Collision Between a Sport Utility Vehicle Operating with Partial Automation and a Crash Attenuator

Mountain View, California
March 23, 2018
Investigation Overview

Thomas Barth, PhD
Investigator-in-Charge
Crash Overview

- Friday, March 23, 2018
- 9:27 a.m.
- Mountain View, California
- US-101 / SR-85 interchange
- 2017 Tesla Model X SUV
- 38-year-old driver
- Partial automation “Autopilot” engaged
Crash Sequence

CRASH ATTENUATOR WAS COLLAPSED AND NONOPERATIONAL PRIOR TO THE CRASH

Source: Caltrans
Crash Sequence

Time to crash: 7.9 seconds
Speed: 64.3 mph
Lead vehicle: 83.7 feet
Distance to crash: 748 feet
Crash Sequence

- Time to crash: 5.9 seconds
- Steering: 5.6 degrees left
- Speed: 64.1 mph
- Lead vehicle: 82 feet
- Distance to crash: 560 feet
- Indication: Hands-off steering wheel

Lead vehicle

Crash attenuator
Crash Sequence

Time to crash: 3.9 seconds
Speed: 61.9 mph
Lead vehicle: None detected
Distance to crash: 375 feet
Vehicle begins to accelerate
Hands-off steering wheel indicated

Lead vehicle (no longer followed)

Crash attenuator
Barricade and cones placed in advance of attenuator prior to crash

Impact speed: 70.8 mph

Source: CHP
Crash Sequence

Source: S. Engleman
Vehicle Damage and Occupant Injuries

2017 Tesla Model X
• 38-year-old driver
• Fatal injuries

2010 Mazda 3
• 25-year-old driver
• Minor injuries

2017 Audi A4
• 51-year-old driver
• No reported injuries

Source: S. Engleman
Emergency response and electric vehicle fire issues will be covered in a future report
Investigative Staff

• Tom Barth, PhD – IIC / Vehicle and Survival Factors Investigator
• Don Karol – Project Manager / Highway and Human Performance Investigator
• Bob Swaim* – Tesla Battery Examination

* Denotes staff who are no longer NTSB employees
Report Development Staff

- Ensar Becic, PhD – Human Performance and Automation
- Bob Squire – Reconstruction
- Monica Mitchell – Writer / Editor
- Charlotte Cox – Writer / Editor
- Dan Horak, PhD – Data Analysis
- Ivan Cheung, PhD – Mapping
- Chris O’Neil – Media Relations
- Julie Perrot – Safety Recommendations
- Jane Foster* – Vehicle Recorders
- Ryan Cudemus-Brunoli* – Intern

* Denotes staff who are no longer NTSB employees
Parties to Investigation

• California Department of Transportation (Caltrans)
• California Highway Patrol (CHP)
Noncontributing Factors

• Driver licensing or qualification
• Driver familiarization with the vehicle and roadway
• Medical conditions
• Fatigue
• Impairment by alcohol or other drugs
• Weather conditions
Safety Issues

- Driver distraction
- Risk mitigation pertaining to monitoring driver engagement
- Risk assessment pertaining to operational design domain
- Limitations of collision avoidance systems
- Insufficient federal oversight of partial driving automation systems
- Need for event data recording requirements for driving automation systems
- Highway infrastructure issues (safety recommendation report issued in August 2019)
Other NTSB Investigations

Lessons learned from three other Tesla crashes were incorporated into the Mountain View crash investigation:

- Williston, Florida
- Delray Beach, Florida
- Culver City, California
Williston, Florida (May 7, 2016)
Delray Beach, Florida (March 1, 2019)
Culver City, California (January 22, 2018)

Source: CHP
Autopilot Performance and Cell Phone Distraction

Don Karol
Overview

• Autopilot system performance
• Driver performance
• Portable electronic device distraction
  - Need for technological solutions
  - Employers’ role in combating cell phone distraction
Levels of Automation

0. No Automation
1. Driver Assistance
2. Partial Automation
3. Conditional Automation
4. High Automation
5. Full Automation

- Supervise automation
- Maintain awareness
- Understand limitations
- Intervene when needed
Autopilot Description

- Monitors travel path
- Maintains set cruise speed
- Maintains vehicle’s position in travel lane
- Brakes when detecting slower-moving vehicles ahead
- Decelerates and follows vehicles ahead at a predetermined following interval
Autopilot Description

- Traffic-Aware Cruise Control (TACC)
  - Longitudinal control (acceleration and deceleration)

- Autosteer lane-keeping assist system
  - Lateral control (maintains lane position)
  - Inadequate sensor input: “Autosteer is temporarily unavailable”
Autopilot Performance

• Autosteer lane prediction and steering
  - Determined by vehicle’s vision system, containing cameras and computing software

• Autosteer operation can be hindered if:
  - System cannot determine lane markings
  - Bright light is interfering with cameras’ view
  - Visibility is poor
  - Cameras are obstructed
Autopilot Performance

- Lane markings were worn
- Autosteer vision system likely lost lane line prediction
- Identified stronger lane line
- Steering movement likely due to vision system limitations
Driver Performance

- Driver had unobstructed view
- Numerous visual cues of hazard ahead
- Driver took no evasive braking or steering action
- Level of inaction indicates inattention to forward roadway
- Driver not supervising Autopilot
Portables Electronic Device Distraction

- Driver used game application on phone
- Cell phone game application active during crash
- Cell phone data consistent with gaming activity
- Unknown if driver was holding phone
- Tesla Carlog data – hands likely off steering wheel
Portable Electronic Device Distraction

- Interacting with a game application – highly distracting
- Involves 3 major types of distraction:
  - Visual
  - Manual
  - Cognitive
- Significantly impairs driver performance
- Crash risk is higher
Combating Portable Electronic Device Distraction

- Efforts have focused on:
  - Legislation
  - Enforcement
  - Education
- Mobile device distraction not decreasing
- Additional countermeasures needed
Technological Solution: Lock-Out Distraction

• Applications that block distraction are available
  - Voluntary activation
  - Not widely used
• Cell phone manufacturers can eliminate distraction
• Lock-out mechanism should be installed as default setting
• Automatically lock out distraction when vehicle is in motion
Employers’ Role in Combating Distracted Driving

• Tesla driver was an Apple employee driving distracted
• Apple, Inc. has no policy prohibiting cell phone use while driving
• Strong policy is an effective strategy
• OSHA can do more to educate employers
• OSHA can increase enforcement
Summary

- Tesla Autopilot vision system limitations
- Driver’s lack of response likely due to cell phone distraction
- Cell phone distraction countermeasures needed
- Distracted driving lock-out mechanism shows promise
- Strong employer cell phone policies needed
- OSHA can do more to educate employers and increase enforcement
Partial Driving Automation and Collision Avoidance Systems

Ensar Becic, PhD
Overview

- Operational design domain (ODD)
- Monitoring driver engagement
- Collision avoidance system (CAS)
Operational Design Domain

• Conditions in which an automated system is designed to operate
  - Geographic location, roadway type and markings, speed range, weather conditions
• ODD constraints are designed to reduce the effect of Level 2 limitations
ODD Constraints

• Autopilot, stated in vehicle manual, is
  - *Not for use* on city streets, in constantly changing traffic conditions, on winding roads with sharp curves
  - *For use only* on divided highways with limited access
• The system allows a driver to use Autopilot outside its ODD
• Level 2 system limitations are industry-wide
Geographic ODD: Mountain View

- Crash location
  - Highway with center median divider
  - Limited access (no cross-traffic)
  - Major interchange (changing traffic conditions)
- Tesla stated ODD does not apply to Level 2 systems
Geographic ODD: Williston and Delray Beach

- **Williston crash location**
  - Outside ODD of Autopilot

- **Delray Beach crash location**
  - Highway with center median divider
  - Not limited access (has cross-traffic)
  - Outside ODD of Autopilot
Needed ODD Improvements

• Manufacturers should include system safeguards to limit the use of Level 2 systems to conditions for which they are designed (H-17-41)

• NHTSA should verify that manufacturers are incorporating the safeguards (H-17-38)
  - Lack of guidance on identifying ODD
Monitoring Driver Engagement

• Driver monitors environment in Level 2 systems
  - Tesla stated that Autopilot can be used on undivided roads with an *attentive* driver
  - Risk of automation complacency and misuse
• Tesla’s method of monitoring driver engagement
  - Driver-applied steering wheel torque
  - System provides series of warnings to driver (visual, 3 stages of auditory warnings)
Driver Engagement: Mountain View

- The crash trip lasted 28.5 minutes.
- Autopilot was engaged for the last nearly 19 minutes.
- Lack of responsiveness indicates distraction and overreliance on automation.
Driver Engagement: Other Level 2 Crashes

- Williston and Delray Beach, Florida; Culver City, California
  - Driver-applied steering wheel torque not detected at time of impact
  - Prolonged inattentiveness by drivers
  - Drivers were ineffective monitors
- Humans are poor monitors of automation
- Monitoring of steering wheel torque is a poor surrogate measure of driver engagement
Needed Driver Monitoring Improvements

- Manufacturers should implement more effective means of monitoring driver engagement when using Level 2
- NHTSA and SAE should develop performance standards for driver monitoring systems to address automation complacency
- An engaged driver remains a critical component even with advanced driver assistance systems
Forward Collision Avoidance Systems

• FCW and AEB
  - Designed to prevent / mitigate rear-end crashes
  - Not required equipment on vehicles

• NHTSA testing protocols developed for NCAP
  - Maximum speed of 45 mph
  - Using only specific vehicle profile targets
  - No requirements to detect non-vehicles
Forward CAS: Mountain View

• Forward CAS are standard equipment on Tesla
  - FCW and AEB have passed NHTSA’s testing protocols

• Mountain View
  - Tesla traveling > 65 mph
  - Approaching an object the system is not designed to detect
  - FCW and AEB did not activate
Forward CAS: Other Level 2 Crashes

• Williston and Delray Beach, Florida
  - Tesla traveling > 65 mph
  - Struck a cross-traffic combination vehicle
  - FCW and AEB did not activate

• Culver City, California
  - Struck a fire truck (vehicle profile not designed or tested for)
  - FCW activated too late for driver to respond (490 msec)
Needed Forward CAS Improvements

• NHTSA should expand testing protocols to include highway speeds and various target profiles, including roadside hardware (H-15-4)

• Improve the effectiveness in domains in which partially automated vehicle systems operate
Summary

• Level 2 systems have limitations, but can improve
  • Defining their ODD and limiting the use to domains for which they are designed
  • Due to risk of automation complacency, effective monitoring of driver engagement is critical

• Forward CAS have limitations, but can improve
  • Broader and challenging testing protocols can incentivize manufacturers to accelerate development
Federal Oversight of Partial Driving Automation Systems

Don Karol
Overview

- DOT and NHTSA oversight
- NHTSA enforcement of safety-related defects
Nonregulatory Approach to Automation

- Removing unnecessary barriers to innovation
- Voluntary guidance rather than regulations
- Guidance focused on Level 3 – 5 systems
- Action based on safety-related defect trends
- Requires robust defect investigation program
NHTSA Enforcement and Defect Investigations

- Evaluate new technology for “unreasonable risk to safety”
- Manufacturers must account for foreseeable misuse
- Systems must account for foreseeable driver inattention
- Forward-looking risk analysis required in investigations
NHTSA Investigation of Tesla Autopilot System

- NHTSA ODI evaluation of Tesla Autopilot found no defects
- Evaluation did not thoroughly assess:
  - Effectiveness of driver monitoring system
  - Foreseeable future misuse of system
  - Risk of future use of system outside ODD
  - Risks associated with system limitations
- NHTSA further evaluation of Tesla Autopilot needed
Summary

- “Hands-off” approach to oversight
- Safety depends on strong defect investigation program
- Shortfalls found in NHTSA’s defect investigation
- Further evaluation of Tesla Autopilot needed
Overview

- Continuously recorded electronic vehicle data
- Crash event data recorders (EDR)
- Data integration for vehicles equipped with advanced driver assistance systems (ADAS)
- Previous recommendations
Continuously Recorded Data

- Records engagement and status of ADAS
- Potentially stored on board vehicle with periodic wireless submission to manufacturer
- Proprietary naming convention and data format requires interpretation by manufacturer
Crash Event Data Recorders

- EDR is a function in the airbag or restraint control module
- Recording begins with crash event or trigger threshold
- EDR is not required by regulation
Crash Event Data Recorders

- If an EDR is installed, 49 CFR Part 563 defines purpose, application, and data-recording requirements
  - Recording of time-series data just prior to and during an event
  - Specifies format of data
  - Minimal survivability requirements for data
  - Data retrievable and interpretable through commercially available means
Crash Event Data Recorders

- Minimum 15 data elements
- Guidance for 30 additional data elements
- Guidance for survivability
- Commercial accessibility
Automated System Data Challenges

• Crash data recorded in airbag control modules contain no ADAS performance information
• ADAS data is not accessible to investigators without manufacturer assistance
• Standard set of parameters is needed to assess driver and vehicle performance
Previous Recommendations

Issued to the US DOT and NHTSA

- Define data parameters for automated vehicles (H-17-37)
- Apply these data parameters as benchmarks for new vehicles (H-17-39)
- Define standard format for reporting system data (H-17-40)
Summary

- Data is crucial for crash investigations
- ADAS data is not recorded by typical EDR functionality
- ADAS data parameters need to be defined
- ADAS data needs to be readily accessible and interpretable by crash investigators
Driver Engagement: Mountain View

- The crash trip lasted 28.5 minutes
  - Autopilot was engaged for the final nearly 19 minutes
Driver Engagement: Mountain View

- Two visual warnings; one auditory warning
Driver Engagement: Mountain View

• Lack of responsiveness indicates distraction and overreliance on automation