Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck Near Williston, Florida May 7, 2016
Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck Near Williston, Florida

Deb Bruce, PhD
Investigator-in-Charge
On-Scene Staff

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- Deb Bruce, PhD, IIC and Highway Factors
- Jerome Cantrell, Vehicle Factors and Motor Carrier Operations
- George Haralampopoulos, Recorders
- Robert Squire, Accident Reconstruction
Investigative Team

- Jane Foster, Electronics Engineering
- Joseph Gregor, PhD, Recorders
- Shane Lack, Simulation Analysis
- Michael LaPonte, Motor Carrier Analysis
- Mary Pat McKay, MD, Medical Analysis
- Alice Park, Animation
- Kristin Poland, PhD, Traumatology
- Kevin Renze, PhD, GeoData Analysis
Report Development Staff

- Deb Bruce, PhD, Project Manager
- Jesus Cudemus, Visual Information Specialist
- Eric Emery, PhD, Mapping Graphics
- Elias Kontanis, PhD, Transportation Disaster Assistance
- Christopher O’Neil, Media Relations
- Gwynne O’Reagan, Writer-Editor
- Julie Perrot, Safety Recommendations
- David Tochen, Legal Counsel
Parties to the Investigation

• Tesla Inc.
• Florida Highway Patrol
Safety Issues

- Operational design domains for vehicle automation
- Monitoring of driver engagement
- Event data recorders for automated vehicles
- Safety metrics and exposure data
- Vehicle-to-Vehicle communication requirements
Last slide with NTSB 50th Anniversary Commemorative Emblem - Making Transportation Safer Yesterday, Today, Tomorrow.
Collision Overview

Robert Squire
Location and Pre-Impact Movement

Google Earth image 11/2016 (modified)
Post-Impact Movement

Google Earth image 11/2016 (modified)

Departure from pavement
Fence impacts
Pole impact
Position of rest
Highway - Westbound
Highway - Eastbound
Vehicle System Data

- System performance data indicated—
  - Automated vehicle control features were in use
  - Cruise control speed was set for 74 mph
  - No driver interaction since last setting of cruise control
    ~2 minutes before crash
- No electronic or physical evidence of precollision evasive action by either vehicle
Collision Animation

**Truck Motion Scenarios**

**Car Speed Remained Constant**

**Scenario A**

Approximate crest of hill

**Scenario B**

Approximate crest of hill

**Car speed:** 74 mph  
**Time to Collision:** 10.4 sec  
**Distance to Collision:** 1128 ft

100 ft

NTSB 50  
Making Transportation Safer  
YESTERDAY ★ TODAY ★ TOMORROW
Vehicles

Courtesy of Florida Highway Patrol
Summary

• The Tesla was operated using automated vehicle control features
• The highway sight distance was sufficient and time was available for either driver to have acted to avoid the crash
• The Tesla system data provided no indication of driver interaction with the vehicle after the final cruise speed was set
Making Transportation Safer

National Transportation Safety Board 1967 2017

Yesterday * Today * Tomorrow
Level 2 Vehicle Automation

Ensar Becic, PhD
Overview

• Tesla Model S 70D
  • Autopilot

• Level 2 automation systems
  • Operational Design Domain
  • Monitoring driver engagement

• Tesla driver actions
Tesla Model S 70D

- Collision prevention/mitigation systems
  - Forward collision warning
  - Automatic emergency braking
  - Lane departure warning
- Driver assistance systems
- Autopilot
Autopilot

- Traffic-Aware Cruise Control (TACC)
  - Longitudinal control (acceleration and deceleration)
- Autosteer
  - Lateral control (maintaining lane position)
- Auto Lane Change
  - Automatic lane change upon driver request
- Firmware version 7.1
Autopilot

• TACC availability
  • Available above 18 mph
**Autopilot**

- TACC availability
  - Available above 18 mph
- Autosteer availability
  - Lane markings detected
  - TACC is engaged
Autopilot

- TACC availability
  - Available above 18 mph
- Autosteer availability
  - Lane markings detected
  - TACC is engaged
- Limitations
  - Roadway
  - Environmental
Autopilot

- Monitors the traveling path
- Maintains set cruise speed
- Maintains vehicle’s position in the travel lane
- Brakes when it detects a slow-moving vehicle ahead
  - Decelerates and follows the vehicle at a predetermined following distance
- Driver is responsible for monitoring driving environment
Overview

• Tesla Model S 70D
  • Autopilot

• Level 2 automation systems
  • Operational Design Domain
  • Monitoring driver engagement

• Tesla driver actions
**SAE Automation Taxonomy**

- SAE International: Categorization of 5 levels of automation systems
  - From a vehicle with no automated systems to a self-driving vehicle

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
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</thead>
<tbody>
<tr>
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<td>No Automation</td>
<td>The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
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<td>n/a</td>
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<td>Driver Assistance</td>
<td>The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
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<td>4</td>
<td>High Automation</td>
<td>The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
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<td>5</td>
<td>Full Automation</td>
<td>The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
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# SAE Automation Taxonomy

- **SAE International:**

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### SAE Automation Levels

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### SAE Automation Taxonomy

**Tesla’s Autopilot**
- Provides lateral and longitudinal control

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**Human driver monitors the driving environment**

**Execution of Steering and Acceleration/Deceleration**

**Monitoring of Driving Environment**

**Fallback Performance of Dynamic Driving Task**

**System Capability (Driving Modes)**
### SAE Automation Taxonomy

**Tesla’s Autopilot**
- **Level 2 automation**

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- **Execution of Steering and Acceleration/Deceleration**
  - System
  - Human driver

- **Monitoring of Driving Environment**
  - Human driver

- **Fallback Performance of Dynamic Driving Task**
  - Human driver

- **System Capability (Driving Modes)**
  - Some driving modes

*NTSB* 50th Anniversary Logo: *Making Transportation Safer*
# SAE Automation Taxonomy

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*Human driver monitors the driving environment*

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**Automated driving system (“system”) monitors the driving environment**

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Overview

• Tesla Model S 70D
  • Autopilot
• Level 2 automation systems
  • Operational Design Domain
  • Monitoring driver engagement
• Tesla driver actions
Autopilot: Operational Design Domain

• Operational Design Domain (ODD)
  • Conditions in which the automated system is designed to operate

• ODD constraints
  • System-based implementation (hard constraint)
  • User-based adherence (soft constraint)
Roadway ODD: System-Based

- Autopilot availability
  - Any roadway with adequate lane markings
- Autopilot constraints
  - Maximum cruise speed of 45 mph when speed limit is not detected
  - Maximum cruise speed of 5 mph over the speed limit on roads without central median divider
  - Maximum cruise speed of 90 mph on roadways with central median divider, regardless of speed limit
Roadway ODD: User-Based

• Driver informed of the constraints through vehicle manual

• Vehicle manual includes warnings pertaining to the intended use of Autopilot
  • Roadways
  • Driver role
Roadway ODD: User-Based

Warning: Autosteer is intended for use only on highways and limited-access roads with a fully attentive driver. When using Autosteer, hold the steering wheel and be mindful of road conditions and surrounding traffic. Do not use Autosteer on city streets or in areas where bicyclists or pedestrians may be present. Never depend on Autosteer to determine an appropriate driving path. Always be prepared to take immediate action. Failure to follow these instructions could cause serious property damage, injury or death.
Roadway ODD: User-Based

US-27A
- 4-lane roadway
- With central median divider
- Not limited access
Roadway ODD: User-Based

SR-24
- 2-lane roadway
- No central median divider
- Not limited access
Autopilot Operation During the Crash Trip

- Autopilot did not detect the truck
  - TACC did not reduce speed
  - Collision mitigation systems did not activate
- Autopilot maintained lane position, cruise speed, and following distance
- Autopilot functioned as designed, but it operated outside of the domain for which it was designed
Level 2: Operational Design Domain

- NHTSA 2016 automated vehicles policy
  - Establish operational domain constraints
    - Operate on specific roadways
  - Focus on Levels 3-5
- Level 2 automated system
  - More operational design limitations compared to Levels 3-5
  - No established guidelines for constraining operational domain
Overview

- Tesla Model S 70D
  - Autopilot
- Level 2 automation systems
  - Operational Design Domain
  - Monitoring driver engagement
- Tesla driver actions
Autopilot: Driver Engagement

- Driver is responsible for monitoring driving environment in Level 2 automation system
- Tesla monitors driver engagement through driver-applied changes to steering wheel torque
  - System provides warnings after extended period of hands-free operation in Autopilot mode
Driver Engagement: Timing of the Alerts

• Dependent on lateral acceleration, speed of Tesla, and presence of a lead vehicle
• On relatively straight roads–
  • Initial visual alert after 3-5 minutes when traveling above 45 mph, depending on the presence of a lead vehicle
    • Up to 5 minutes, if a lead vehicle is detected in that period
  • No alert when traveling less than 45 mph
Driver Engagement: Timing of the Alerts

- After the initial visual alert–
  - 2 auditory alerts
  - Final auditory alert and slowdown
The crash trip lasted 41 minutes

- Autopilot was engaged for 37 minutes
Hands on the steering wheel for 25 seconds
Driver Engagement During the Crash Trip

Lack of responsiveness indicates overreliance on automation
Driver Engagement in Level 2

- Role of the Level 2 driver–
  - Remain engaged and monitor the environment
  - Not required to physically operate the vehicle
  - Monitor the automation
    - Decades of research show that humans are very poor at this task
  - Steering wheel torque monitoring is a poor surrogate measure of driver engagement
Summary

• The Tesla was a Level 2 automated vehicle
• Autopilot did not detect the truck
• Autopilot functioned as designed; however, it permitted operation outside of its operational domain
• Tesla driver’s lack of responsiveness indicates overreliance on automation
• Monitoring steering wheel torque is not an effective method of ensuring driver engagement
Last slide with NTSB 50th Anniversary Commemorative Emblem—Making Transportation Safer Yesterday, Today, Tomorrow.
Driver Assistance System Data

Joseph A. Gregor, PhD
Overview

• Description of data recovered from the Tesla Model S
• Issues related to data recording and data access
Data Stored in Memory in Vehicle

Main user interface touchscreen (exemplar)

Interface unit from this investigation
Data Storage and Download

- Stored data uplinked to Tesla servers
- Vehicle data recorded since last uplink must be merged with Tesla server data
- Merged data set queried, and results are converted to engineering units – mph, degrees, meters
Recovered Data

- Large dataset recorded by vehicle but only a subset was directly relevant to investigation
  - Autopilot state and Cruise setting information
  - Speed, acceleration, motor torque, steering angle
  - System status information
Recovered Data

- GPS track data not recorded on SD card
- Camera images related to most recent emergency braking activation event also stored
Recovered Data

• Subset of data reflecting vehicle operation analyzed
  • TACC and Autosteer in use for majority of drive
  • Vehicle automation systems recognized vehicles ahead of Tesla
  • Vehicle automation systems responded as expected

• Lead vehicle sensed ahead of Tesla about 1.5 minutes before crash

• No indication of any obstacle ahead of Tesla, or of any change in vehicle operation, after this time
Event Data Recorders

- Event data recorders (EDRs) not required on light vehicles
- 49 CFR Part 563 defines purpose, application, and data-recording requirements, if EDR is installed—
  - Minimum set of 15 data elements
  - Guidance for 30 optional data elements
  - Guidance for survivability and accessibility
- EDR rule is not sufficient for vehicles with automated systems
Automated System Data Challenges

• Data are not accessible to investigators without manufacturer assistance

• Standard set of parameters is needed to assess driver and vehicle performance
Summary

• Very large set of recorded data recovered from the vehicle
• Data consistent with normal Autopilot operation
Safety Metrics and Exposure Data

Deb Bruce, PhD
Overview

• Data can improve our ability to evaluate safety benefits
• Needed by industry, manufacturers, operators, researchers, and regulators
• Standard system of reporting will facilitate data aggregation and comparison
Metrics for Safety Assessments

Events can be hard braking, evasive action, crashes, system disengagement, or system failure.

Exposure can be hours of automated system use, on number of equipped vehicles, within a manufacturer’s fleet.
Importance of Safety Metrics

• Quantify safety
• Benefit/Cost analysis
• System analysis
• Determine system improvements
Summary

- Well-defined event and exposure data
- Automated system categorization must address similar functionality
- Periodic and consistent data-reporting timeframes
Connected Vehicle Technology and Vehicle-to-Vehicle Requirements

Deb Bruce, PhD
Overview

- Description of Vehicle-to-Vehicle (V2V) systems
- History of recommendations
- Research and rulemaking history
- Scope of new Federal Motor Vehicle Safety Standard (FMVSS)
How do V2V systems work?

• Use Dedicated Short-range Radio Communications
• Exchange basic safety messages (location, heading, speed) with other vehicles
• Radio spectrum allocated by Federal Communications Commission
• Supplement the capabilities of vehicle-resident sensors
History of V2V

• 1995 NTSB recommendation to allocate and reserve available radio spectrum

• 2013 recommendations H-13-30 to develop minimum performance standards and H-13-31 to require V2V systems on all new vehicles
Research and Rulemaking

- Recent research includes—
  - 2014 Readiness of V2V Technology for Application
  - 2016 Heavy Vehicle V2V Research
  - 2014 advance notice of proposed rulemaking included heavy trucks
  - 2016 notice of proposed rulemaking to establish a new FMVSS addressed only light vehicles
Summary

• Limitation of partial fleet requirement
• High risk posed by heavy trucks
• Ability to enhance vehicle-resident crash avoidance technologies