data				
Drive Rail Cycle [*at least 0.16 km (0.1 mi) traveled*]	**DRC1**	**DRC2**	**DRC3**	**Total**
Autopilot activations	22	7	3	32
Driving time (hh:mm:ss)	2:04:47	1:20:16	0:40:47	4:05:50
Autopilot time (hh:mm:ss)	1:40:56	1:09:19	0:37:26	3:27:41
Percent time in Autopilot	81%	86%	92%	84%
Trip distance	169.3 km (105.2 mi)	117.5 km (73.0 mi)	65.2 km (40.5 mi)	352.0 km (218.7 mi)
Autopilot distance	152.0 km (94.5 mi)	112.5 km (69.9 mi)	63.0 km (39.1 mi)	327.5 km (203.5 mi)
Percent distance in Autopilot	90%	96%	97%	93%
Hands Not Detected Visual alerts	19	10	7	36
Hands Not Detected First Chime alerts	9	6	6	21
Hands Not Detected Enhanced Chime alerts	0	0	0	0
Hands Not Detected Slowing alerts	0	0	0	0
TOTAL HANDS NOT DETECTED ALERTS	28	16	13	57
Avg. response time to initial hands not detected alert (sec)	11.9	12.6	16.0	13.0
Hand Detections	43	17	10	70
Autopilot time with Hands Detected (h:mm:ss)	0:01:45	0:00:38	0:00:26	0:02:49
Autopilot time with Hands Not Detected (h:mm:ss)	1:35:55	1:08:05	0:37:00	3:21:00
Percent of Autopilot time with Hands Detected	1.8%	0.9%	1.1%	1.4%
Number of brake applications	37	14	5	56
Number of Steering Overrides	2	1	0	3

Table 4: Trip summary and ADAS operational data from the Tesla on the date of the crash.

Autopilot Activation During Crash Drive Rail Cycle				
Autopilot Activation	**AP1**	**AP2**	**AP3**	**Total**
Autopilot time (mm:ss)	20:58	10:17	6:11	37:26
Autopilot distance	34.0 km (21.1 mi)	18.2 km (11.3 mi)	10.8 km (6.7 mi)	63.0 km (39.1 mi)
Hands Not Detected Visual alerts	4	3	0	7
Hands Not Detected Chime alerts	3	3	0	6
Hands Not Detected Enhanced Chime alerts	0	0	0	0
Hands Not Detected Slowing alerts	0	0	0	0
TOTAL HANDS NOT DTECTED ALERTS	7	6	0	13
Avg. response time to initial Hands Not Detected alert (sec)	15.4	16.7	N/A	16.0
Hand Detections	5	4	1	10
Autopilot time with Hands Detected (mm:ss)	00:14	00:09	00:03	00:26
Autopilot time with Hands Not Detected (mm:ss)	20:44	10:08	06:08	37:00
Percent of Autopilot time with Hands Detected	1.1%	1.4%	0.9%	1.1%

Table 5: Summary of Autopilot data for the Tesla's active drive rail cycle at the time of the crash.

Conclusion

There were multiple allegations concerning the driver's operation of the Tesla, his level of engagement, and the overall circumstances of the crash. Questions also arose concerning the respective drivers' pre-crash operation of the Tesla and Freightliner, the visibility characteristics of the roadway and intersection, and the performance of the Tesla's ADAS technology and CA systems. Through a review of the data gathered during this investigation, and all information available concerning the Tesla as of the date of this technical report, the SCI investigator achieved the following conclusions:

(1) The Tesla's Autopilot system was engaged and the driver used the TACC and Autosteer features to maintain an eastbound cruising trajectory on the roadway at the time of the crash.

(2) Multiple sources of possible distraction were present in the Tesla at the time of the crash. Although there was evidence to suggest that the driver may have been distracted leading up to the crash, no conclusions regarding the driver's use of video entertainment could be made. Furthermore, due to the fatal outcome of the driver, the SCI investigator was unable to determine the specific sources and level of the driver's distraction from the driving task. During the most recent activation of Autopilot prior to the crash, there were no escalating warnings concerning driver inattention.

(3) Both the driver of the Freightliner and the driver of the Tesla had more than sufficient line-of-sight of the roadway, intersection, and opposing approaches. Visibility of the large semi-trailer and its engagement in a slow-speed turning trajectory across the Tesla's travel path was clear and unobstructed for the Tesla's driver. From the moment at which the Tesla's driver could have seen the entire Freightliner and intersection, the driver had more than 7 seconds to initiate avoidance action prior to impact.

(4) As the Tesla approached the intersection, the driver made no attempt to control the Tesla's trajectory, nor did he provide any steering or braking input in an attempt to avoid the crash.

(5) The Tesla's multiple ADAS and CA technologies, including Autopilot and FCW, were functional at the time of the crash. Although these technologies had limitations, the ADAS system did not respond to an impending crash event.

(6) Regardless of the operational status of the Tesla's ADAS technologies, the driver was still responsible for maintaining ultimate control of the vehicle. All evidence and data gathered concluded that the driver neglected to maintain complete control of the Tesla leading up to the crash.

2015 TESLA MODEL S 70D OCCUPANT DATA

Driver Demographics

Age/Sex:	40 years/Male
Height:	183 cm (72 in)
Weight:	86 kg (190 lb)
Eyewear:	No
Seat Type:	Forward-facing bucket seat with integrated head restraint
Seat Track Position:	Rearmost
Manual Restraint Usage:	3-point lap and shoulder safety belt
Usage Source:	Vehicle inspection
Air Bags:	Driver's CAC frontal, knee, and seat-mounted side-impact deployed; IC air bag available, unknown if deployed
Alcohol/Drug Involvement:	None
Egress From Vehicle:	None
Transport From Scene:	None
Type of Medical Treatment:	None

Driver Injuries

Injury No.	Injury	AIS 2015	Involved Physical Component	Confidence
1	Extensively lacerated upper brain stem	140212.6	Sill/undercarriage of semi-trailer	Certain
2	Extensively lacerated cerebrum	140688.3	Sill/undercarriage of semi-trailer	Certain
3	Extensively lacerated cerebellum	140474.3	Sill/undercarriage of semi-trailer	Certain
4	Open fracture of calvarium, with exposure and loss of brain tissue	150406.4	Sill/undercarriage of semi-trailer	Certain
5	Open fracture of skull base, with exposure and loss of brain tissue	150206.4	Sill/undercarriage of semi-trailer	Certain
6	Small contusions of right and left lungs	441411.3	Sill/undercarriage of semi-trailer	Probable
7	Fracture of bilateral maxilla	250800.2	Sill/undercarriage of semi-trailer	Certain
8	Fracture of bilateral mandible	250600.1	Sill/undercarriage of semi-trailer	Certain
9	Extensive lacerations of face	210604.2	Sill/undercarriage of semi-trailer	Certain
10	Extensive lacerations of the right fronto-parietal scalp	110600.1	Sill/undercarriage of semi-trailer	Certain
11	Extensive lacerations of the left superior frontal scalp	110600.1	Sill/undercarriage of semi-trailer	Certain

Injury No.	Injury	AIS 2015	Involved Physical Component	Confidence
12	Small contusions near tip of tongue	243401.1	Self-inflicted	Probable
13	Multiple linear and punctate lacerations to left cheek	210602.1	Sill/undercarriage of semi-trailer	Certain
14	Left cheek abrasions	210202.1	Sill/undercarriage of semi-trailer	Certain
15	Multiple linear and punctate lacerations to left mandible	210602.1	Sill/undercarriage of semi-trailer	Certain
16	Left mandible abrasions	210202.1	Sill/undercarriage of semi-trailer	Certain
17	Contusion to the right arm (10x4 cm), medial deltoid	710402.1	Sill/undercarriage of semi-trailer	Certain
18	Irregular abrasions to left arm (20x13 cm) from elbow to wrist along ulnar aspect	710202.1	Sill/undercarriage of semi-trailer	Certain
19	Multiple contusions to dorsum of left hand	710402.1	Sill/undercarriage of semi-trailer	Certain
20	Small irregular abrasions to dorsum of left hand	710202.1	Sill/undercarriage of semi-trailer	Certain
21	Small irregular abrasions to left fingers	710202.1	Sill/undercarriage of semi-trailer	Certain

Source – Autopsy Report (internal)

Driver Kinematics

The 40-year-old male was positioned in the driver's bucket seat of the Tesla. He had adjusted the seat to its rearmost track position, with the seatback slightly reclined. The driver used the available 3-point lap and shoulder safety belt system for manual restraint, determined through an inspection of the post-crash condition of the safety belt system.

As the Tesla traveled eastbound, it occupied the right (outboard) travel lane. It continued along a straight and level section, reached a hillcrest, and began to travel downslope on approach to the intersection. Although the Freightliner truck tractor with semi-trailer initiated a left turn across the Tesla's travel path in both drivers' line of sight, the driver of the Tesla did not provide any avoidance braking or steering action prior to impact. Injuries to the driver indicated that his head was turned to the right at the time of the crash. Although this was supportive of the allegations of distraction, no conclusion could be made with regard to the driver's level of attentiveness. The Tesla maintained a straight eastbound trajectory and underrode the semi-trailer. The upper A-pillars, windshield, and windshield header of the Tesla engaged the sill of the trailer at the mid-aspect of its right plane. Corresponding engagement sheared both pillars above the beltline, and began to shear/deform all components of the Tesla's greenhouse. The sill of the semi-trailer intruded into the occupant compartment space. Longitudinal forces were sufficient to result in the deployment of the Tesla's frontal air bags.

The driver responded to the frontal force by initiating a forward trajectory. He loaded the safety belt system, and remained restrained in the driver's seat position. As the Tesla maintained its forward momentum, the driver's upper torso and head contacted the intruding right sill and undercarriage of the semi-trailer. The driver's trajectory was reversed as the Tesla continued forward. Engaged against the sill of the semi-trailer, the driver was displaced rearward against the seatback. He contacted undercarriage components as the Tesla continued completely beneath the semi-trailer and continued eastbound along the divided roadway. The driver sustained numerous injuries as a result of contact and displacement with the sill and undercarriage of the semi-trailer, including open skull fractures with exposure and loss of brain tissue, extensive lacerations to the brain, and multiple other head and facial injuries. Injuries to the driver's left arm suggest that his left arm was raised at the time of the impact.

The deceased driver remained restrained in the Tesla as it traveled a distance along the roadway, departed the right side, and continued through the grass swale. The second and third crash events with the chain link fence produced forces that were not of sufficient magnitude to elicit a kinematic response from the driver's body. At impact with the utility pole, the driver's body initiated an abrupt forward trajectory. His body contacted the previously deployed frontal air bag, evidenced by blood transfer documented during the SCI vehicle inspection.

As the Tesla continued forward and initiated a CCW yaw, the driver's body remained forward and slumped over the steering wheel and deflated driver's CAC air bag. His body remained in that position as the Tesla finally came to rest, and as he was reportedly found by witnesses and on-scene emergency services personnel. The Tesla's final rest position was located more than 270 m (886 ft) from the initial point of impact with the semi-trailer. No medical treatment was rendered to the deceased driver. His body was later removed from the vehicle and transferred by the Medical Examiner to a local facility for autopsy.

2014 FREIGHTLINER CASCADIA / 2003 UTILITY TRAILERS INC. SEMI-TRAILER

Description

The 2014 Freightliner Cascadia was a conventional truck tractor identified by the VIN: 3AKJGHDV4ESxxxxxx. Odometer information was not available. An on-scene image of the Freightliner is depicted in **Figure 25**. The Freightliner was configured with two dual-wheel drive axles. No further information concerning the truck tractor or its history was available. The Freightliner was pulling a 2003 Utility Trailers dual-axle refrigerated box semi-trailer that was identified by the VIN 1UYVS25303Uxxxxxx.

Figure 25: Right front oblique view of the 2014 Freightliner Cascadia tractor-trailer (*on-scene image obtained from the investigating law enforcement agency*).

The UTI semi-trailer was manufactured in November 2002. It measured 16.15 m (53.0 ft) long, and had a placarded GVWR of 29,500 kg (65,000 lb). The trailer was loaded with 16 pallets of produce that weighed 567 kg (1,250 lb) each [combined cargo weight of approximately 9,072 kg (20,000 lb)] at the time of the crash.

Exterior Damage

The Freightliner truck tractor was not directly involved in any of the crash event impacts. As a result, no efforts were made to locate the Freightliner for inspection. The UTI semi-trailer had been held by the investigating law enforcement agency following the crash. After being released to its owner, it was transferred to a local yard and sold. The SCI investigator successfully located the UTI semi-trailer and achieved cooperation for inspection (**Figure 26**).

Figure 26: Left front oblique view of the 2003 Utility Trailers Incorporated refrigerated semi-trailer.

Damage to the semi-trailer was located at the base of the right plane and undercarriage near its center aspect.

In the damage pattern was a pair of penetrations through the sill panel and fascia of the semi-trailer's frame. These penetrations were caused by the respective left and right pillars/roof side rails of the Tesla as it engaged and underrode the UTI semi-trailer. Damage associated with the left aspect of the Tesla measured 55 cm (21.7 in) wide, while damage from the Tesla's right aspect measured 30 cm (11.8 in). The total width of the damage measured 195 cm (76.8 in). It began 681 cm (268.1 in) forward of the rear plane (320 cm [126.0 in] forward of the forward rear axle). In its post-crash position with its landing gear down, the bottom edge of the semi-trailer was 103 cm (40.6 in) above ground level. Appropriate retro-reflective conspicuity treatment adorned the UTI semi-trailer. **Figure 27** depicts the damage pattern to the semi-trailer from the Tesla. One of the lateral structural support beams of the semi-trailer's frame was sheared from the undercarriage (**Figure 28**) by the left aspect of the Tesla during the underride impact engagement.

Figure 28: Undercarriage damage to UTI semi-trailer and missing I-beam from engagement with the Tesla.

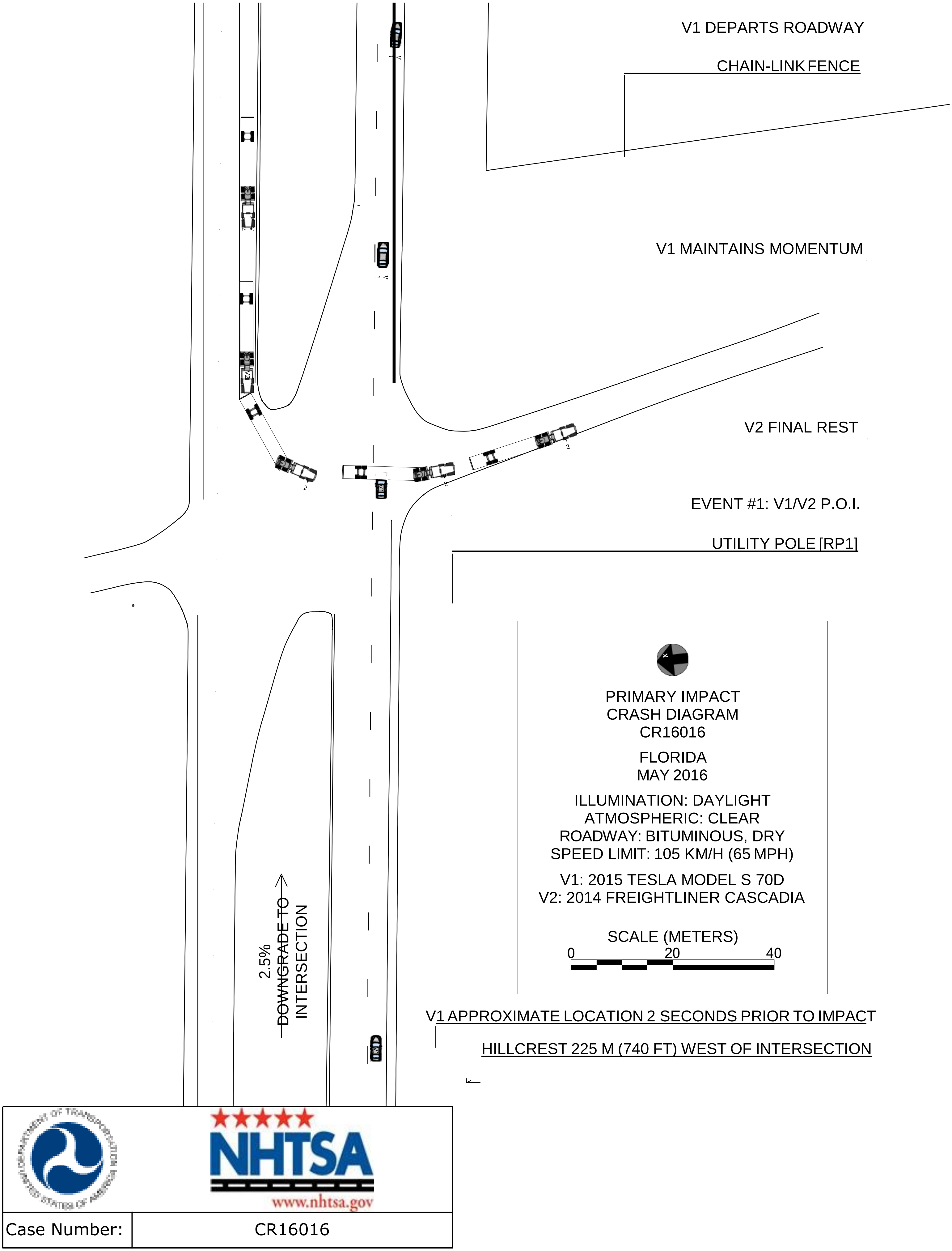
Figure 27: Damage to the right plane of the UTI semi-trailer from impact by the Tesla.

Minor deflection of the sill was observed on the left plane of the semi-trailer, indicative of the location of the Tesla's exit from beneath the semi-trailer. In the center aspect of the damage pattern on both sides was the location of the center amber marker light. Both amber lights were disintegrated. The right plane marker light mount was sheared from the semi-trailer's frame, while the left plane mount was deformed. The Truck Deformation Classification (TDC) assigned to the UTI semi-trailer was 03RTFRA. No WinSMASH calculations could be performed because the vehicle class, impact type, and lack of damage were beyond the scope of the model's capabilities.

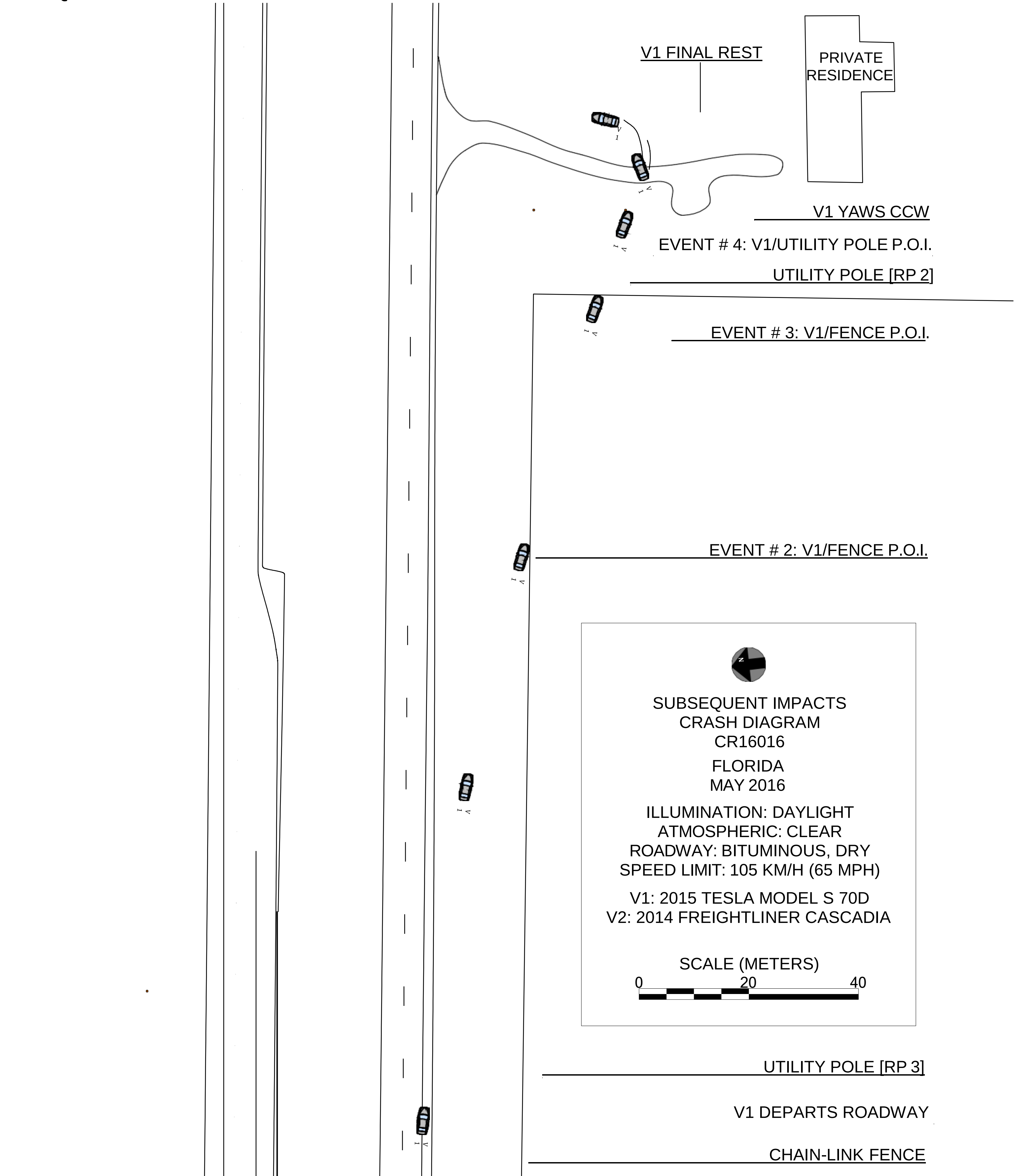
Occupant Data

The Freightliner was operated by a 62-year-old male driver at the time of the crash. According to official records documenting the crash (PAR), the driver was restrained by a 3-point lap and shoulder safety belt system. The Freightliner was not directly involved in any crash event impacts, and the driver was not subjected to any direct crash forces. He was not injured, and did not receive any medical treatment or transport.

PRIMARY IMPACT CRASH DIAGRAM



SUBSEQUENT IMPACTS CRASH DIAGRAM



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ATTACHMENT A

Truck Tractor Speed Reconstruction

Truck Tractor Speed Reconstruction

Time Distance Formulas:

$$S = \frac{1}{2} * a * t^2$$

$$V = a * t$$

S = distance traveled a = acceleration

t = elapsed time V = Speed (velocity)

The driver stated that he stopped in the crossover, waited for non-contact traffic, and then accelerated the vehicle across the eastbound lanes to the point of impact. Based on SCI observations at the scene, the approximate stopped location of the truck tractor is depicted on the drawing. From on this approximate location, the distance traveled by the truck tractor to the point of impact was approximately 25 m (82 ft). Note that the truck tractor does not travel along a curved path, rather it travels along a nearly straight path. Due to the length of the semi-trailer and its off-tracking at an intersection, the trailer does travel along a radius of approximately 26 m (85 ft). However, for the purposes of reconstruction, the path radius has no bearing on the time/distance analysis of the truck tractor.

Based on observational studies, the average acceleration of loaded heavy trucks has been measured to be approximately 0.11g. Therefore:

S = 82 ft

a = 0.11*g g = 32.2 ft/sec/sec

Substituting and solving:

Elapsed time from stop to POI: $t = SQRT\ \left(2 * \frac{82}{(0.11 * 32.2)}\right)$ t = 6.8 sec

Velocity at the POI based on constant average acceleration:

V = 0.11g *(6.8) = 24.1 fps = 16.4 mph = 26.4 km/h

Bracket the solution by varying the distance by ±15%

- If S = 82 ft +15% = 94.3 ft then $t = SQRT\ \left(2 * \frac{94.3}{(0.11 * 32.2)}\right)$ t = 7.3 sec
  - and V = 25.9 fps = 17.6 mph = 28.3 km/h

- If S = 82 ft – 15% = 69.7 ft then $t = SQRT\ \left(2 * \frac{69.7}{(0.11 * 32.2)}\right)$ t = 6.3 sec
  - And V = 22.3fps = 15.2 mph = 24.5 km/h

The truck tractor accelerated approximately 6.3 to 7.3 sec and reached a speed of 24 to 28 km/h (15 to 18 mph) based on the assumptions, research, and observations listed above. These assumptions and calculations have been performed in absence of any data from the Freightliner truck, which was not available as part of this SCI investigation.

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U.S. Department
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National Highway
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