NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Advanced Driver Assistance Systems Research

NHTSA Safety Research Portfolio Public Meeting: Fall 2021

October 19, 2021

Panel Presentations

1. **NHTSA's Heavy Vehicle Crash Avoidance Test Track Research** – Devin Elsasser
2. **Sensor Degradation Research –** Stephen Stasko, PhD
3. **Overview of the Partnership for Analytics and Research in Traffic Safety (PARTS) –** Chris Wiacek
4. **ADAS Tests Performed with Additional Actors –** Garrick Forkenbrock
5. **Driving Automation Level 2 Event Classification –** Garrick Forkenbrock
6. **Future Work and Upcoming Results –** Aaron Greenwood, PhD

NHTSA’s Heavy Vehicle Crash Avoidance Test Track Research

Devin Elsasser

Objectives

- Perform test track research on heavy vehicles equipped with forward collision warning and automatic emergency braking systems
- Provide in-house expertise with heavy vehicle crash avoidance performance and advanced driver assistance systems
- Test track data and vehicle-level performance estimates
- Develop objective test track procedures
- Technical reports

Past Heavy Vehicle FCW/AEB Test Track Research

- Initial research started with retrofits
  - Air-braked class 8 truck-tractors
  - Motorcoach
- Follow-on research with production vehicles
  - Air-braked class 8 truck-tractors
  - Single unit trucks
    - Air-braked class 6 and 7
    - Hydraulically-braked class 3
- Observations
  - Test procedure applicability
  - Systems demonstrate test track performance improvements

See additional resources page for links to test procedures, papers, and reports from past work.

Current Research

- Continue to develop and refine objective test procedures
- 2021 test track research started with a 2021 class 8, air-braked, truck-tractor equipped with FCW/AEB (DA 5.0)
- Follow-on work with additional test units
  - Considering more research with heavy and medium duty trucks
  - Considering more work with vehicle types
    - Examples
      - Cab-chassis/straight truck
      - Buses and motorcoaches

Test Track Tools

Surrogate Vehicles

Some examples of the recent tools used to test heavy vehicles

Surrogate Vehicles

Past to present examples

- Foam cars
- Strikeable Surrogate Vehicle (SSV)
    - Fixed guide rail
    - Carbon fiber rear ¼ shell
- Low profile robotic vehicle and guided soft target/global vehicle target (GST/GVT)
    - Commercially available
    - More options for maneuvers and testing locations
    - 360-degree foam/vinyl strikable surrogate
    - Armor plating available for heavy vehicle testing

Heavy Vehicle Simulation Research

Simulation research helps supplement test track research projects

Simulation Research and Testing

Enables the study of:

- More types of vehicles (tractor/trailer, truck, and bus); can modify vehicle models to test different configurations
- Sensors; can specify range, define detection region, and some system performance aspects based on test track characterization data
- Tunable generic hydraulic and pneumatic brake models
- No speed limits and larger test matrices; more variables can be parameterized and studied
- Levels of modeling fidelity

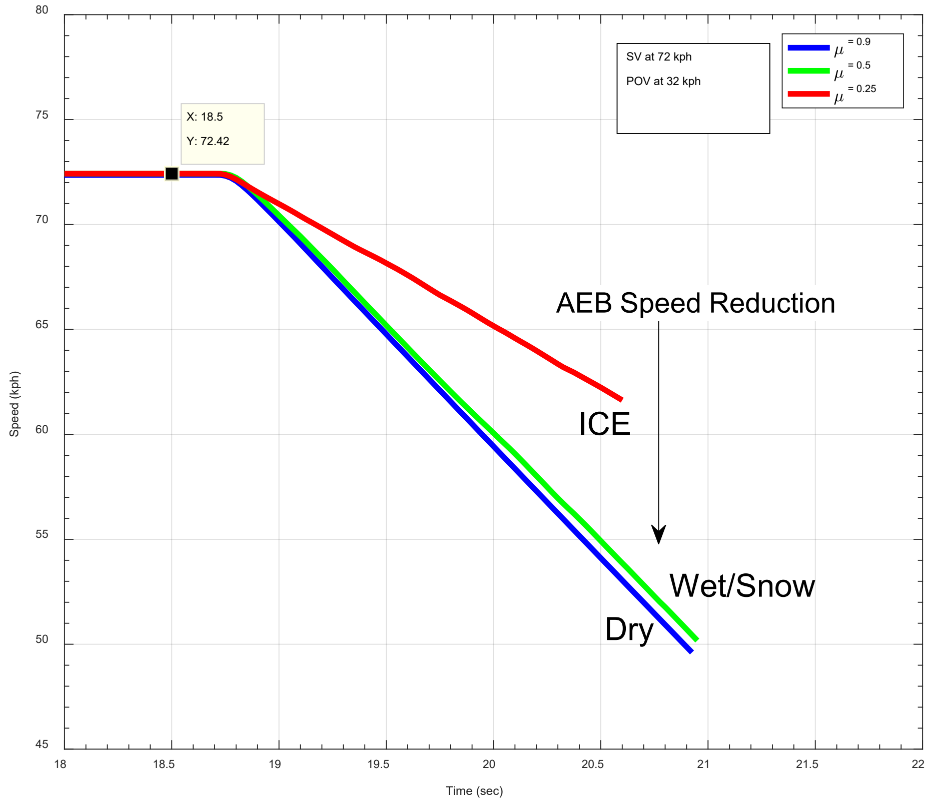
Road Environment

- Test roads meeting test track procedure specifications
- Synthetic road with geometric complexities
  - Curves/grades/superelevation, road junctions, and lanes with different line styles. Can be set according to AASHTO recommended practices.
  - Surface contaminants like water, snow, ice can be added and simulated

Traffic Environment

- Vulnerable road users, pedestrians, bicyclists can be added to scenarios.
- Principal other vehicle for testing can be based on a passenger vehicle, SUV, or a heavy vehicle.

Road/Tire Friction Example



Additional Resources

www.nhtsa.gov,

www.transportation.gov,

https://rosap.ntl.bts.gov/welcome

Publications:

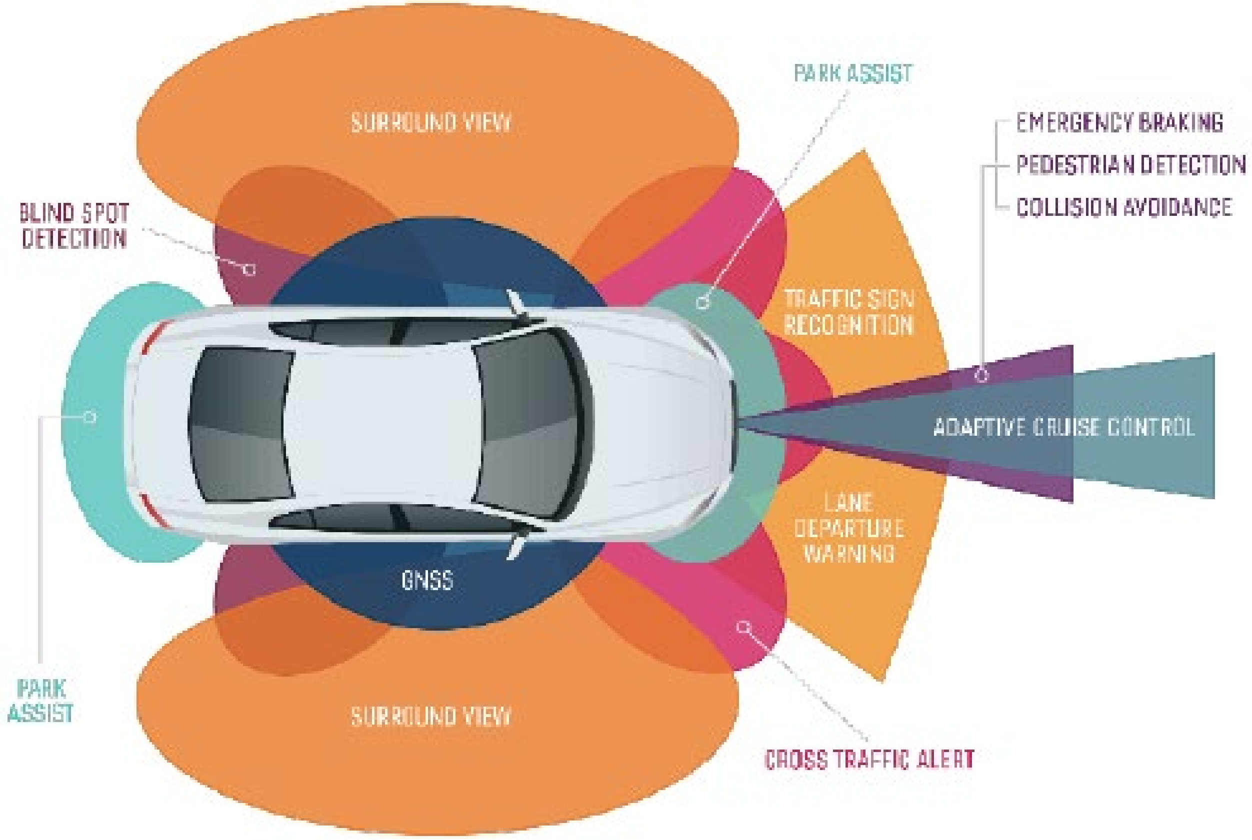
1) 2015, Class 8 Truck-Tractor and Motorcoach Forward Collision Warning and Automatic Emergency Braking Test Track Research – Phase I https://www.regulations.gov/contentStreamer?documentId=NHTSA-2015-0024-0003&attachmentNumber=2&contentType=pdf
2) 2016, SAE paper, “Heavy Vehicle Hardware-in-the-Loop Automatic Emergency Braking Simulation with Experimental Validation” doi:10.4271/2016-01-8010, https://www.sae.org/publications/technical-papers/content/2016-01-8010/
3) 2018, Class 8 Truck-Tractor and Motorcoach Forward Collision Warning and Automatic Emergency Braking System Test Track Research – Phase II https://downloads.regulations.gov/NHTSA-2015-0024-0006/attachment_1.pdf
4) 2019 Test Track Research Procedures Released, https://rosap.ntl.bts.gov/view/dot/42186/dot_42186_DS1.pdf
5) 2020, SAE paper “Heavy Vehicles Kinematics of Automatic Emergency Braking Test Track Scenarios” https://www.sae.org/publications/technical-papers/content/2020-01-0995/
6) 2020, SAE paper “NHTSA’s 2018 Heavy Vehicle Automatic Emergency Braking Test Track Research Results” https://www.sae.org/publications/technical-papers/content/2020-01-1001/

Sensor Degradation Research

Stephen Stasko, PhD

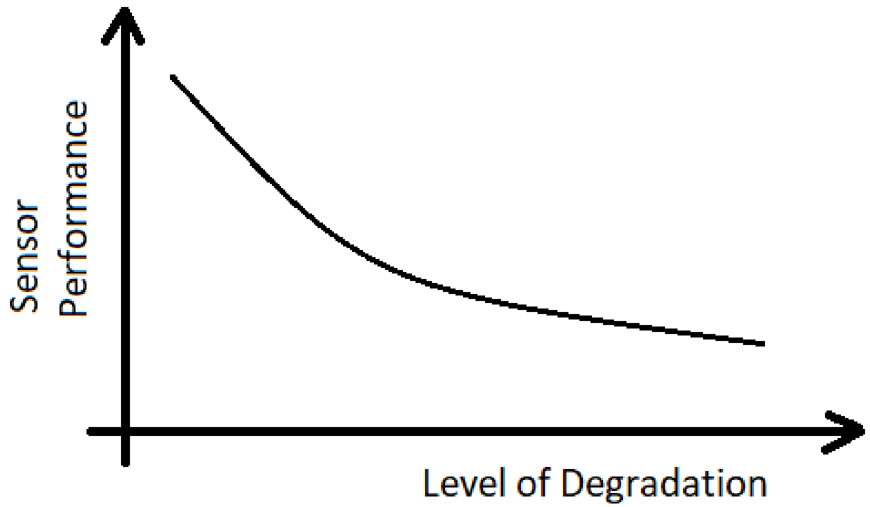
Sensor Degradation Study

- Motivation
  - Proliferation of Sensors on board vehicles
  - Criticality of sensor performance to safety
  - Average vehicle age is approaching 12 years



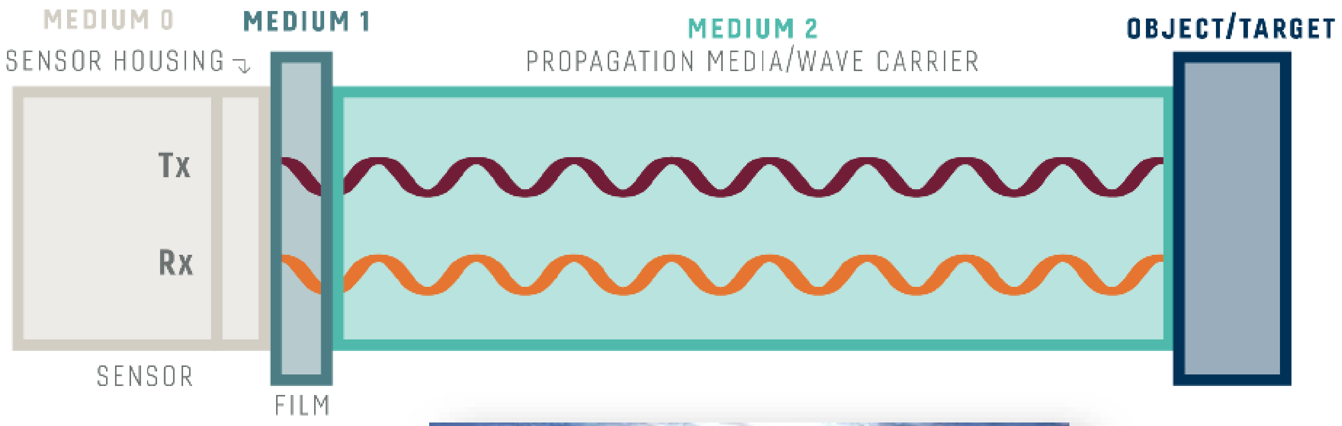
Project Goals

- Research Questions:
  - What are the sources of degradation?
  - How can degradation be quantified?
  - How can the effect on sensor output be quantified?
  - What effect may sensor degradation have on ADAS performance?

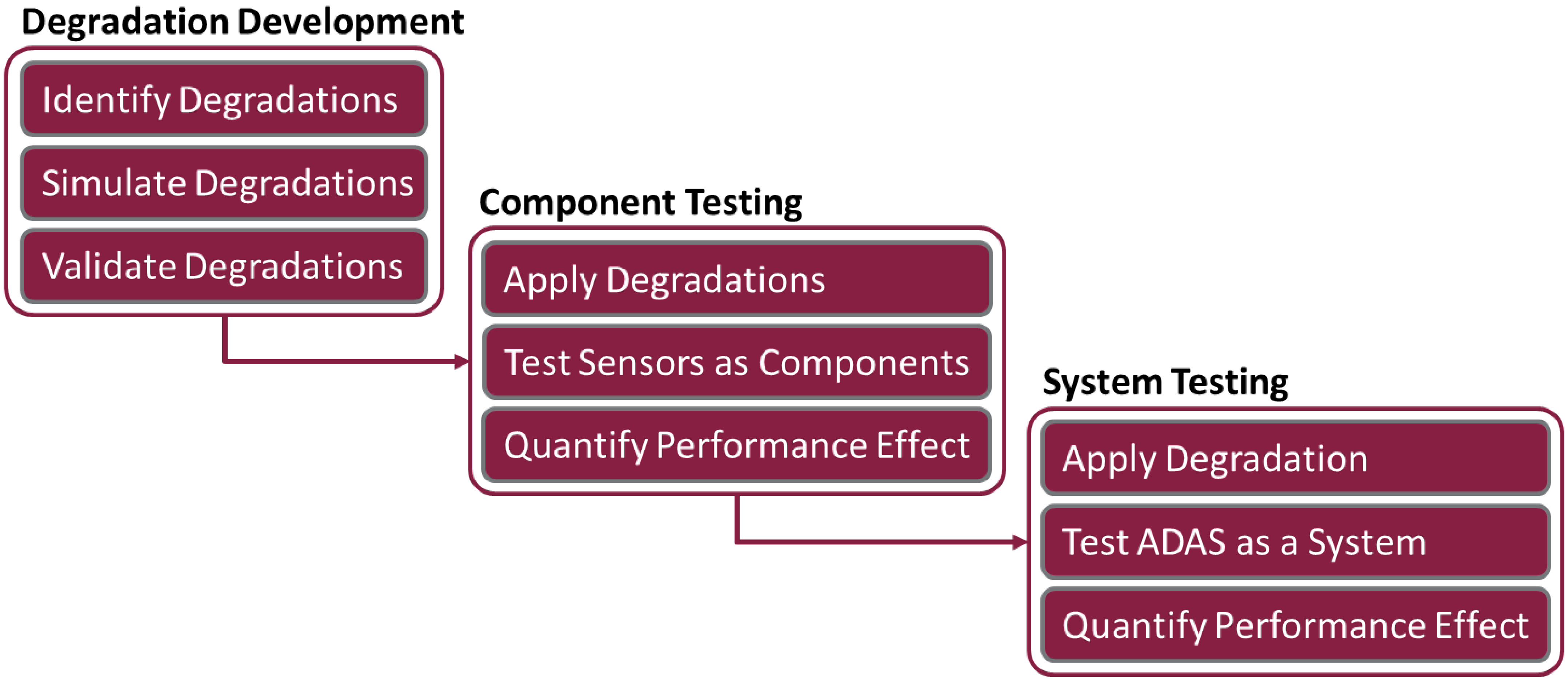


Sensor Degradation Study Approach

- Knowledge Acquisition
  - Literature search
  - Industry interviews
- Industry state of the art and understanding of the problem
  - Testing
  - Mitigations
- Identify degradations of interest and develop methods to measure their impact



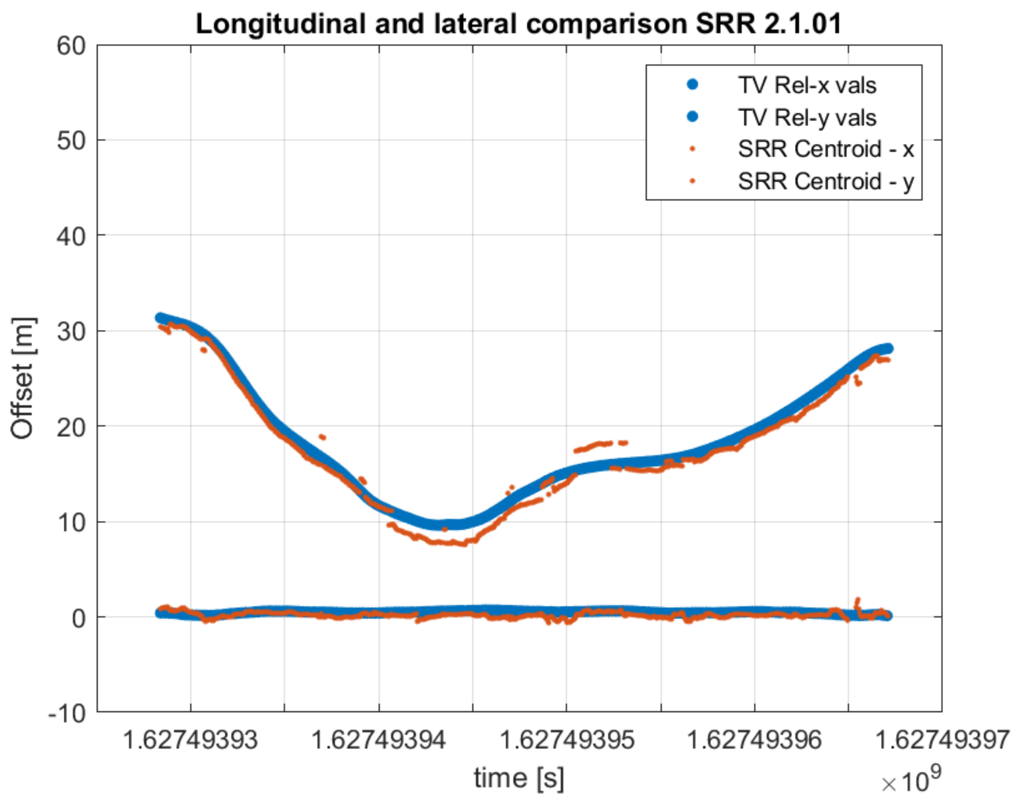
Testing Strategy

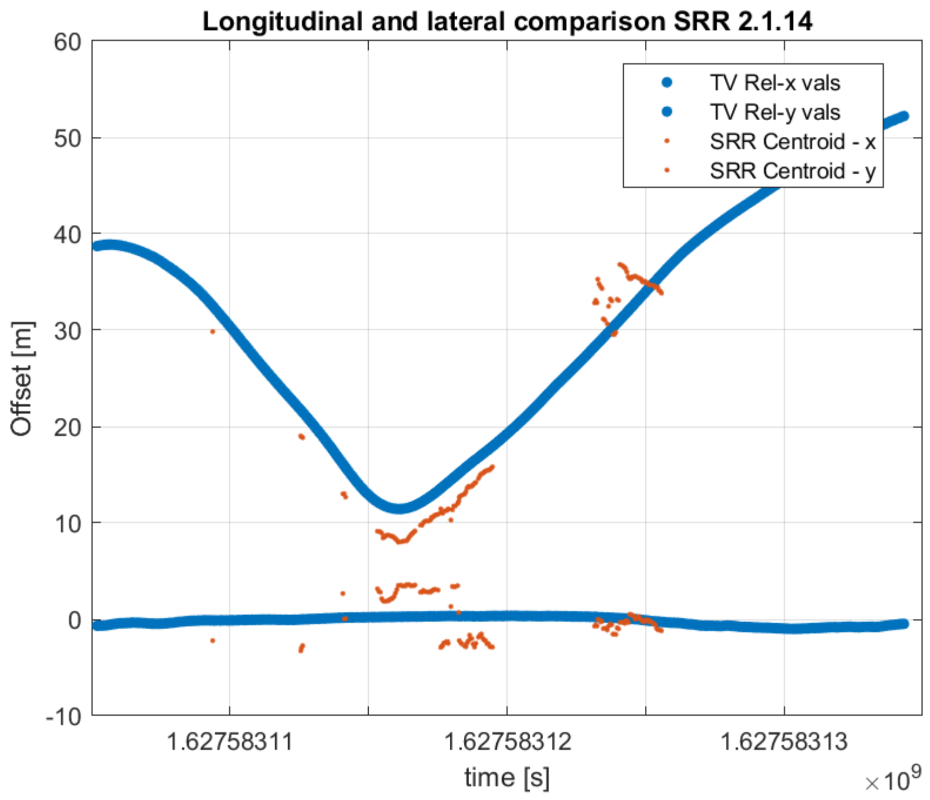


Sensor Level Degradation Testing

Degradation	Camera	Radar	LiDAR
Mount displacement	x	x	x
Debris accumulation	x	x	x
Repair not to OEM spec	x	x	
Obstructions/blockage	x	x	
Pitting/scratches	x	x	x
Water absorption		x	
Discoloration	x		x
Lighting	x		

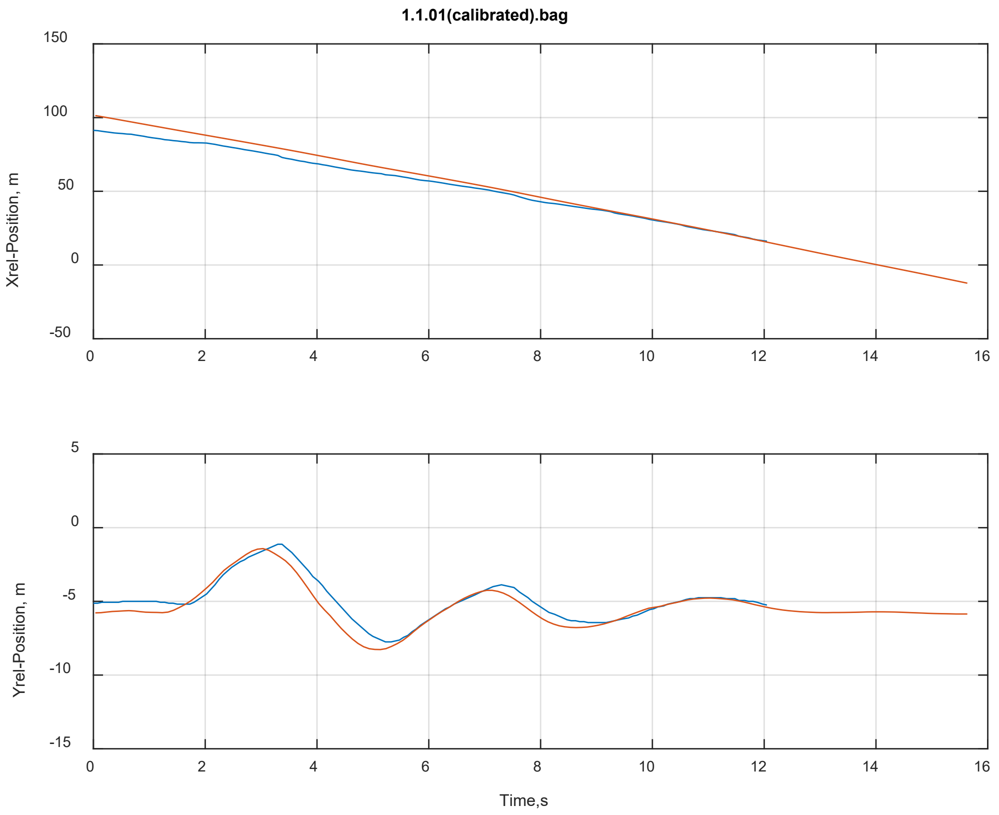
Sensor Testing Results - Radar

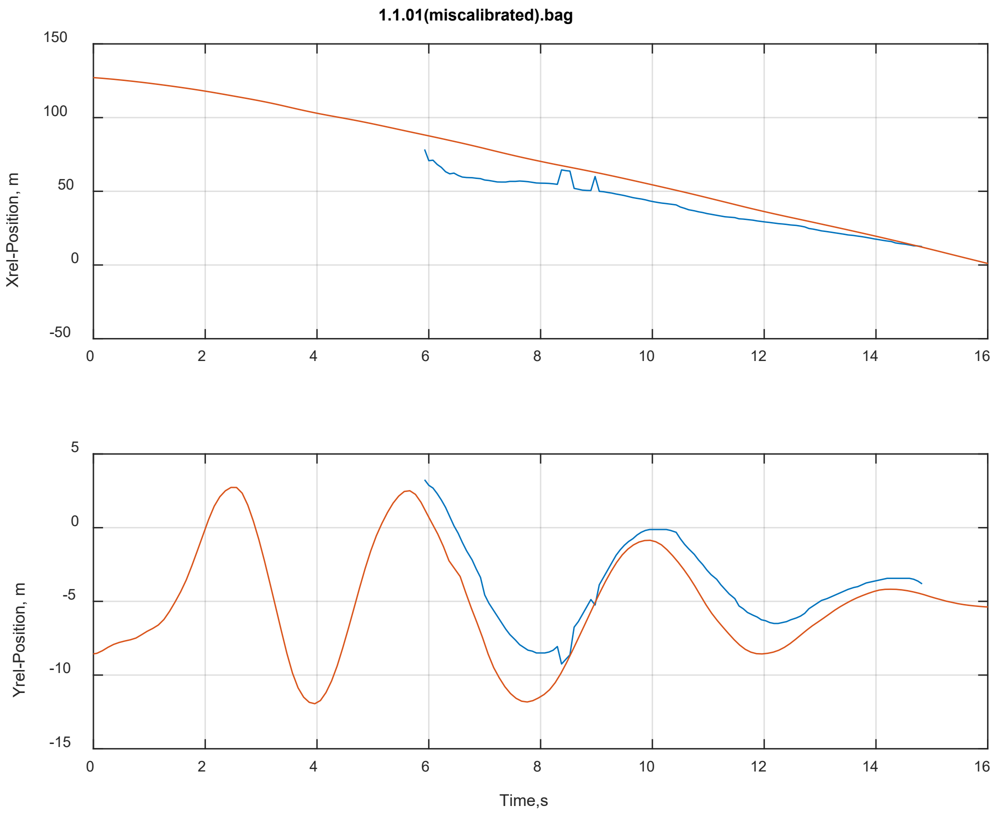




- Short Range radar behind a poly bondo mesh
- The poly bondo mesh largely blocks the signal and introduces lateral offsets

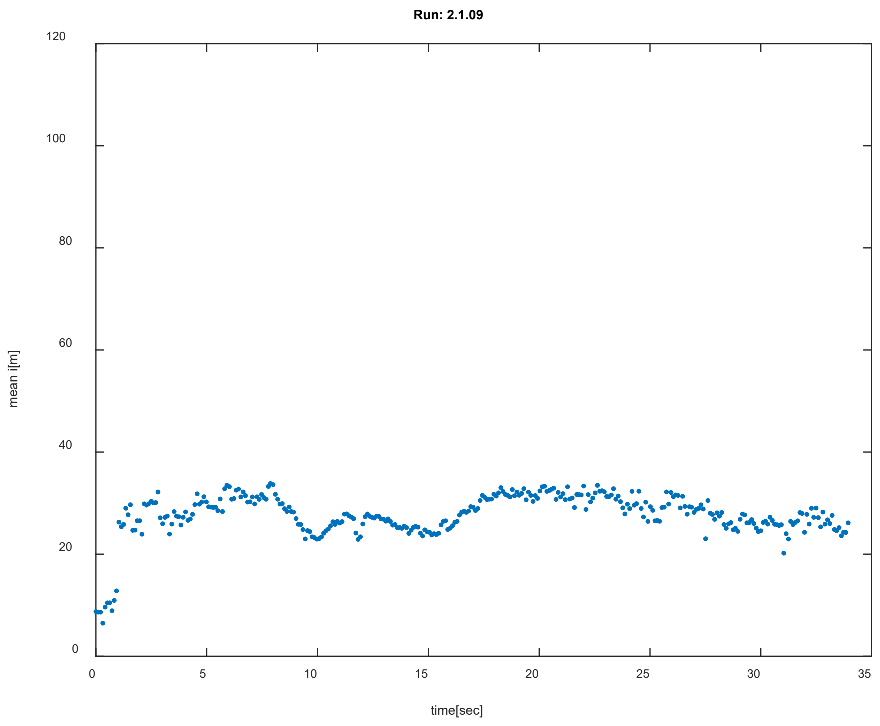
Sensor Testing Results - Camera

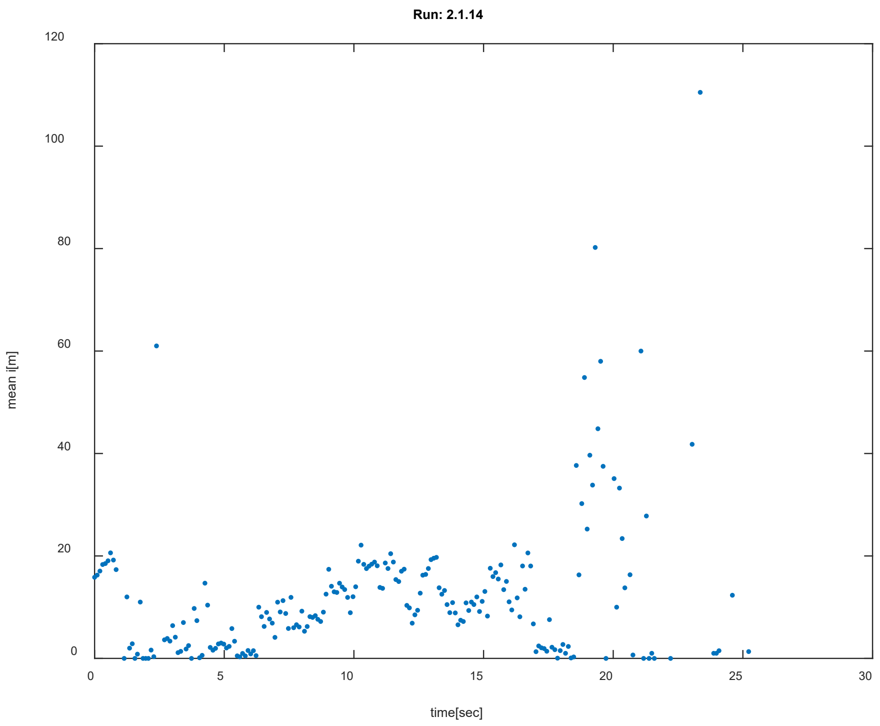




- Camera mounting angle mis-calibrated
- The uncalibrated camera led to offsets in the reported range and a overall reduction in object detection distance

Sensor Testing Results - Lidar





Degraded (sandblasted)

- Lidar degraded with a sandblasted surface
- The degradation lowered the mean intensity by 56%

Next Steps

Rank (from highest degradation impact)	Optical Degradations Applies to Camera and LiDAR
1	Off gas
2	Sealant
3	Tinted
4	Sand Blasted
5	Shellac

Rank (from highest degradation impact)	Bumper Degradations Applies to Radar
1	JBweld
2	Bondo plus Mesh
3	Pine Needles
4	Epoxy
5	Blacktop

- Downselect to the high impact degradations.
  - A mix of natural and “man made” degradations
  - A number of degradations are related to repair
- ADAS System testing
  - Based on NCAP tests

Overview of the Partnership for Analytics and Research in Traffic Safety (PARTS)

Chris Wiacek

About PARTS

PARTS is a Unique Public-Private Partnership (PPP) for Safety Analysis

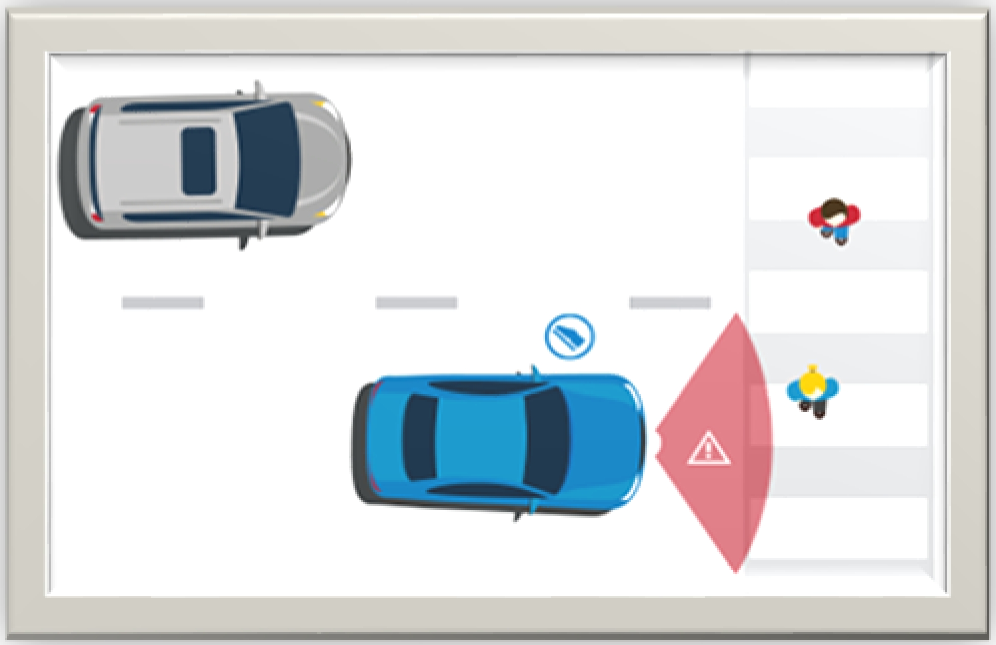
About PARTS

Uniquely pools real-world data, information, and resources for collaborative safety analysis and discovery.

About PARTS

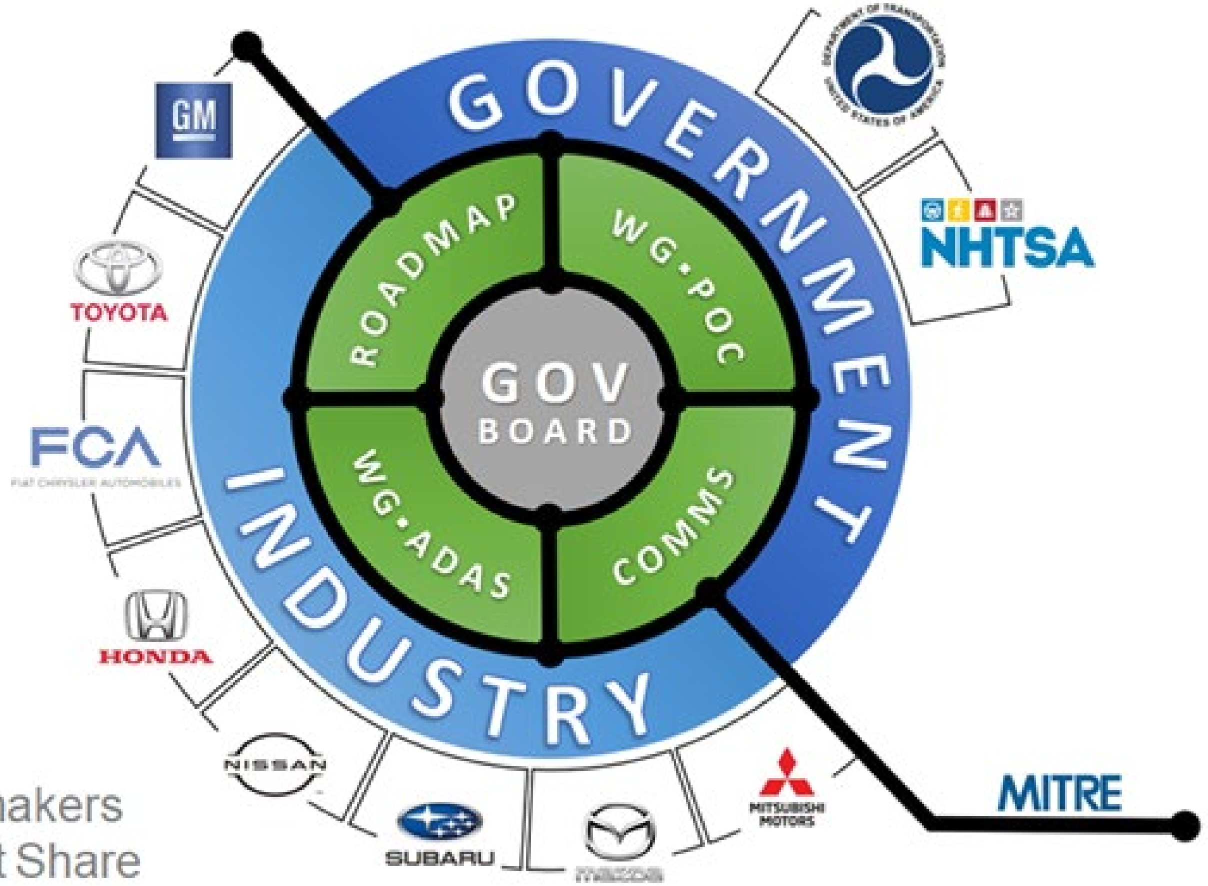
Goal: Gain real-world insights into safety benefits and emerging safety opportunities that can improve performance of advanced safety technologies

About PARTS



Focus on ADAS now to lay the foundation for Automated Driving Systems, connected vehicles, and other real-world advanced technologies in the future

Participation



Eight Automakers
70% Market Share

Roadmap

PARTS TIMELINE

This Roadmap builds on the 2018-2019 Prototype Phase that demonstrated the success of the partnership model for traffic safety.

2020-2022

Foundational Stage

Generate meaningful ADAS effectiveness results while maturing partnership processes and governance and preparing for long-term impact and sustainability.

2022-2025

Expanding Stage

Increase the depth and breadth of analyses by expanding to most U.S. passenger vehicles and integrating new datasets – all while building enabling capabilities, maturing technical environment, and expanding public presence of the partnership.

2025-2030

Advancing Stage

Become a leading source for accelerated safety insights through rapid collection of data directly from vehicles to provide a better window into emerging issues and traffic safety.

ADAS Effectiveness Study

Research Questions

1. What is the overall effectiveness of ADAS features against relevant crashes?
2. What factors influence ADAS feature effectiveness and to what extent?
3. What combination of ADAS features contribute to the reduction of fatalities, injuries, and crashes?

ADAS Features

- Forward Automatic Emergency Braking (AEB)
- Forward Collision Warning
- Pedestrian Detection Warning & P-AEB
- Lane Departure Warning
- Lane Keeping Assistance
- Lane Centering
- Blind Spot Warning / Intervention

ADAS Effectiveness Study

Analysis

NHTSA Crash Data

- Start with 9 states and expanding up to 15

Vehicle Build Data

- 50 million vehicles
- 94 models
- 7 vehicle segments
- Model Year 2015 – 2021

More Information On PARTS

Website:

NHTSA.gov/PARTS

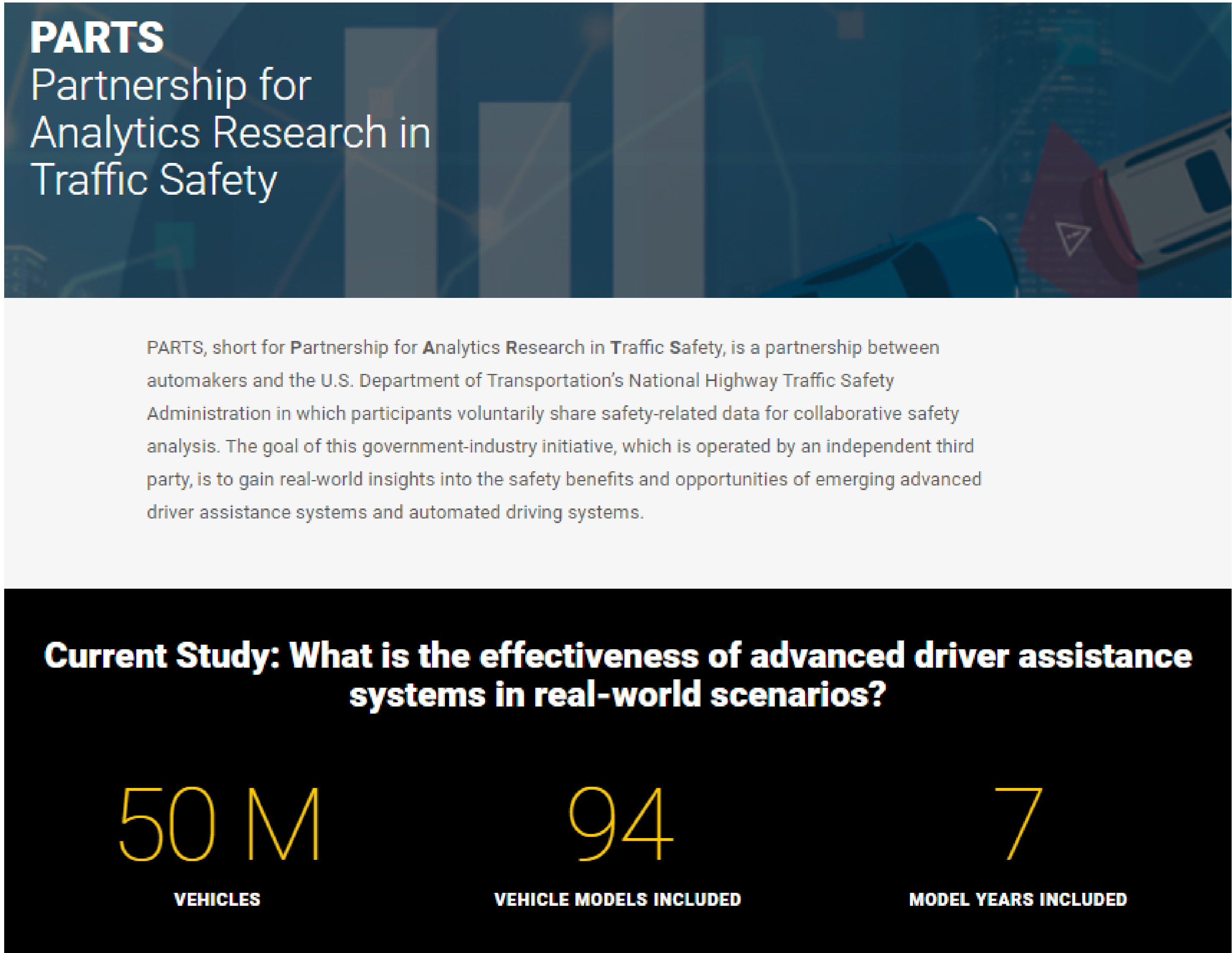
Governance Board Co-Chairs:

Joseph.Kolly@dot.gov

Tim.Czapp@fcagroup.com

Email:

PARTS@mitre.org



ADAS Tests Performed with Additional Actors

Garrick Forkenbrock

Goals

- Perform exploratory research
- Gain knowledge of complex test track scenario choreography
  - Valuable for future research programs
  - Useful for simulation comparison and validation

Pilot Research Scope

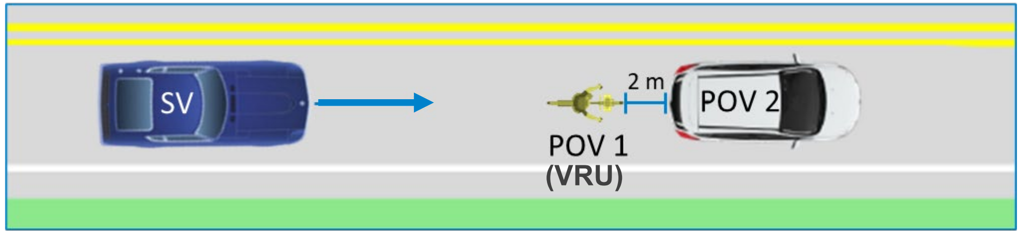
- Add additional actors to known test scenarios
  - Crash Imminent Braking (CIB)
  - Traffic Jam Assist (TJA)
  - Intersection Safety Assist (ISA)
- Document test observations

Crash Imminent Braking

Exploratory vulnerable road user (VRU) work

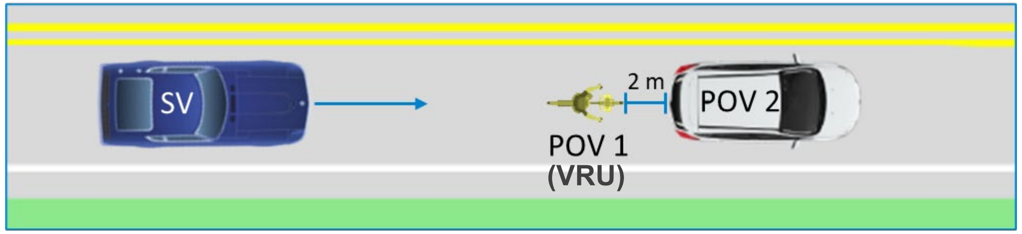
- 1 subject vehicle
- Stopped and slower moving lead vehicles
- Low-speed subject vehicle approaches
- Multi-actor results compared to single-actor baselines

Lead Vehicle(s) Stopped



SV: 15 and 25 mph
POV: 0 mph

Lead Vehicle(s) Moving



SV: 25 mph
POV: 10 mph

Crash Imminent Braking

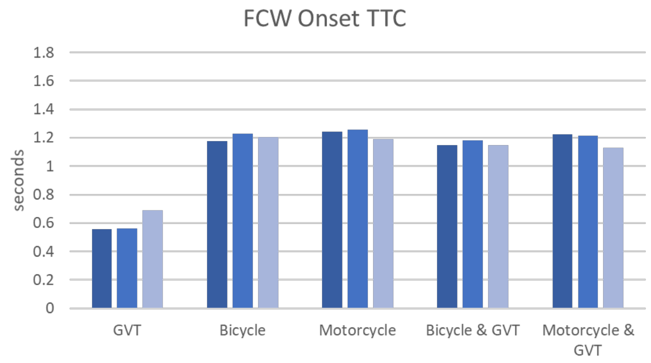
Individual Surrogate Vehicles

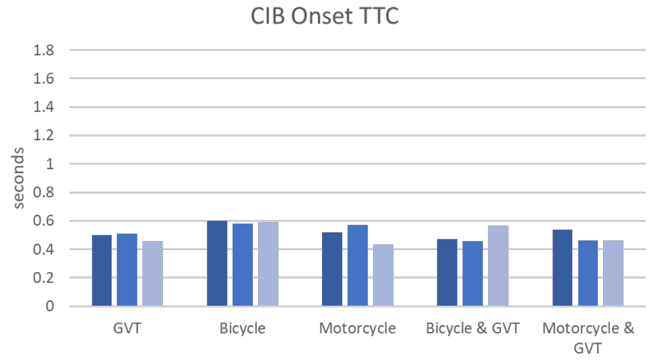
Surrogate Combinations

Crash Imminent Braking – Test Observations

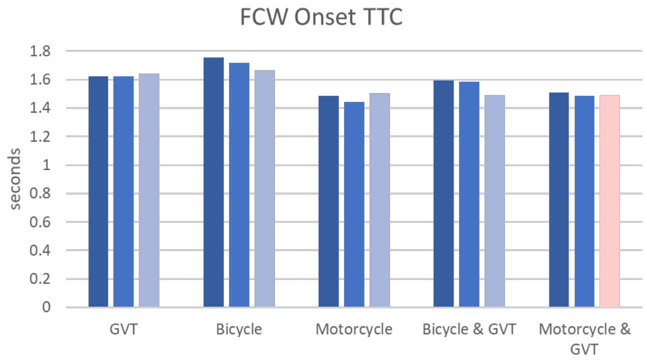
Lead Vehicle(s) Stopped

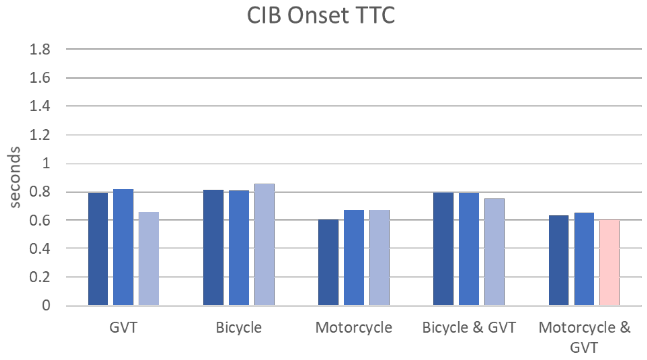
SV: 15 mph





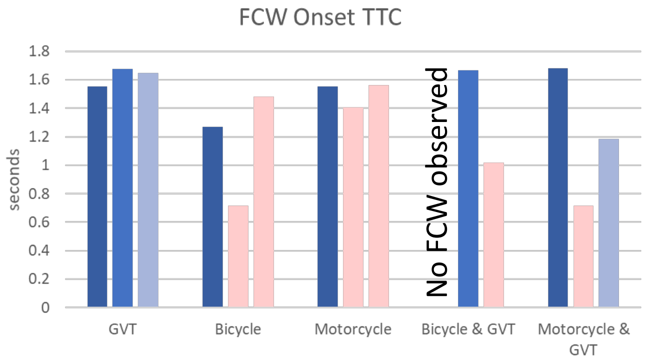
SV: 25 mph

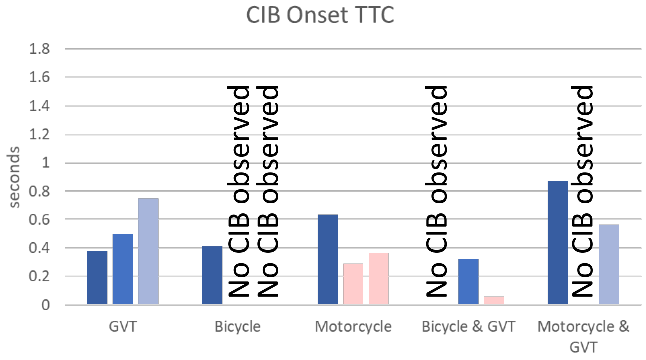




Lead Vehicle(s) Moving

SV: 25 mph, POV: 10 mph





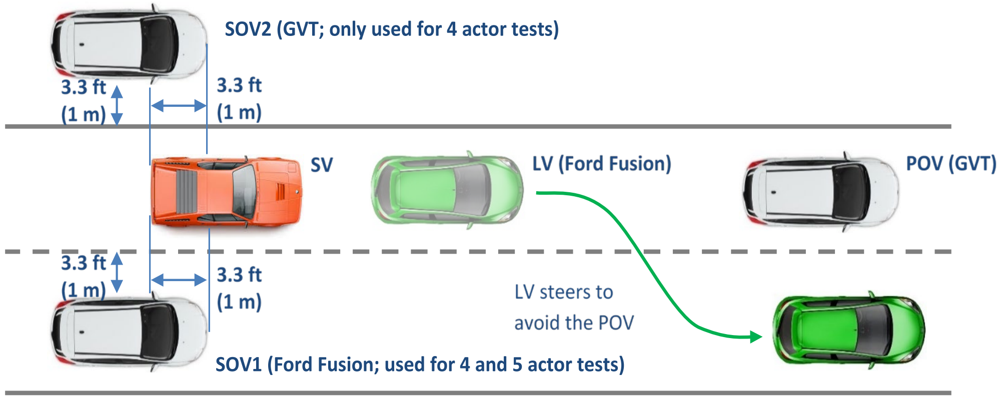
Trial concludes with an SV-to-POV impact

Traffic Jam Assist

Exploratory test cases

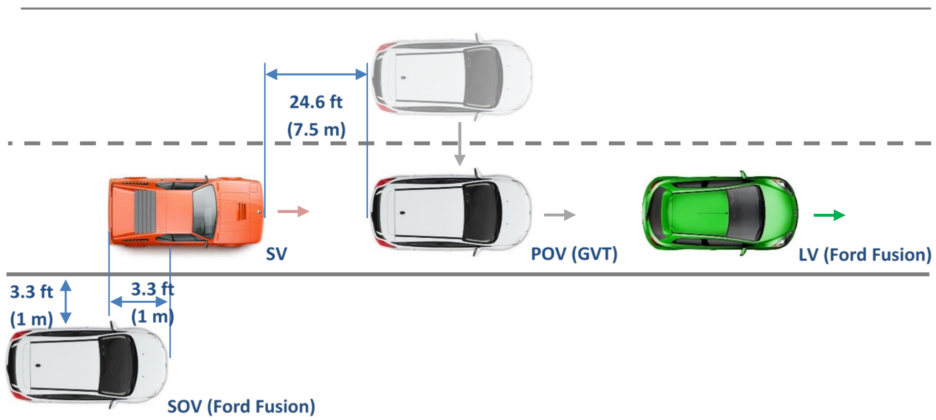
- Based on test scenarios defined in NHTSA's TJA draft research test procedure
- May provide a useful way to research crash avoidance decision-making

Suddenly Revealed Stopped Vehicle (cut-out)



SV, SOVs, LV: 25 and 35 mph
POV: 0 mph

Lead Vehicle Lane Change with Braking (cut-in)



All vehicles: 25 and 35 mph

Suddenly Revealed Stopped Vehicle

(35 mph example)

Traffic Jam Assist – Test Observations

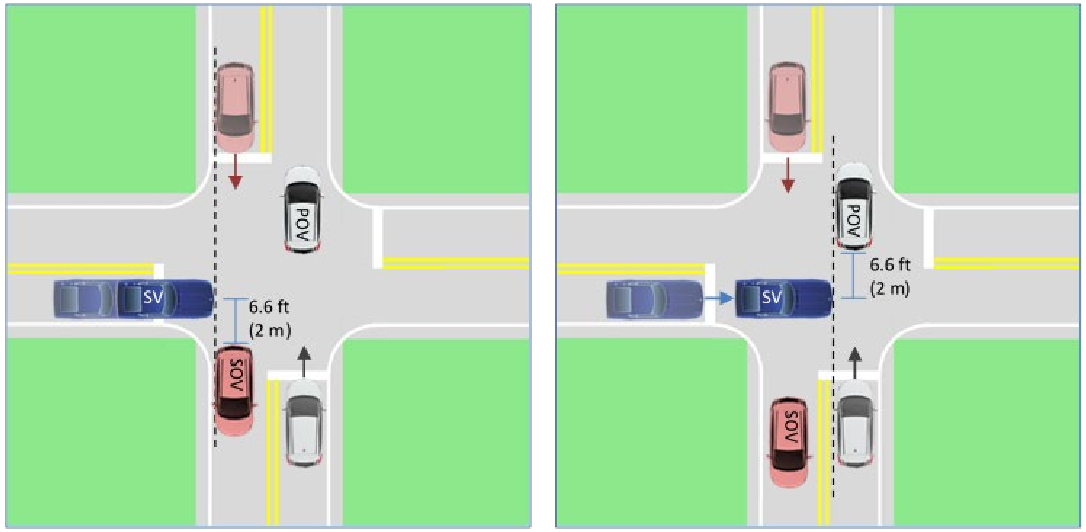
- Overall
  - Increasing the number of actors was successfully demonstrated, but…
  - Increasing the test speed from 25 to 35 mph required additional tuning of the robotic controllers
  - Some test parameters were unable to be consistently achieved
- Suddenly Revealed Stopped Lead Vehicle
  - As the number of actors and test speeds increased, there was a corresponding decrease in the consistency of the SV-to-POV lane-change onset headway.
- Lead Vehicle Lane Change with Braking
  - When the test speed was increased to 35 mph, the onset of the POV braking was not always achieved within 250 ms of the lane change completion
- More detailed results are provided in DOT HS 813 169

Intersection Safety Assist

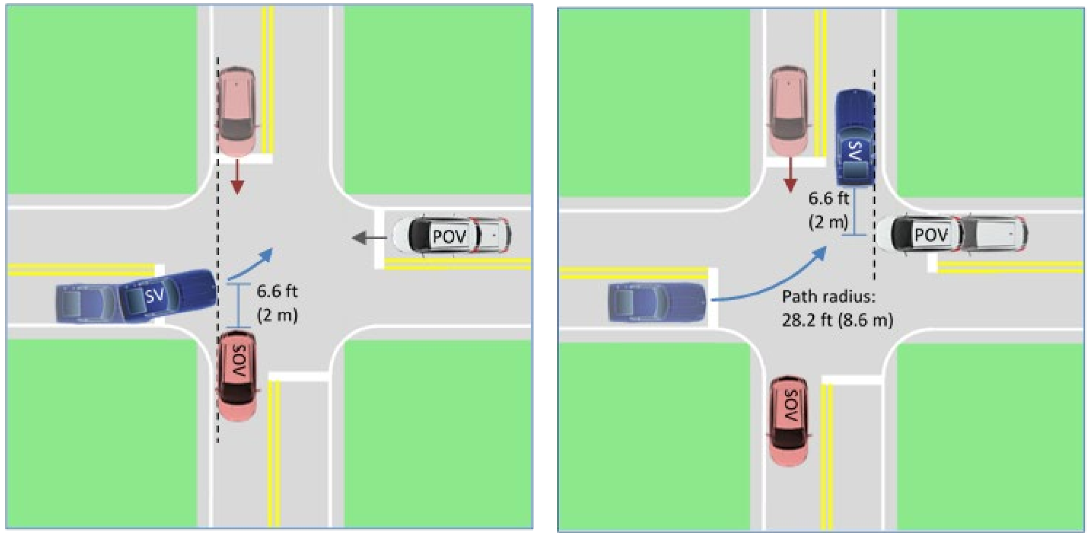
Exploratory test cases

- Based on test scenarios defined in NHTSA's ISA draft research test procedure
- May provide a useful way to research crash avoidance and near-miss decision-making

Straight Crossing Path x2



Straight Crossing Path + Left Turn Across Path



Maximum steady state speed = 25 mph

Straight Crossing Path x2

(Multiple Conflicts, Near Miss Choreography, SV = 25 mph)

Straight Crossing Path + Left Turn Across Path

(Multiple Conflicts, Near Miss Choreography, SV = 25 mph)

Intersection Safety Assist – Test Observations

- Overall, these tests demonstrated the feasibility of adding add an additional actor with near-miss choreography
- All validity requirements were satisfied for 5 of 6 test scenario and sub-scenario combinations
    - The allowable SV-to-SOV near-miss distance was exceeded during the Straight Crossing Path + Left Turn Across Path trials where the SV accelerates from rest
- More detailed results are provided in DOT HS 813 185

Driving Automation Level 2 Event Classification

Garrick Forkenbrock

Research Objectives

- Expand the agency's understanding of how level 2 driving automation systems operate on real-world roads
- Develop a way to categorize events observed during periods of level 2 driving automation
- Apply the categorization method to drives performed with a variety of vehicles, operated on different kinds of roads
- Report drive observations and key findings

Research Overview

- 3 real-world test routes
- 5 light vehicles
  - 3 evaluations during 2018
  - 2 evaluations during 2019-20
- 1 heavy vehicle
  - During 2020

The light vehicle drives described today are documented in two NHTSA reports

- DOT HS 812 980 (Part 1)
- DOT HS TBD TBD (Part 2)

Methodology

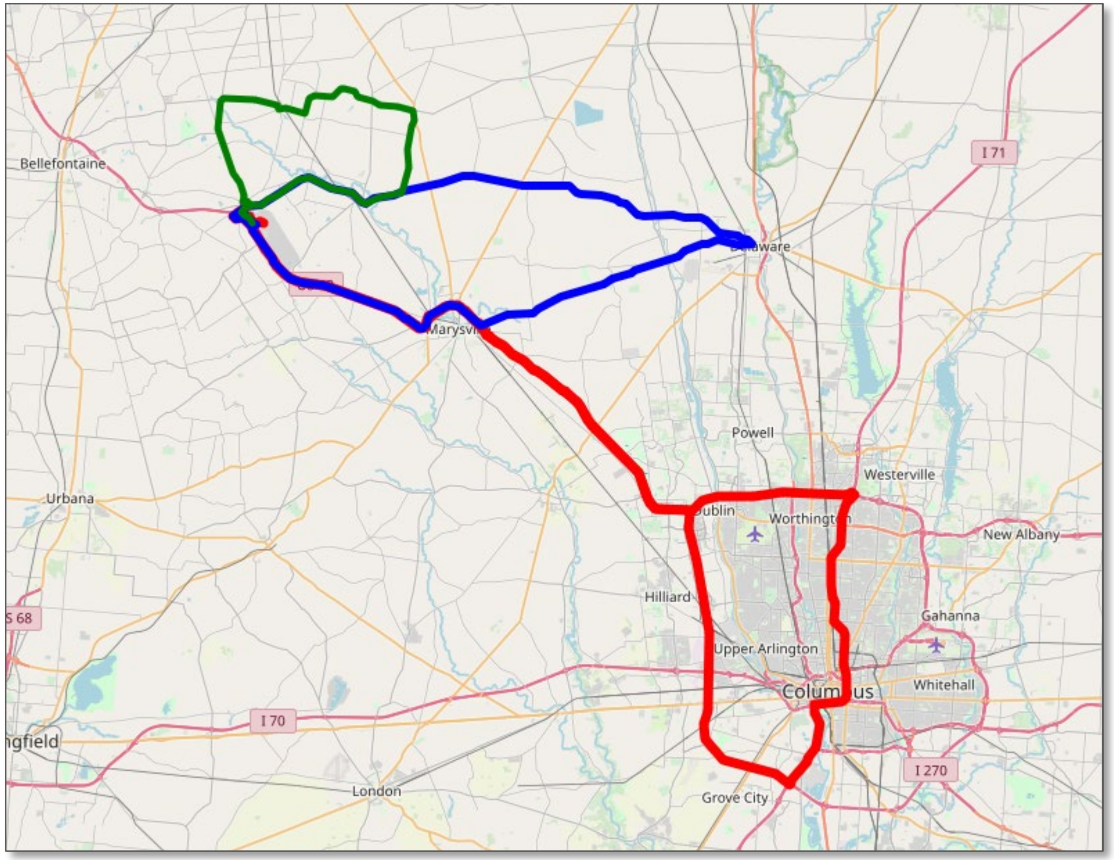
- Professional drivers operated each vehicle in SAE driving automation level 2
- The drivers held their hands just above or lightly touching the steering wheel

- Two in-vehicle synchronized cameras recorded each drive
- Drivers highlighted noteworthy events using a remote trigger attached to the steering wheel

Methodology (continued)

- Each drive occurred during daylight hours
- No attempt was made to equalize the number of drives per operating condition
  - e.g., wet and dry conditions
  - e.g., time of day (low vs. high traffic volume)
- 3 drivers were nominally used per vehicle / route combination
- Drivers reviewed their videos during post processing. They detailed:
  - Roadway Type, Road Conditions, Lane Line Conditions
  - The type of event (Type I, II, or III)
  - Their own comments

Driving Routes



Highway Route

- 108 miles
- Limited-access divided-highway with on/off ramps
- ≈ 2 hours to complete

Mixed Route

- 63.1 miles
- Mix of highway, rural, and residential roads
- ≈ 1.5 hours to complete

Rural Route

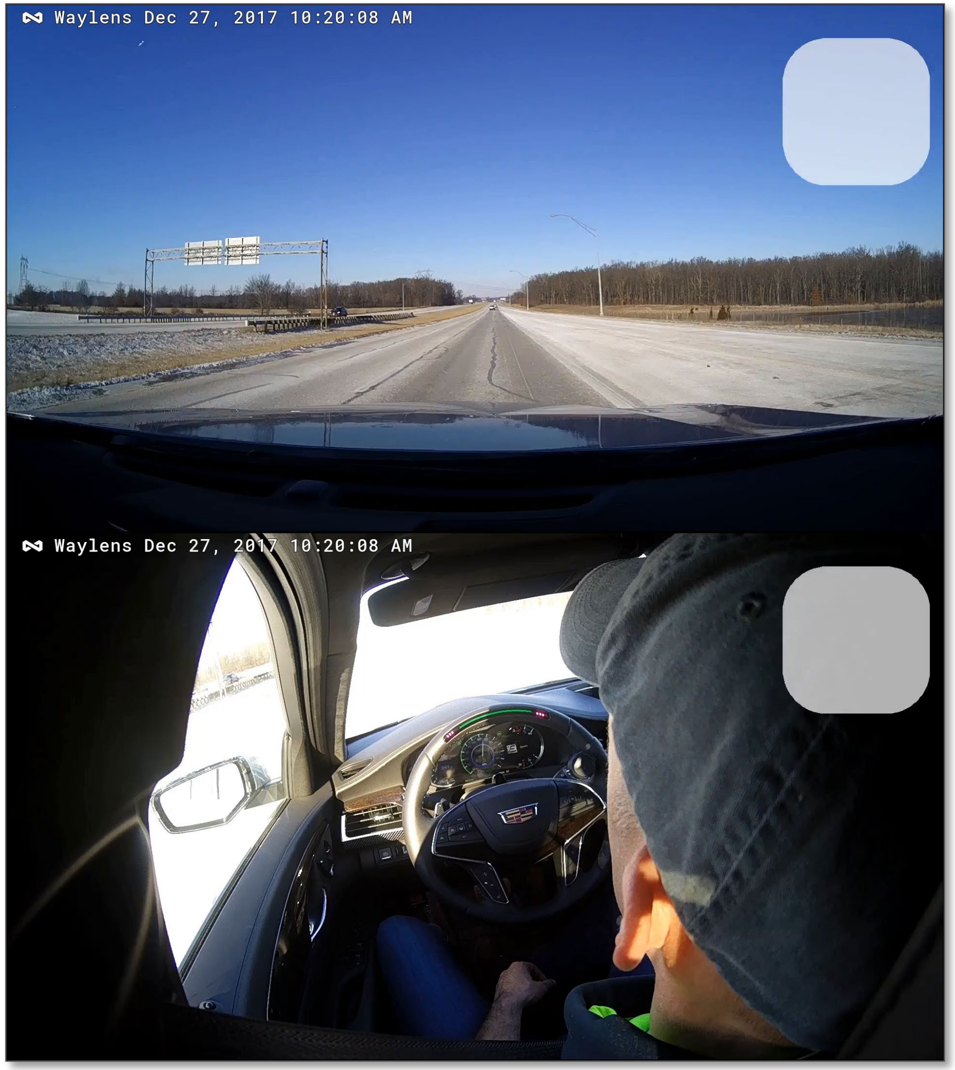
- 32.4 miles
- Single-lane per direction-of-travel roads
- ≈ 57 minutes to complete

Type I Events

- During otherwise normal and unremarkable driving operation, the system
    - Suddenly terminated its level 2 driving automation operation;
    - Issued a takeover notification to the driver; and
    - Transferred at least lateral control back to the driver.
- This required that the driver immediately resume manual control of the vehicle's accelerator pedal and/or steering wheel.

Type I Event Example (Light Vehicle)

On a divided highway



Type II Events

- The system exhibited some form of subjectively noteworthy operation, but the driver did not believe it was necessary to manually override the system to regain full control of the vehicle.
- At the time of a Type II event the system was actively providing lateral and longitudinal control of the vehicle without issuing an alert or warning to the driver.
- Examples:
    - Steering was not smooth through a curve
    - Ping-ponging within the lane
    - Favoring the left lane line and driving close to on-coming traffic

Type II Event Example (Light Vehicle)

Dithering within lane (straight road)

Type II Event Example (Heavy Vehicle)

Left biased lane position near other traffic

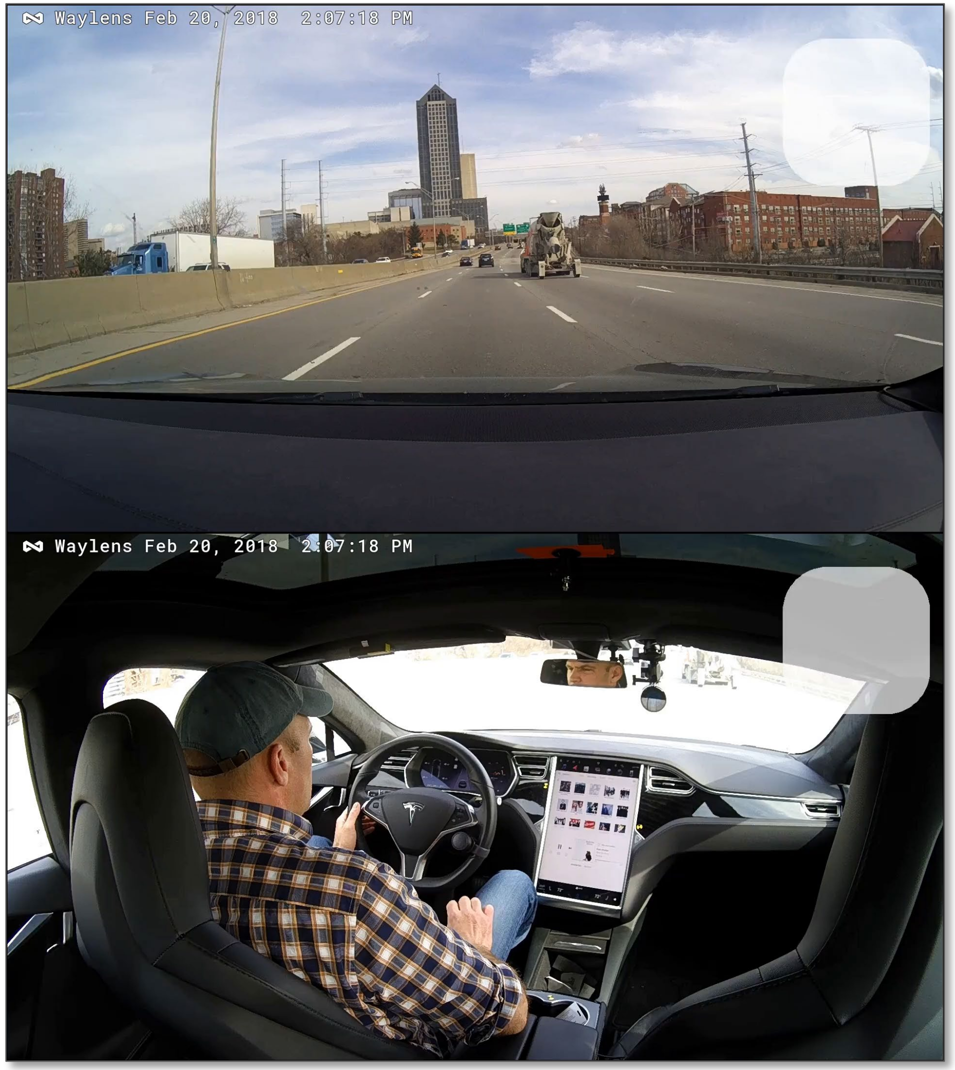
Type III Events

Unlike the other event types, Type III events are defined in two ways.

- Driving situations where the driver, believing the vehicle was unable to automatically perform the driving task any further, performed a **manual override** input to immediately disengage the system and resume full manual control, or
- While operating in level 2 driving automation without traffic in an adjacent lane, breached a lane boundary but then **automatically returned** towards the center of the original travel lane (i.e., without any intervention from the driver).

Type III Event Examples (LV; driver interventions)

Merge towards other traffic

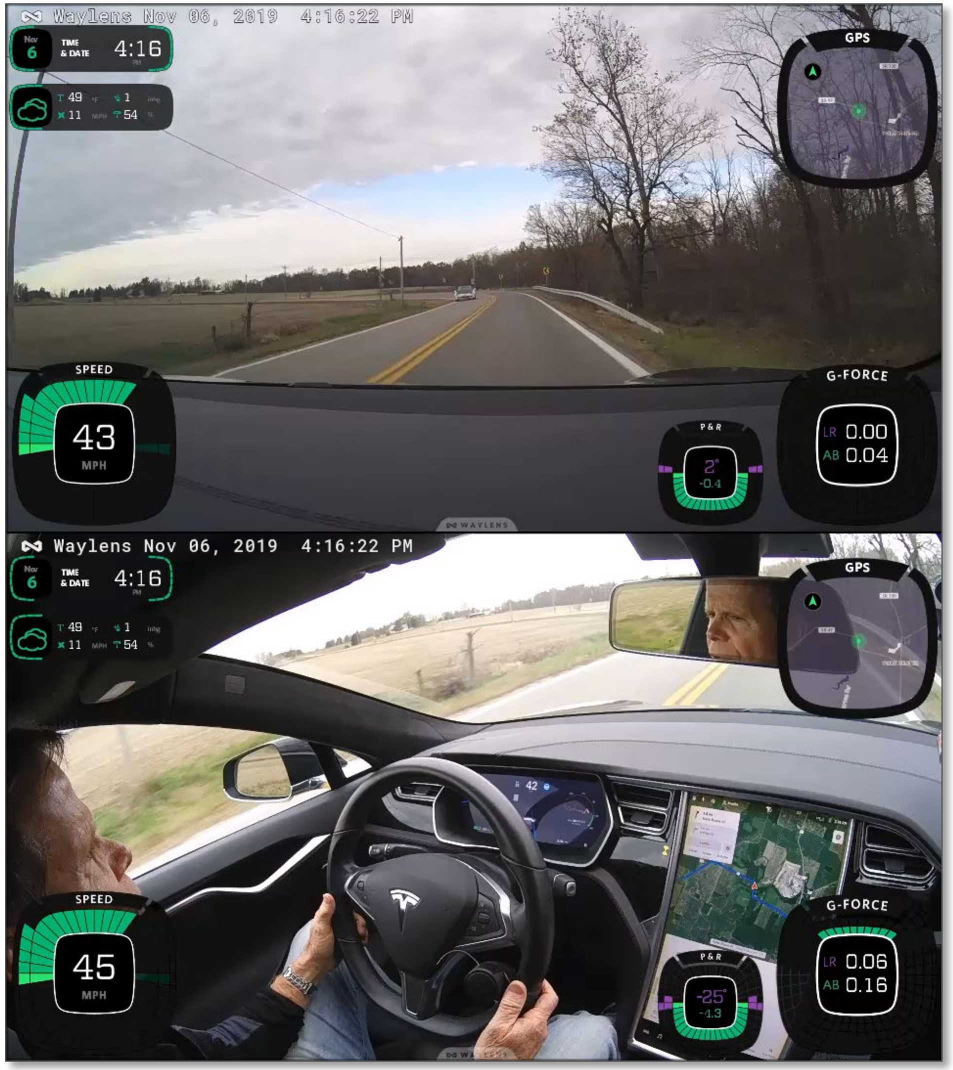


Path-following error

Type III Event Examples (LV; system recovery)

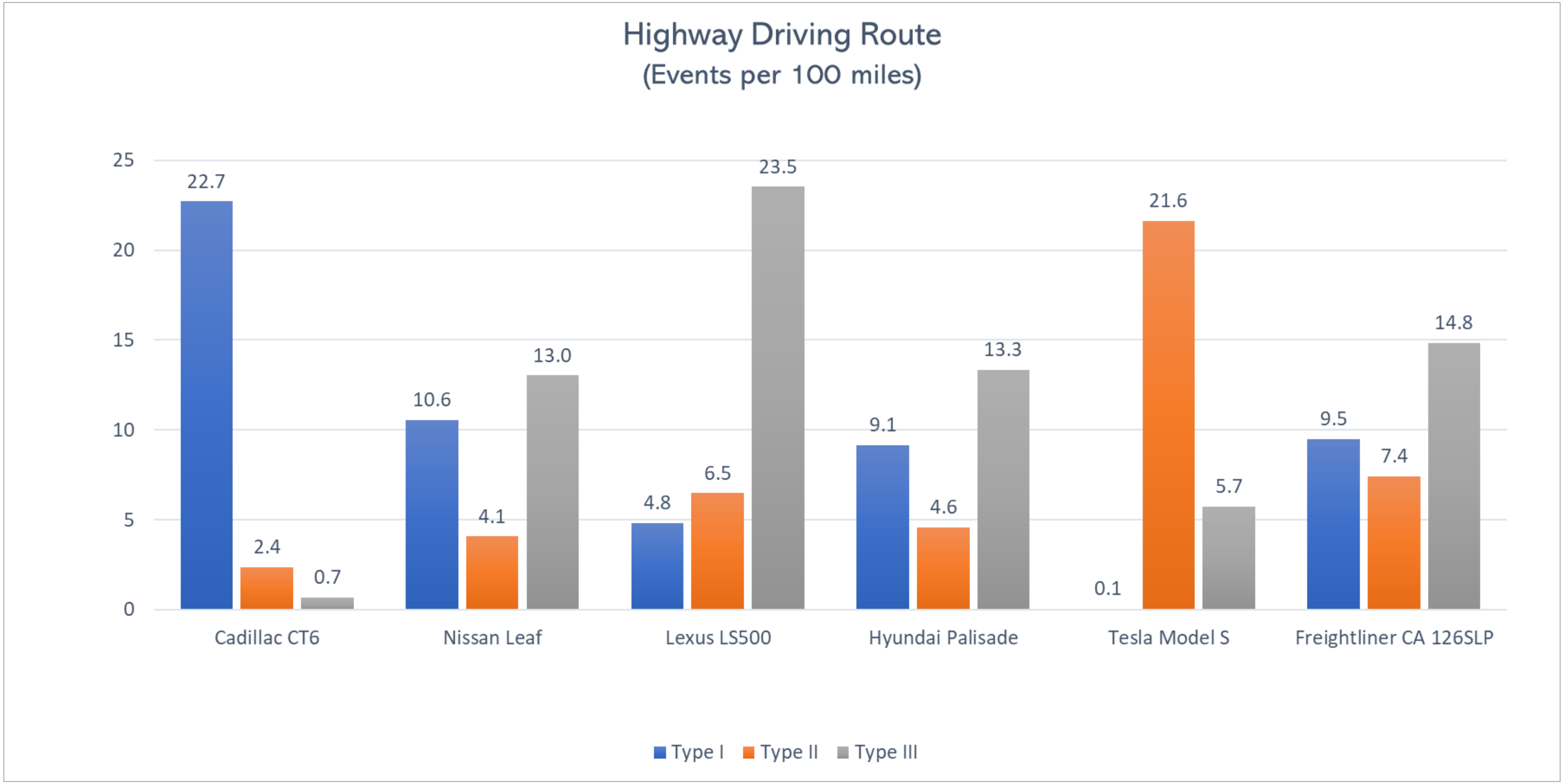
Cutting corner (over right shoulder line)

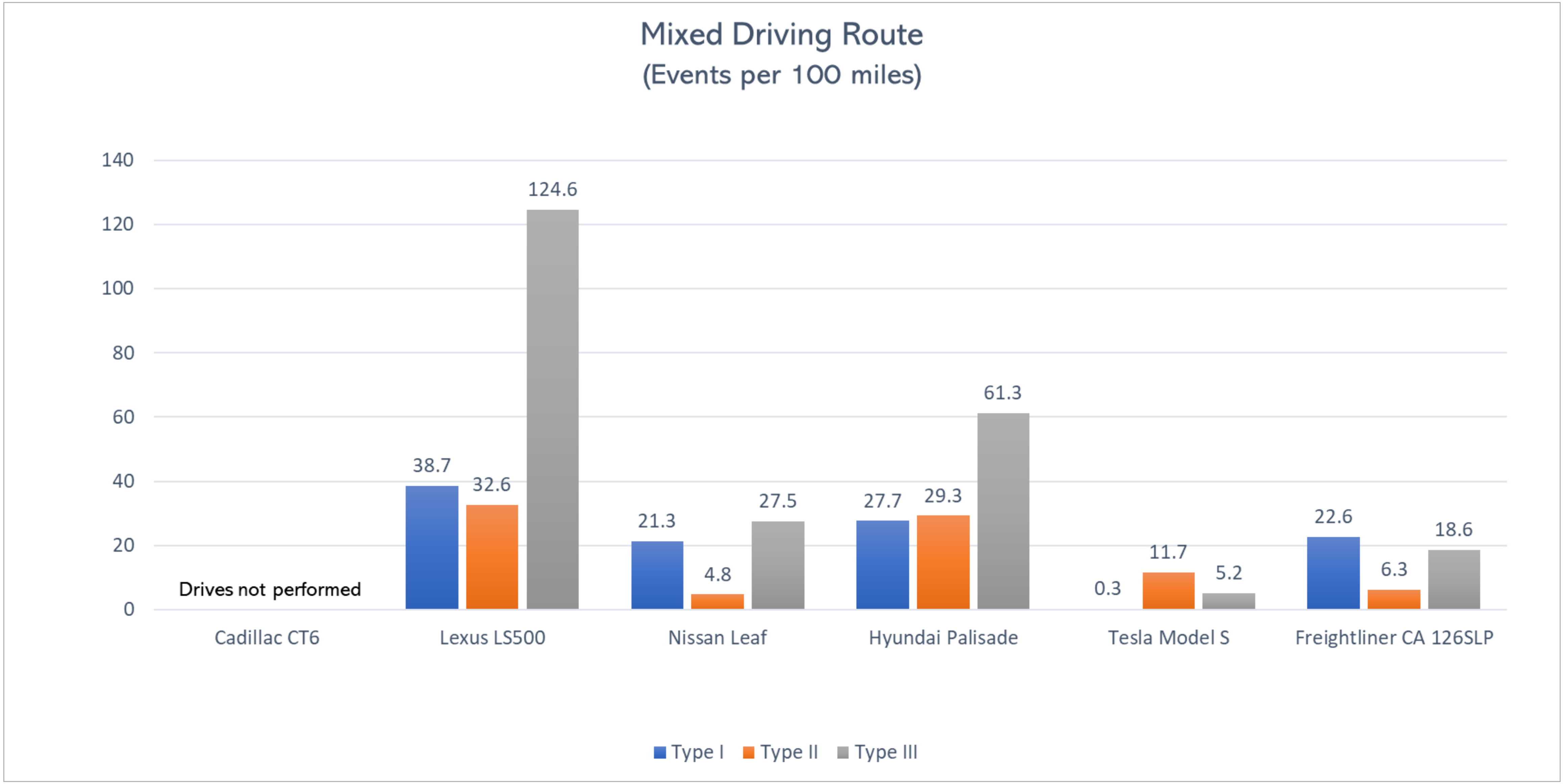
Cutting corner (over center line)

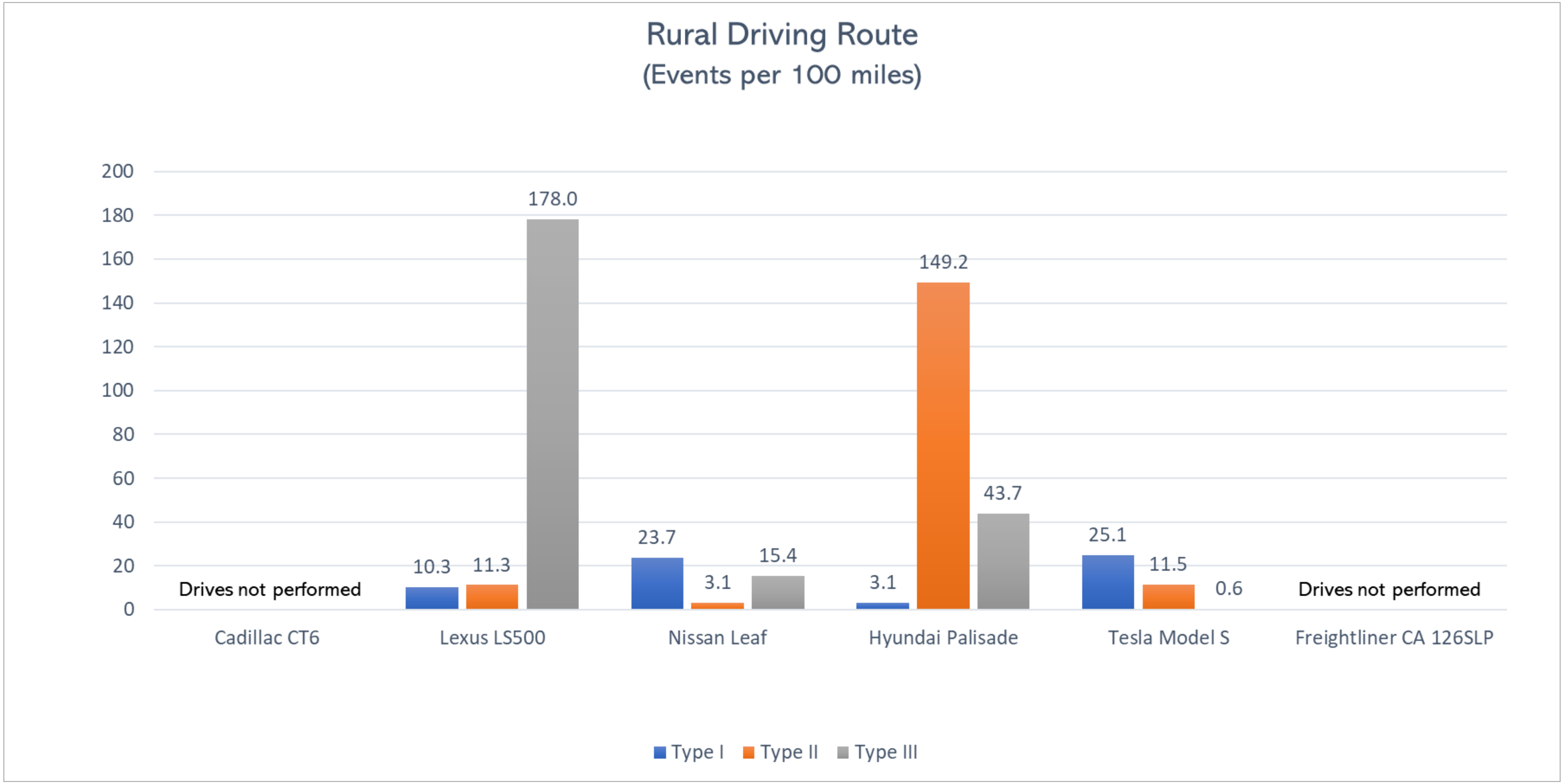


Type III Event Example (Heavy Vehicle)

Steering dither with nearby traffic


Highway Driving Route
(Events per 100 miles)
25
20
15
10
5
0
22.7
2.4
0.7
10.6
4.1
13.0
4.8
6.5
23.5
9.1
4.6
13.3
0.1
21.6
5.7
9.5
7.4
14.8
Cadillac CT6
Nissan Leaf
Lexus LS500
Hyundai Palisade
Tesla Model S
Freightliner CA 126SLP
Type I
Type II
Type III


Mixed Driving Route
(Events per 100 miles)
140
120
100
80
60
40
20
0
124.6
38.7
32.6
61.3
21.3
4.8
27.5
27.7
29.3
0.3
11.7
5.2
22.6
6.3
18.6
Drives not performed
Cadillac CT6
Lexus LS500
Nissan Leaf
Hyundai Palisade
Tesla Model S
Freightliner CA 126SLP
Type I
Type II
Type III


Rural Driving Route
(Events per 100 miles)
200
180
160
140
120
100
80
60
40
20
0
Drives not performed
10.3
11.3
178.0
23.7
3.1
15.4
3.1
149.2
43.7
25.1
11.5
0.6
Drives not performed
Cadillac CT6
Lexus LS500
Nissan Leaf
Hyundai Palisade
Tesla Model S
Freightliner CA 126SLP
Type I
Type II
Type III

Summary Overview

(Provided in the two technical reports)

Driving route summaries

- Roadway type
  - Exit ramp, merge lane, normal
- Road condition
  - Dry/wet, straight/curved, flat/not flat
- Lane line condition
  - Good, degraded, missing

Event type summaries

- Type I
  - Occurrence only
- Type II
  - Dithering in lane, line hugging, other
- Type III
  - Lane departure with system recovery, lateral intervention, longitudinal intervention

Future Work and Upcoming Results

Aaron Greenwood, PhD

Introduction

- ADAS Safety technologies are increasingly standard or available
- NHTSA Research will characterize performance of common ADAS systems in scenarios with high safety risk.
  - Addresses bicycles and motorcycles, vulnerable road users overrepresented in crash statistics
  - Addresses high-speed and head-on collisions, which have high fatality risk.

Automatic Emergency Braking with Motorcycles

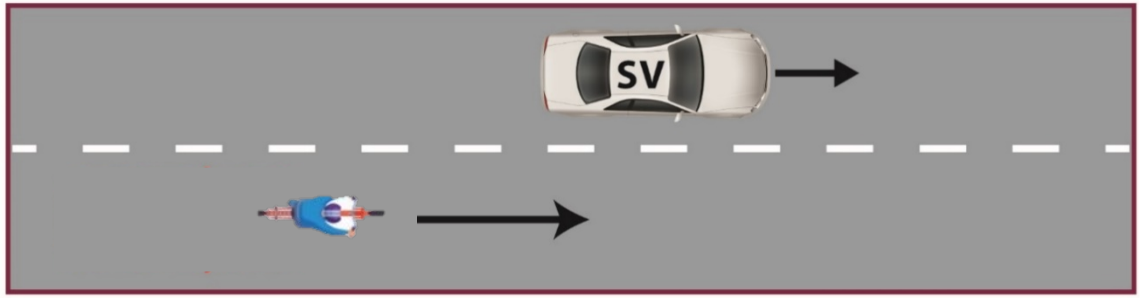
- Scenarios to test:
  - Leading motorcycle stopped
  - Leading motorcycle decelerating
  - Leading motorcycle travelling more slowly
- Day and night conditions
- Lane position
  - Centered
  - Offset 25%
- Vehicle speeds of up to 70 mph

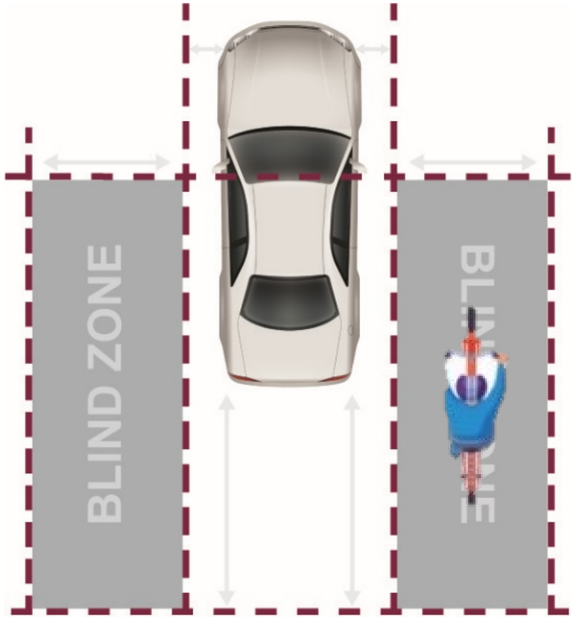
Automatic Emergency Braking with Bicycles

- Scenarios to test:
  - Leading bicycle stopped
  - Leading bicycle decelerating
  - Leading bicycle travelling more slowly
- Day and night conditions
- Lane position
  - Centered
  - Offset 50%
- Vehicle speeds of up to 45 mph

Blind Spot Detection and Intervention with Motorcycles

- Scenarios to test:
  - Constant speed
  - Motorcycle overtaking
- Centered in adjacent lane
- Vehicle speeds of up to 45 mph

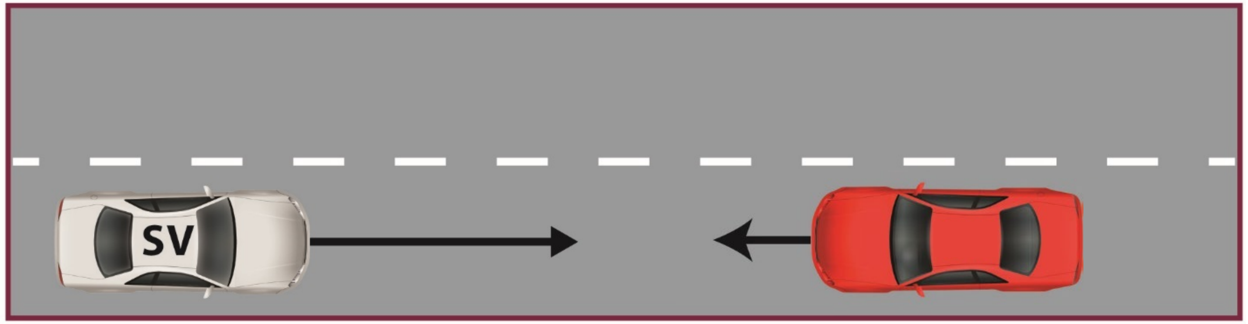




Head-On AEB Testing

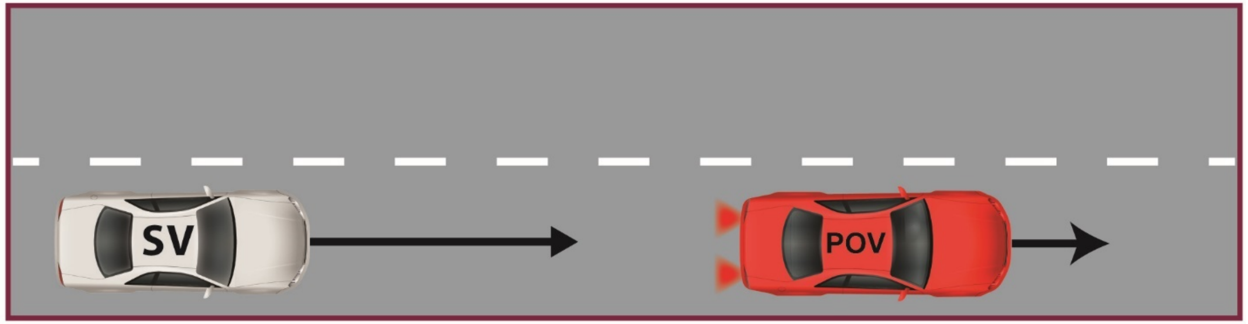
- Subject vehicle will approach a Global Vehicle Target (GVT, a soft target) with both moving head-on, initially at constant speed.
- Vehicle speeds of up to 40 mph
- Speed differentials of up to

  45 mph



Higher Speed AEB Testing

- Existing tests use subject vehicle speeds of up to 45 mph
- New test conditions:
  - Lead Vehicle Moving
    - Speeds of up to 70 mph
  - Lead Vehicle Decelerating
    - Speeds of up to 50 mph
    - Two different headways
      - 30 m
      - 13.8 m



Expected Outcomes

- Build an understanding of capabilities and limitations of existing ADAS safety system performance a variety of conditions.
- Identify research needs and next steps for further improving ADAS safety system effectiveness.

Thank you for your time and attention

Devin Elsasser: devin.elsasser@dot.gov
Stephen Stasko: stephen.stasko@dot.gov
Chris Wiacek: chris.wiacek@dot.gov
Garrick Forkenbrock: Garrick.forkenbrock@dot.gov
Aaron Greenwood: aaron.greenwood@dot.gov