NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

ADS Research

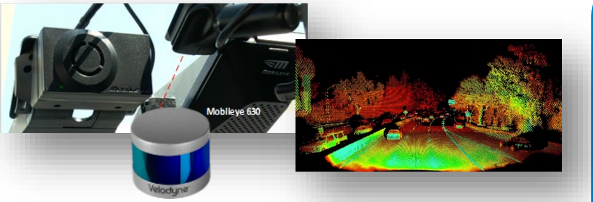
NHTSA Safety Research Portfolio Public Meeting: Fall 2021

October 19, 2021

NHTSA Automated Driving System Research


System Safety Performance

Test track, simulation, & on-road tools development; Testable cases; safety metrics and measures



Subsystems Testing and Functional Safety

Sensor capabilities/limitations, fusion, redundancies; Perception, maneuvers & execution


Crashworthiness

Alternative seating configurations, advanced test dummies; Unoccupied vehicle compatibility

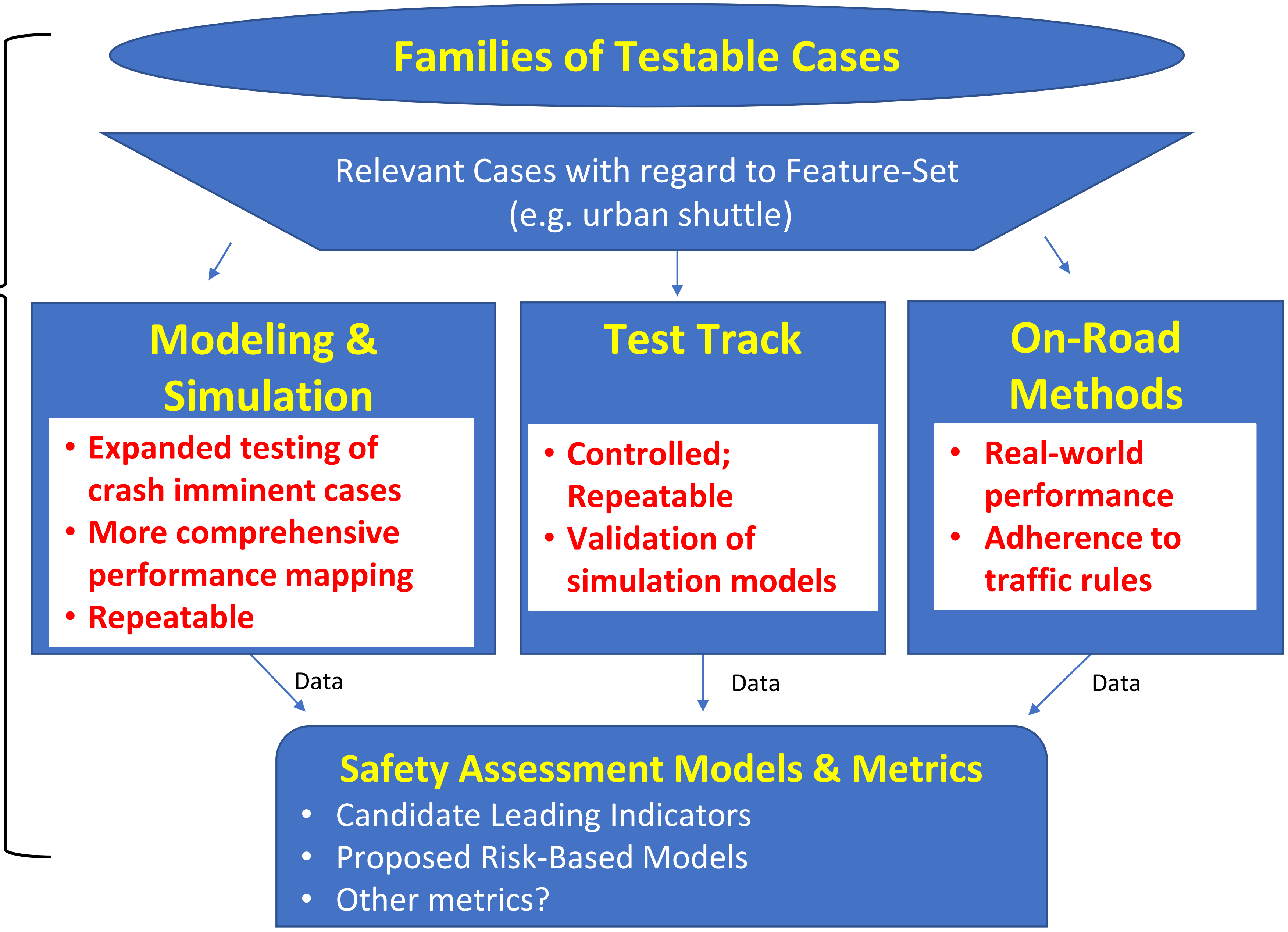

Human Factors

Human-Machine Interface; Driver Monitoring Systems; Communication of intent; accessibility; teleoperations

ADS Research Areas

- **System Safety Performance**
- Sub-system Testing & Functional Safety
- Crashworthiness
- Human Factors

- Cybersecurity, Resiliency, Best Practices, …

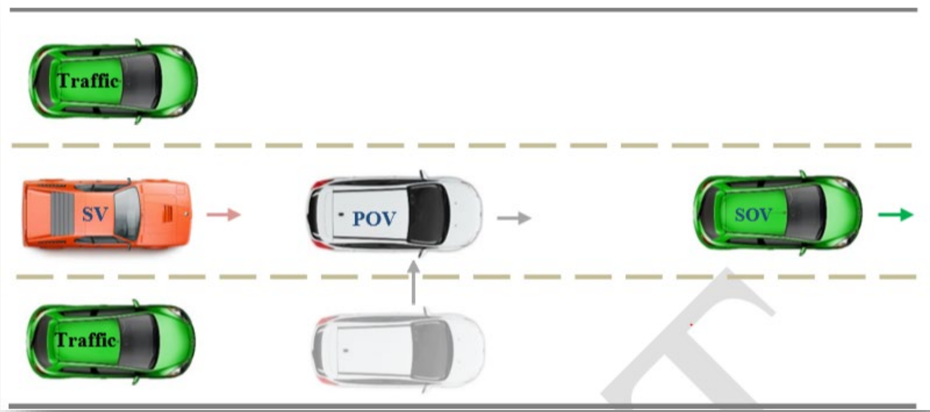


Sample NHTSA System Safety Research Projects

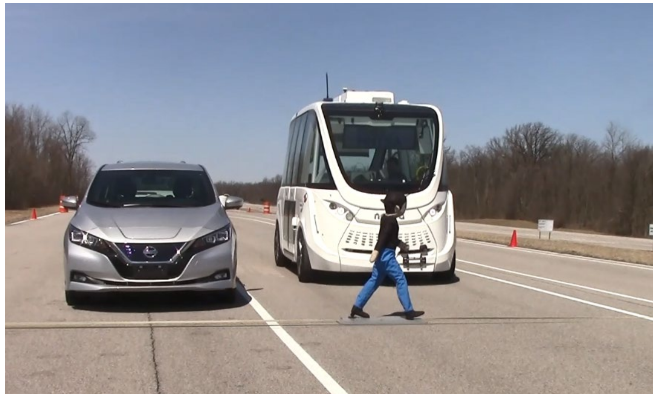
Complex Test Track Execution

Simulation

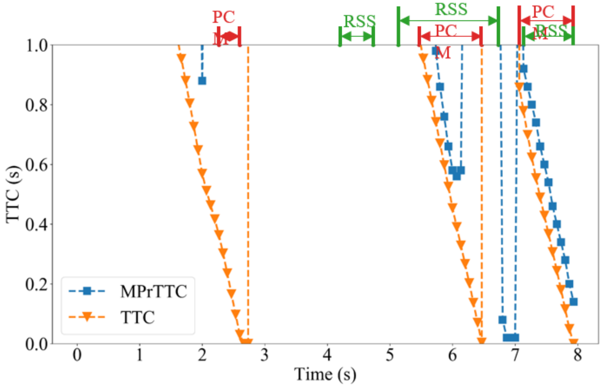
On-road
Ground Truth Trip Recorder



Testable Cases



Prototype Exploratory Testing



Metric Evaluations

Panel Presentations

1. **On Road Testing Methods –** Sebastian Silvani
2. **Review of ADS Metrics Research –** Alrik Svenson
3. **Refining Testable Cases and Scenarios for Evaluating L3 through L5 ADS Concepts –** Paul Rau
4. **ADS Simulation Research –** Scott Schnelle
5. **ADS Test Track Testing Methods Research –** Devin Elsasser
6. **Upcoming ADS Research –** Jay Chen

On Road Testing Methods

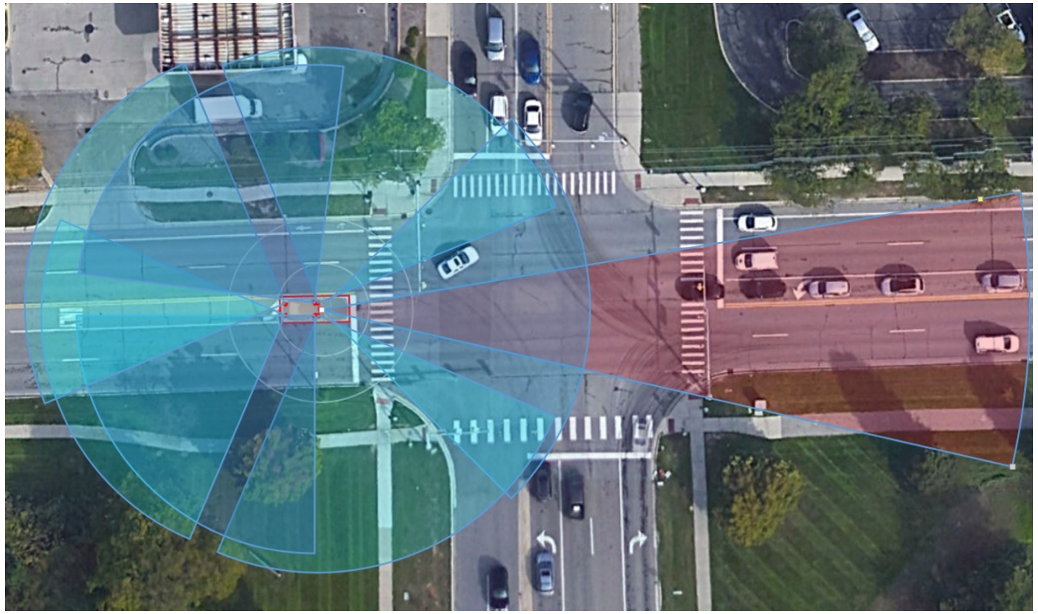
Sebastian Silvani

Project Motivation and Overview

- Demonstrate feasibility of an on-road data collection mechanism to capture vehicle and surrounding data
  - Detect other vehicles/objects and vehicle's kinematics with sufficient accuracy
  - Identify selected scenarios
  - Calculate simple metrics during regular driving
  - Calculate advanced metrics in key scenarios

- Project includes concept of operations (metrics and scenarios) and building a prototype data collection system (Ground Truth Trip Recorder)

- Developing a working proof of concept

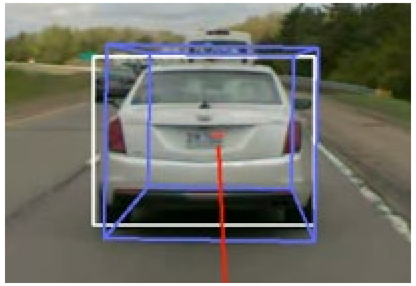


Concept of Operations

Data Collection (GTTR)

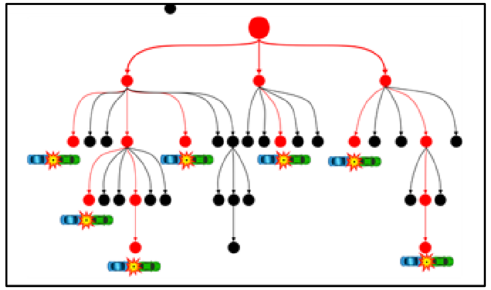
- Relatively easy install, no damage to vehicle
- 17 remote sensors, HD map, 360 degree coverage
- Simple pre-trip calibration
- Unscripted on road driving for data collection

Data - Processing



- Onboard recording & timestamping
- Post-processing for object fusion and tracking
- Targeted scenario identification
- Database population

Metrics of Driving



- Choice of metrics and models
- Kinematic and competency metrics
- Aggregating across driving

Ground Truth Trip Recorder

- 7 radars
- 8 cameras
- 2 lidars
- Thermal camera
- Illumination sensor
- Inertial nav system*
- Timing GPS

Lidars, Cameras, Thermal camera, GPS

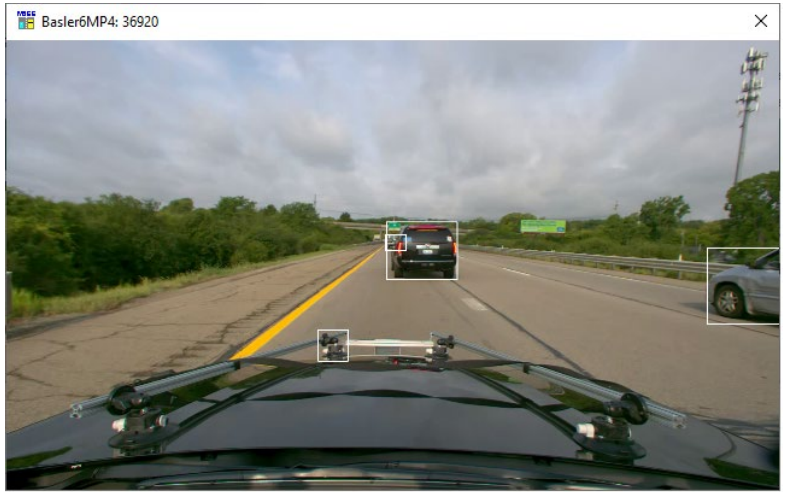
Forward Radar

Side Radars

** Real time kinematic (RTK) GPS, 3 accelerometers, 3 angular rate sensors, plus filtering to give an integrated location and motion solution*

Ongoing Data Collection, Processing, and Analysis

- Approximately 62 hours, 1,858 miles (65 TB) collected
- Targeted Scenario Events Identified
  - 4-way stop—120 events
  - Protected left—149 events
  - Highway merge—164 events
  - Highway cut-in—61 events
- Scenario Performance Analysis
  - Simple kinematic metrics (“roadmanship”)
  - Advanced safety models
  - Traffic competency
  - Aggregated metrics



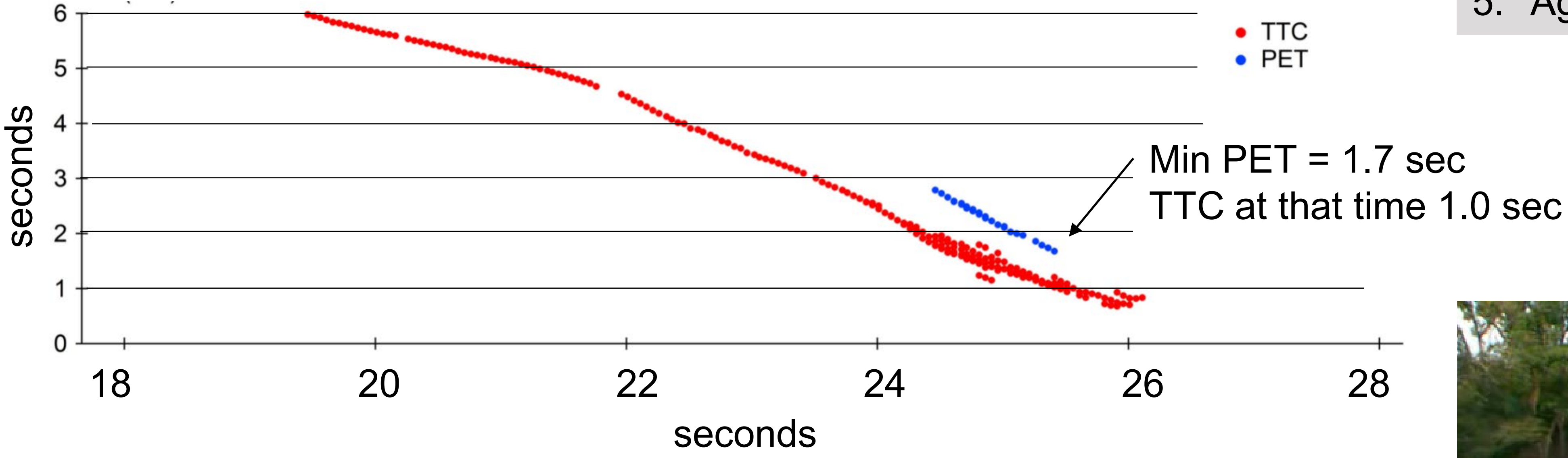
POV Cut-in at 8 m and 2 m/s relative speed

Example: Left Turn Across Path

Traditional Metrics

Data Analysis
1. Scenario identification
2. Basic kinematic metrics
3. Advanced safety models
4. Competency/traffic metrics
5. Aggregate metrics

Time to collision (TTC) &
Post-encroachment time (PET) (sec)

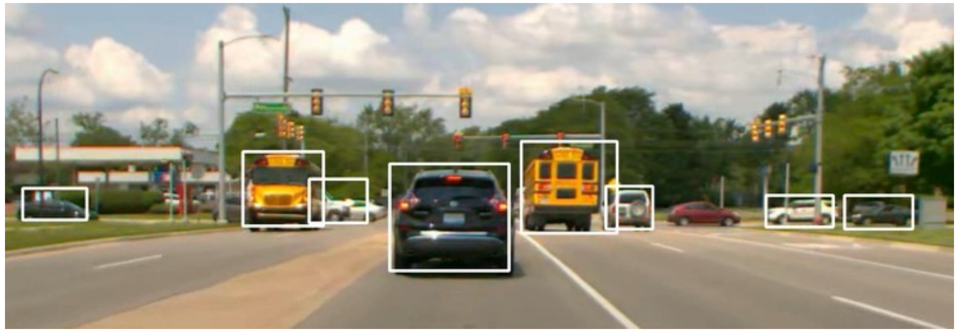


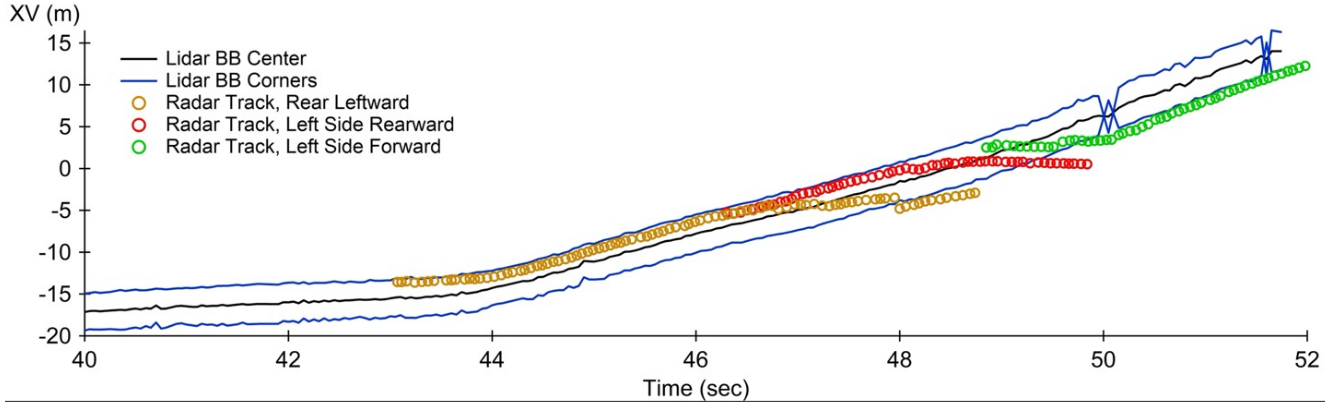
TTC: Range / Range rate

PET: Time between first vehicle leaving the overlap zone and the second vehicle entering

Next Steps

- Expand On-road data collection
- Refine GTTR specifications
- Utilize advanced safety metrics across scenarios
- Develop method to aggregate metrics
- Provide driving assessment feasibility





Review of ADS Metrics Research

Alrik Svenson

Overview of ADS Metrics Research

- Addresses the design and use of metrics to evaluate vehicle performance.
- Leading metrics – early confirmation of safety
- Examine different classes of metrics
- Assess and extend advanced metrics
- Use of metrics to provide overall safety evaluation

Assumptions

- Metrics covered in this study assume that:
  - All (decision-risk) relevant actors are detected and classified correctly without processing delays.
  - There are known limits on how each type of road actors might move.

  - Then, they calculate a measure of instantaneous crash risk.

Applying Metrics to Assess Vehicle Performance

Metric Types to Assess Elements of Safe Driving

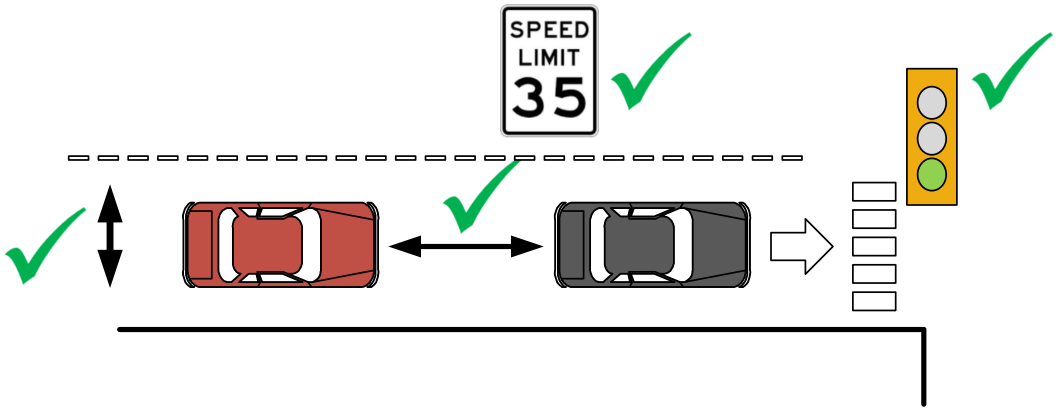
✓✓ Primary metric ✓ Secondary metric

Driving Components	Kinematic Metrics	Competencies & Traffic Rules	Crash Involvement Measures
Defensive driving	✓✓	✓	N/A
Crash-imminent responses	✓	✓	✓✓
Traffic rule compliance	✓	✓✓	✓

Traditional Leading Metrics - Examples

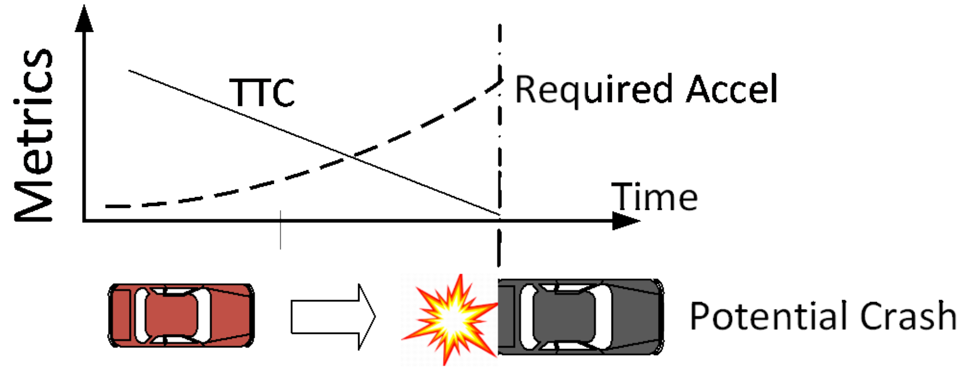
Basic Competencies and Traffic Rules

- Lane-keeping performance
- No tailgating or speeding
- Traffic signal compliance
- Proper lane choices



Traditional Kinematic Metrics (Fixed Paths)

- Assume paths of the vehicles* are known.
- Simple behavior of nearby vehicles is assumed
- Compute metric output quantity, e.g.
  - Time to collision (TTC)
  - Acceleration to avoid collision
  - Post-encroachment time (PET, crossing paths)

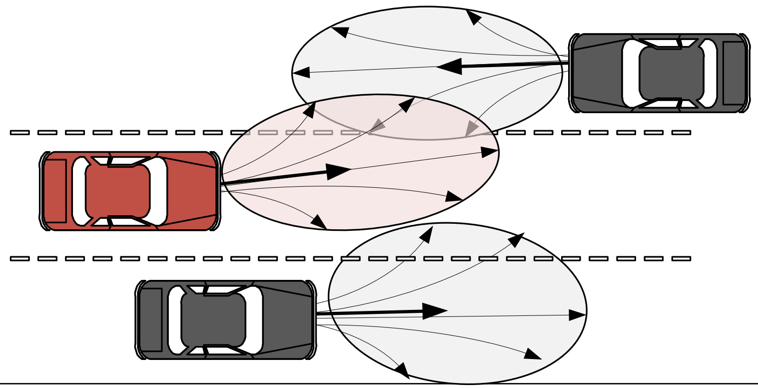


*Vulnerable road users can be included in these metrics

Advanced Kinematic Metrics

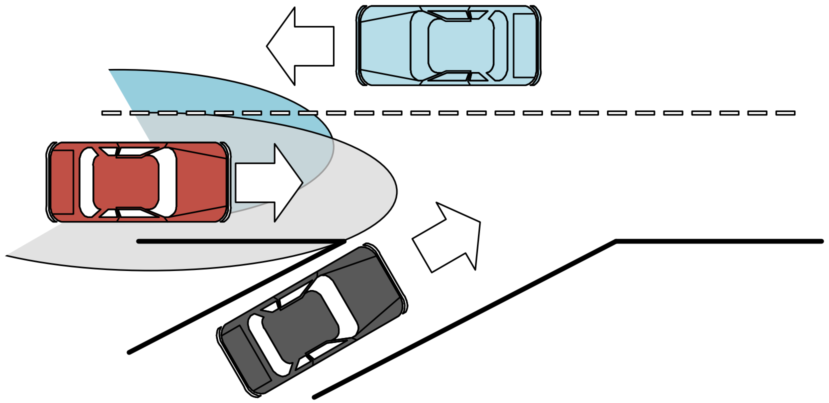
Model-Predictive Kinematic Metrics (Variable Paths)

- Considers <u>multiple</u> possible actions and paths by nearby road users
- Allows many possible subject vehicle responses
- Computes metric output quantity (e.g., TTC)
- E.g., MPrISM (NHTSA), PCM Criticality metric (Pegasus), SMAR (UMTRI)



Safety Envelope Approaches

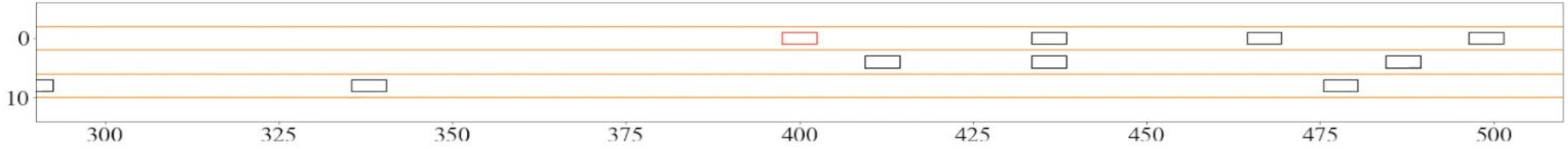
- Considers possible actions and paths by nearby road users
- Computes the safety margin needed to respond and avoid others
- Monitors violations of the safety margin
- E.g., RSS (Intel)



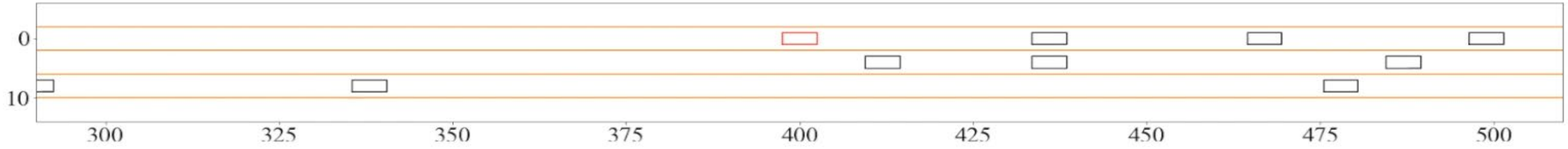
Animation Comparing Metrics

- The vehicle will be marked as all red when the metric threshold is exceeded.

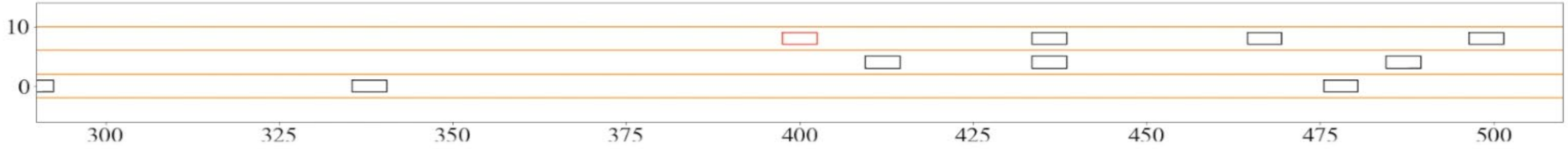
TTC



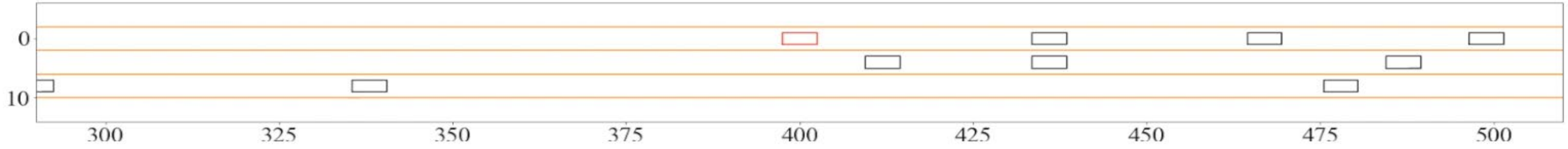
RSS



PCM

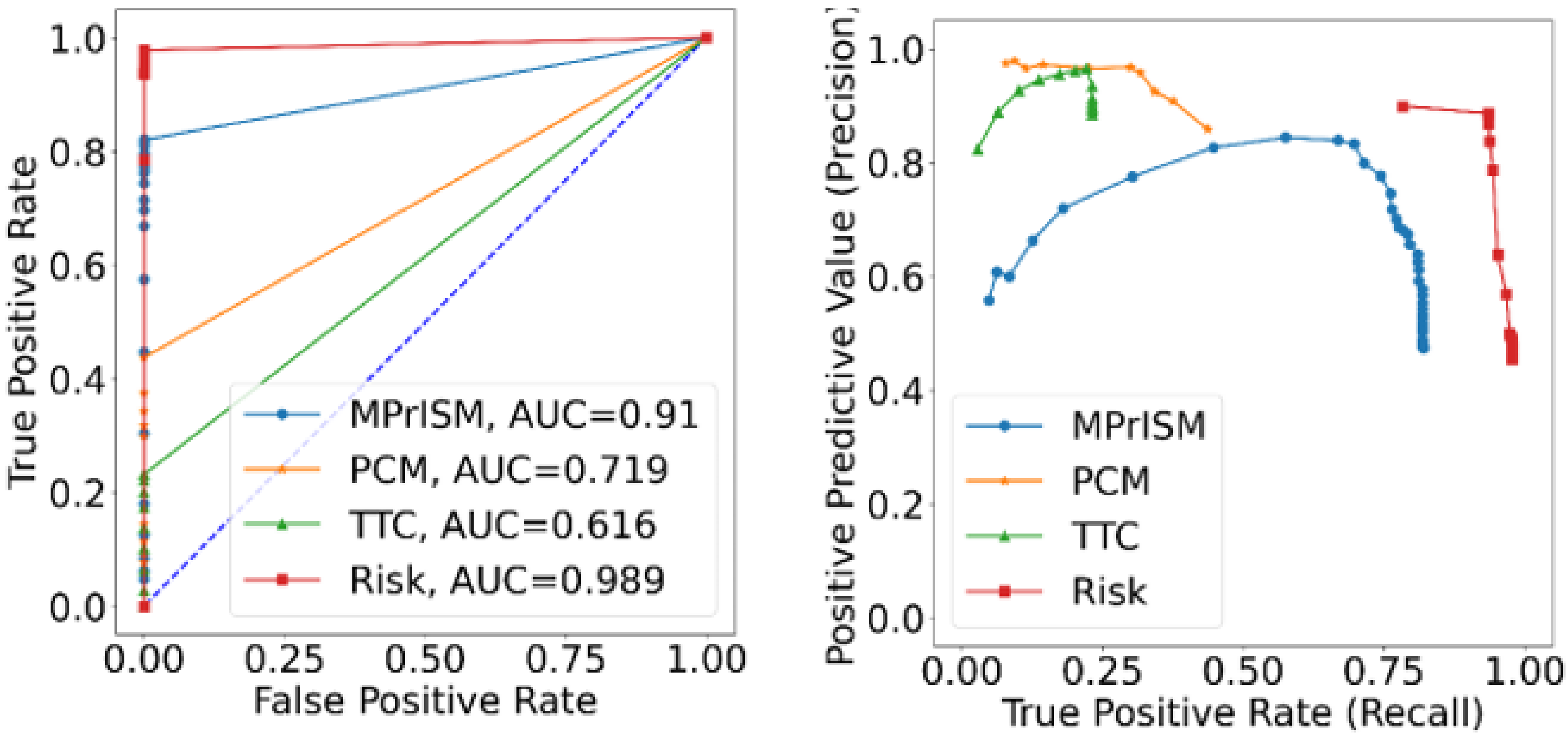


MPrISM



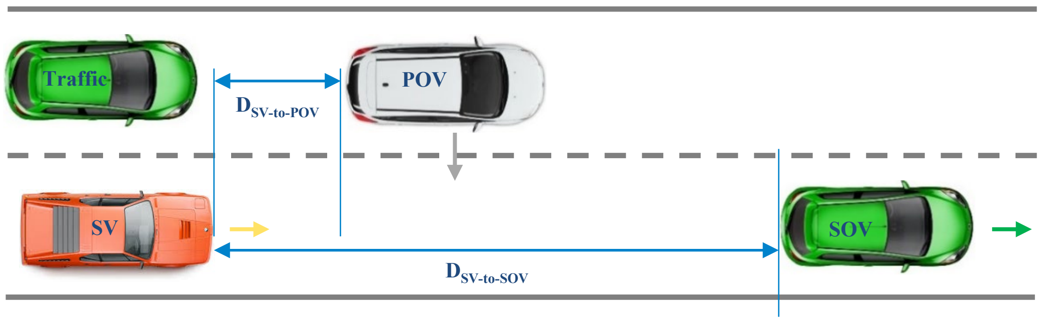
Method to Evaluate Metrics Using a Large Data Set

- Assess metric performance given a large set of simulated events (crashes and non-crashes).
  - Figure below is for illustration only and shows a preliminary test set and single set of parameter choices.



Next Steps

- Continue to refine metrics for use by NHTSA to evaluate the safety performance of ADS-equipped vehicles.
- Using vehicle data collected from the GTTR and other sources to validate metrics in various driving scenarios.



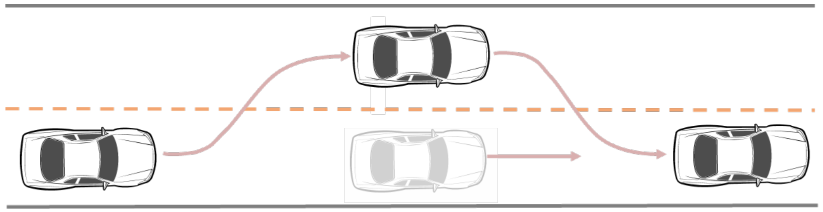
Refining Testable Cases and Scenarios for Evaluating L3 through L5 ADS Concepts

Paul Rau

Refining Testable Cases and Scenarios for Evaluating ADS Level 3 Through Level 5 Concepts

Purpose:

Develop a method to guide the design and selection of cases to efficiently and reliably test the performance of an Automated Driving System (ADS) per SAE J3016 - using lane change scenario data for piloting purposes.



Tasks:

Develop a model-based feature representation of multivariate driving scenario data to further define testable cases.

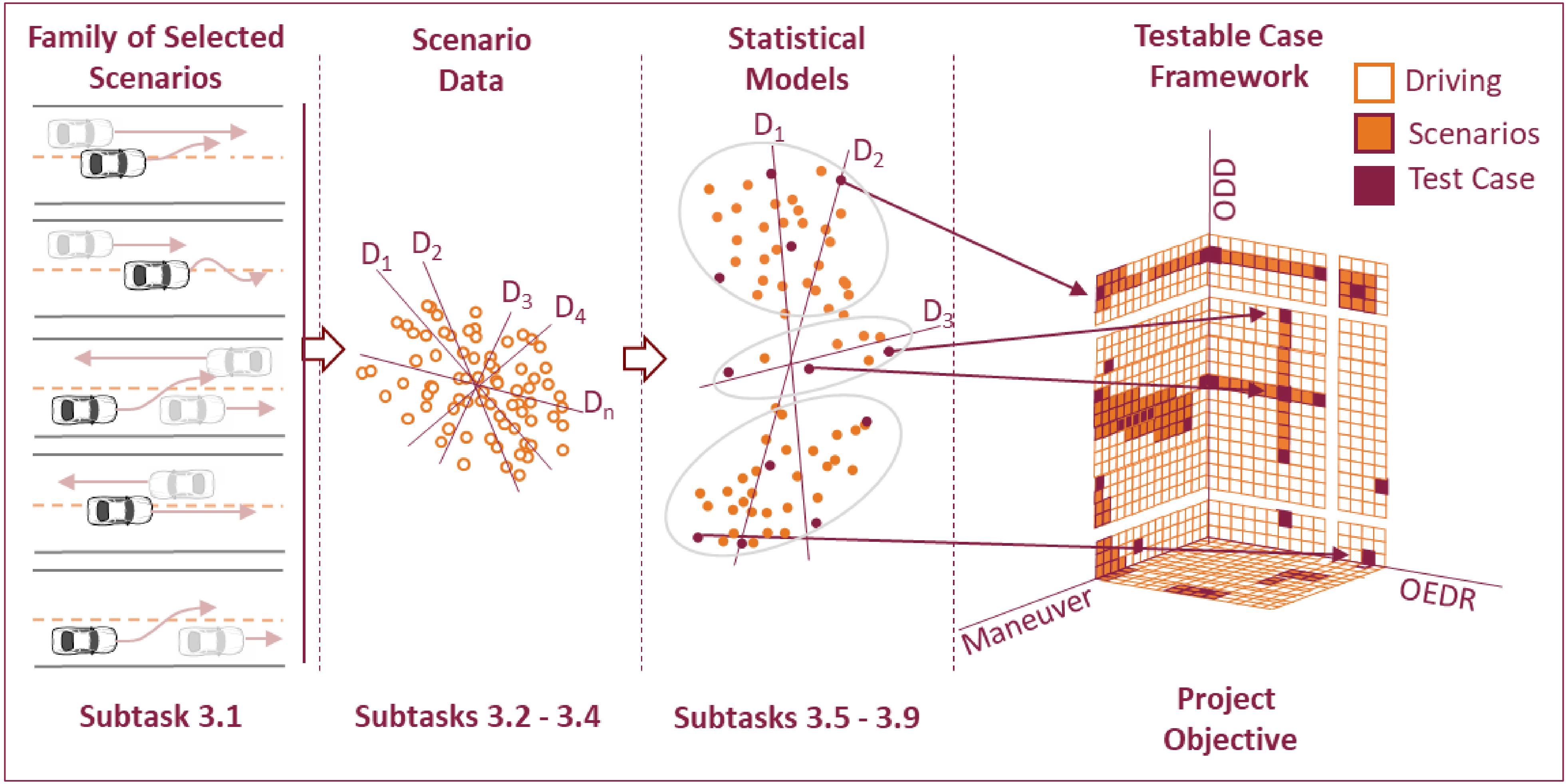
Apply a previous testable cases framework to identify ADS test cases, and quantify the relationship and boundaries between test cases.

Contribution

Adds a data analytics approach to traditional test track, simulation, and on-road test methods to select and evaluate a minimum number of normal driving and safety critical test cases that represent a maximum number of real-world scenarios

Provides a flexible predictive model, along with methods for accommodating non-standard scenario data, to identify test cases for evaluating the safe execution of new or existing Automated Driving System (ADS) competencies

Technical Overview



Project Development Steps - With Expert Participation

Survey and Select Scenarios

Common Scenario Data Dictionary

Standardize Testing Venue Data

Import Scenarios in Standard Form

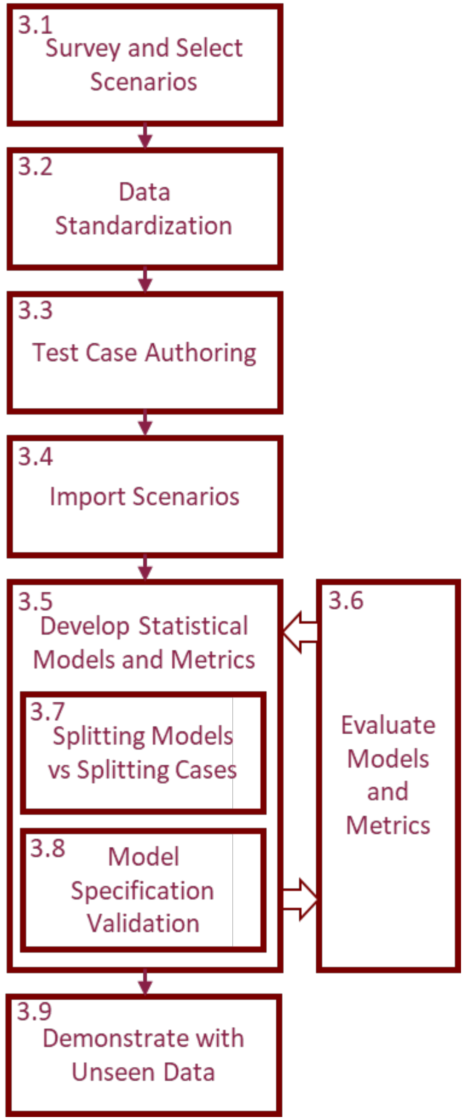
Common Model Training Set Format

Verify and Validate Model Output

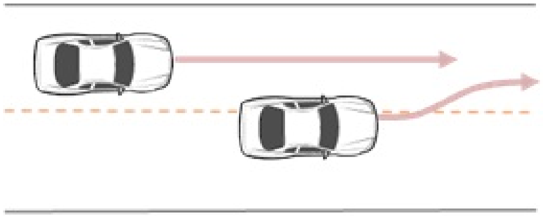
Trace Model Outputs Back to Inputs

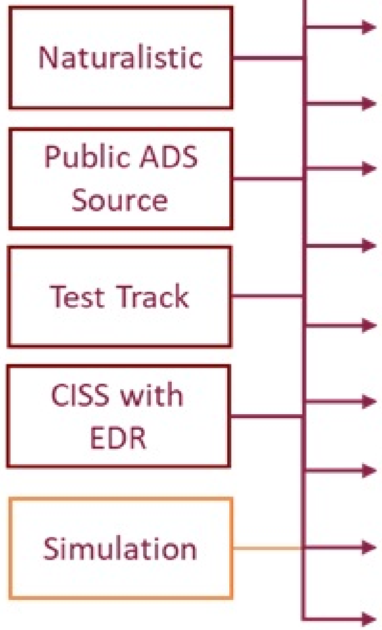
Demonstrate Models with Unseen Data

Examine Non-Standardized Scenarios



Scenario Sources for Statistical Models





Venue	Count	Description
NDS	500,665	Routine lane changes greater than 31 mph
NDS	435	Routine lane changes, located in random samples
Public ADS	306	Lane changes in proximity of automated driving system
NDS	5003	Routine merges
Test Track	567	Routine merges
NDS	919	Cut-ins
Simulation	10,799	3 core cases X ~3600 simulated variations
NDS	1394	Near-crashes
NDS	53	Crashes
Test Track	5	Event avoidance lane changes
CISS	145	CISS EDR cases
	520,291	Total

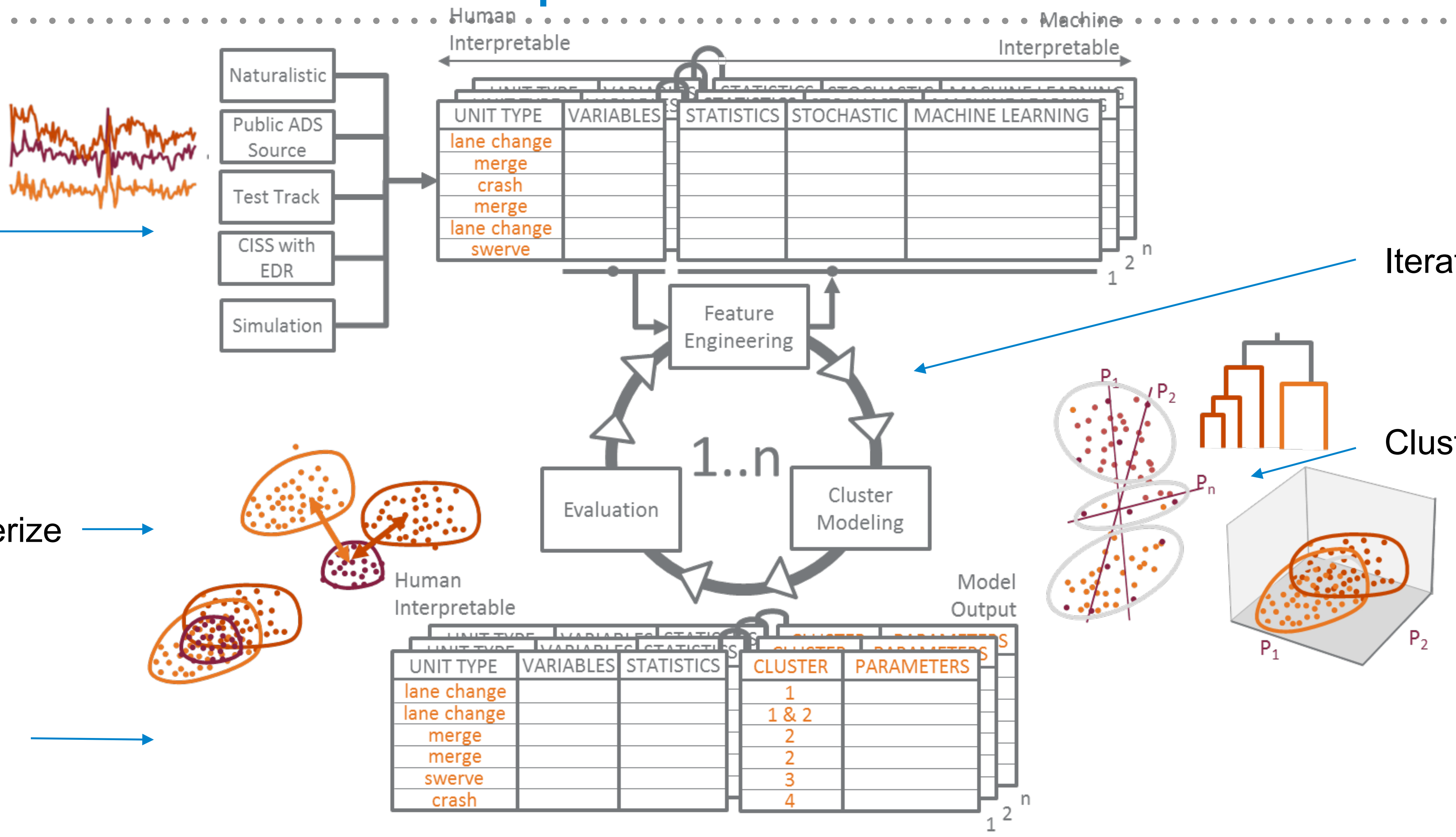
CISS: Crash Investigation Sampling System
EDR: Event Data Recorder
NDS: Naturalistic Driving Study

Iterative Model Development Process

Input

Parameterize

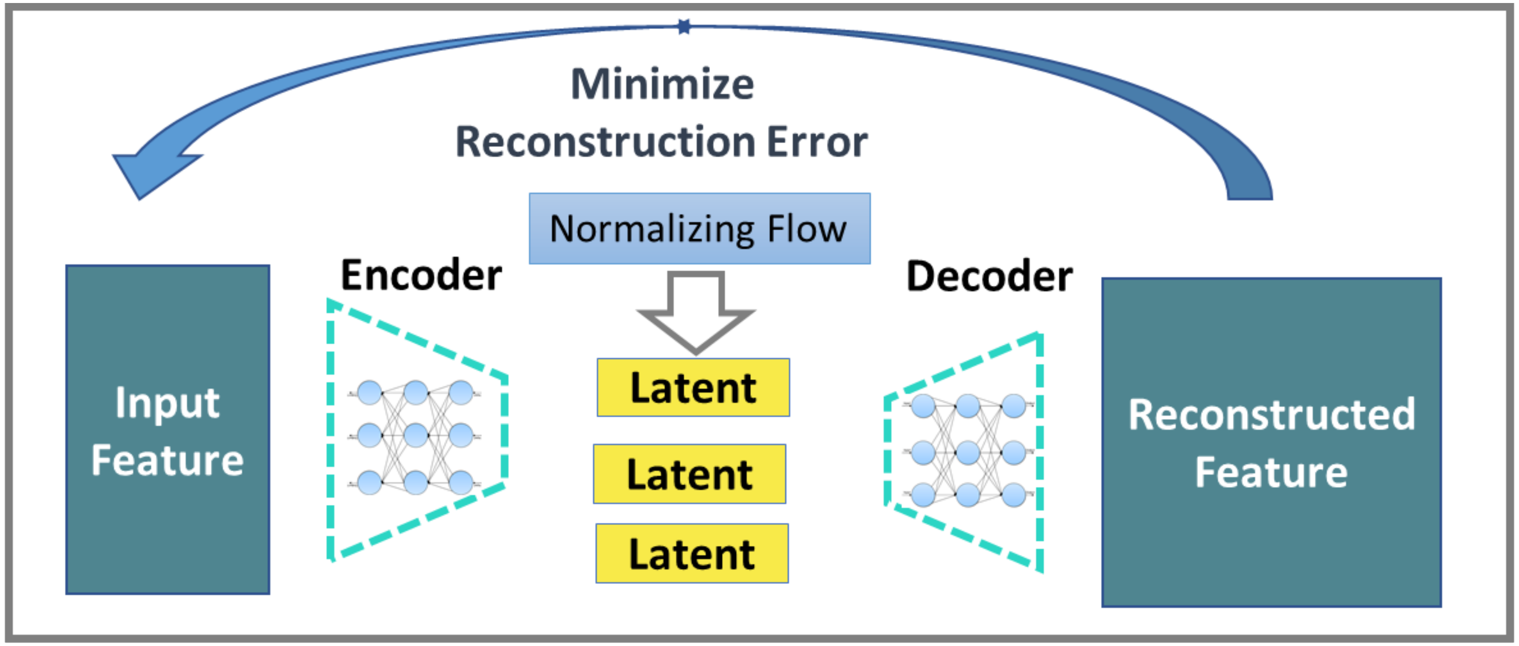
Analyze

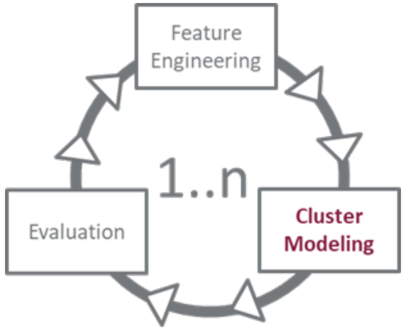


Iterate

Cluster

Extract and Visualize Model Feature Clusters





The latent distributions represent full features

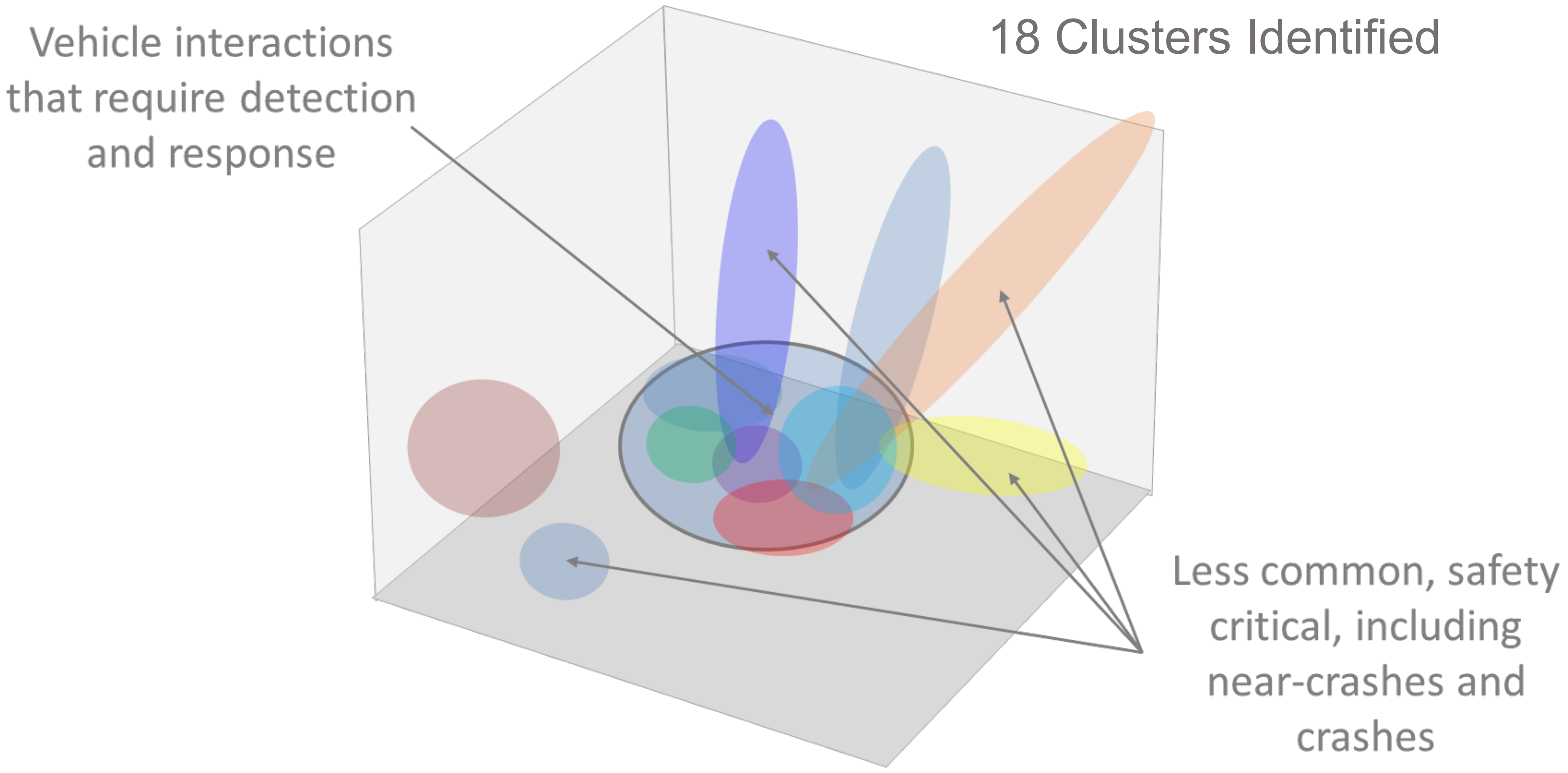
Overall based on the variational inference modeling framework

Clustering Procedures

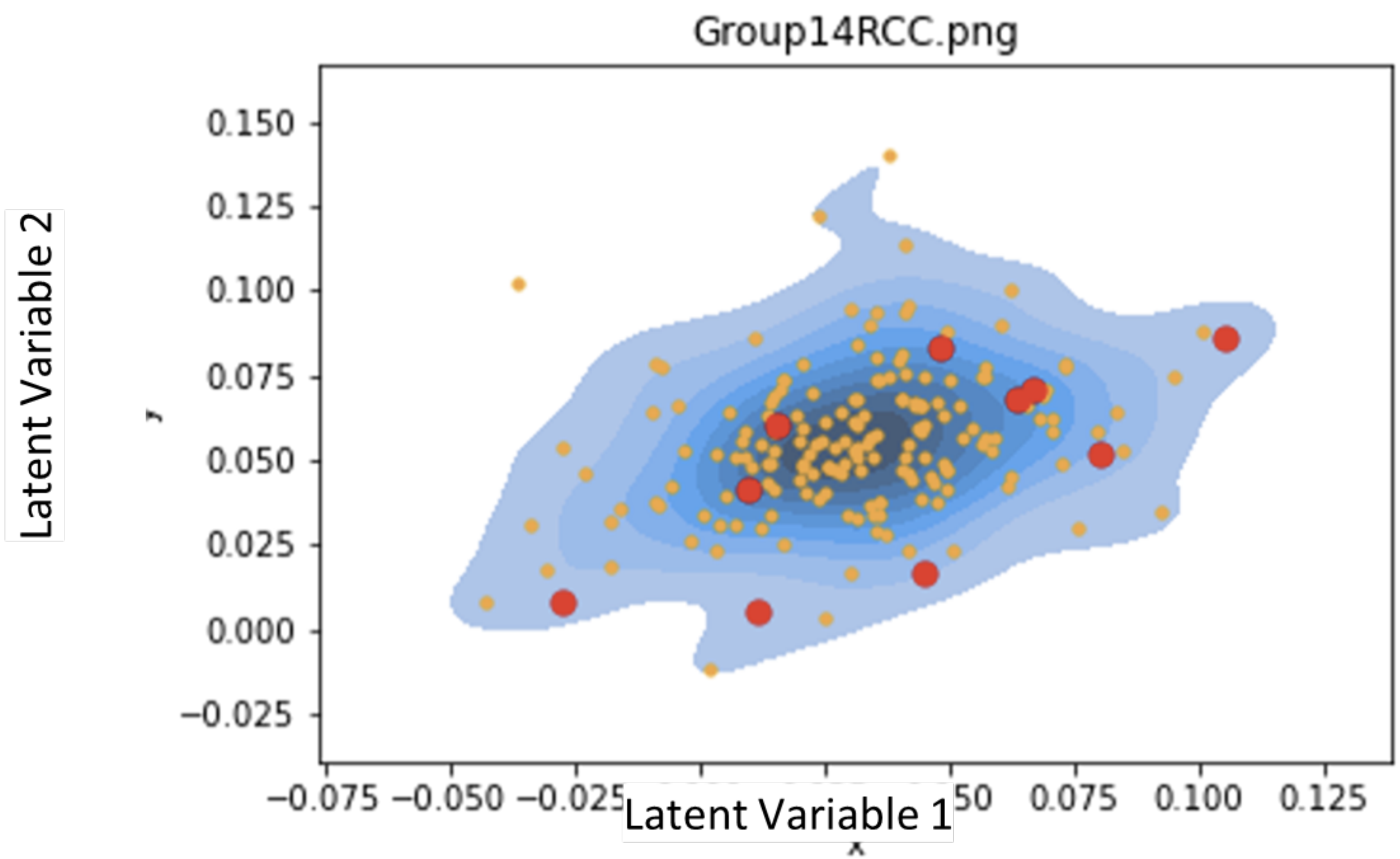
Gather similar driving scenarios together and separate dissimilar scenarios into different groups

Feature Type	Clustering Methods			
	Hierarchical/ Partitioning Clustering	Machine Learning Clustering	Time Series Clustering	Gaussian Mixture Model (GMM)
Statistical	✓	✓		✓
Model-based	✓	✓		✓
Autoencoder-based feature representation		✓		✓
Raw data		✓	✓	

Sharpen Feature Clusters (Notional)



Classify Driving Risks Within Feature Clusters



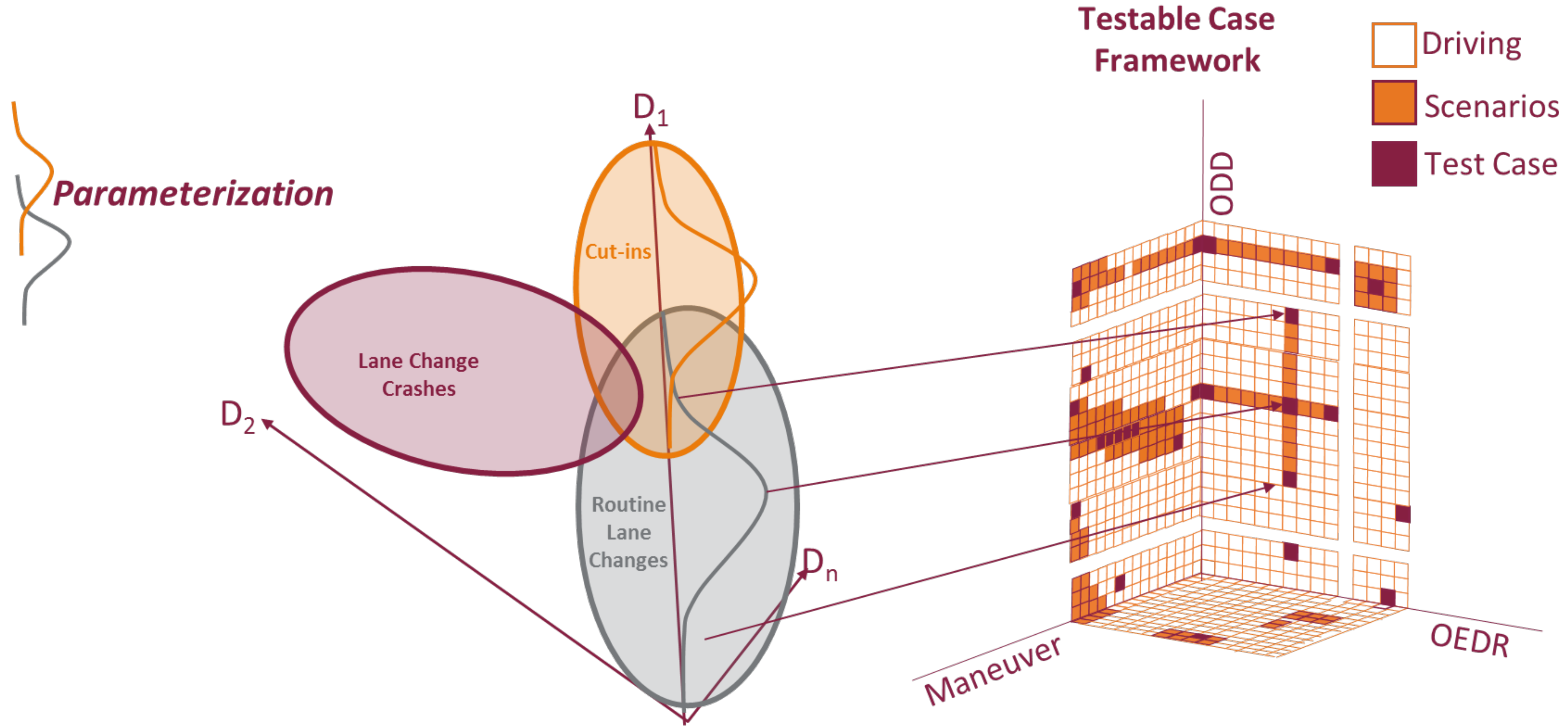
🟡 : normal lane change
🔴 : safety critical events

High density: More likely to happen

Low density: Less likely to happen

- Certain feature combinations occurs more frequent than others
- Safety Critical Events tend to occur on low density regions

Identify Safety Critical Testable Cases



Summary of Key Points

- Developed methods and tools to efficiently select ADS test cases
- Focused on lane-change scenarios. Over 500,000 scenarios gathered from various sources and testing venues
- Transformed scenarios into a common language and format for input into statistical models (parameterizing the scenario data)
- Tested various models for their ability to analyze scenario parameters and group cases into feature “clusters”
- Selected a deep learning model to group the lane change scenarios into 18 clusters
- Identified specific cases within each cluster that represented normal and crash imminent test outcomes
- Provided a method for parameterizing new test data for analyzing other types of scenario categories and to efficiently select test cases

ADS Simulation Research

Scott Schnelle

Objectives

1. Review current state of vehicle simulation software
2. Research scenario description methods
3. Execute and validate test track procedures in simulation

Previous Work

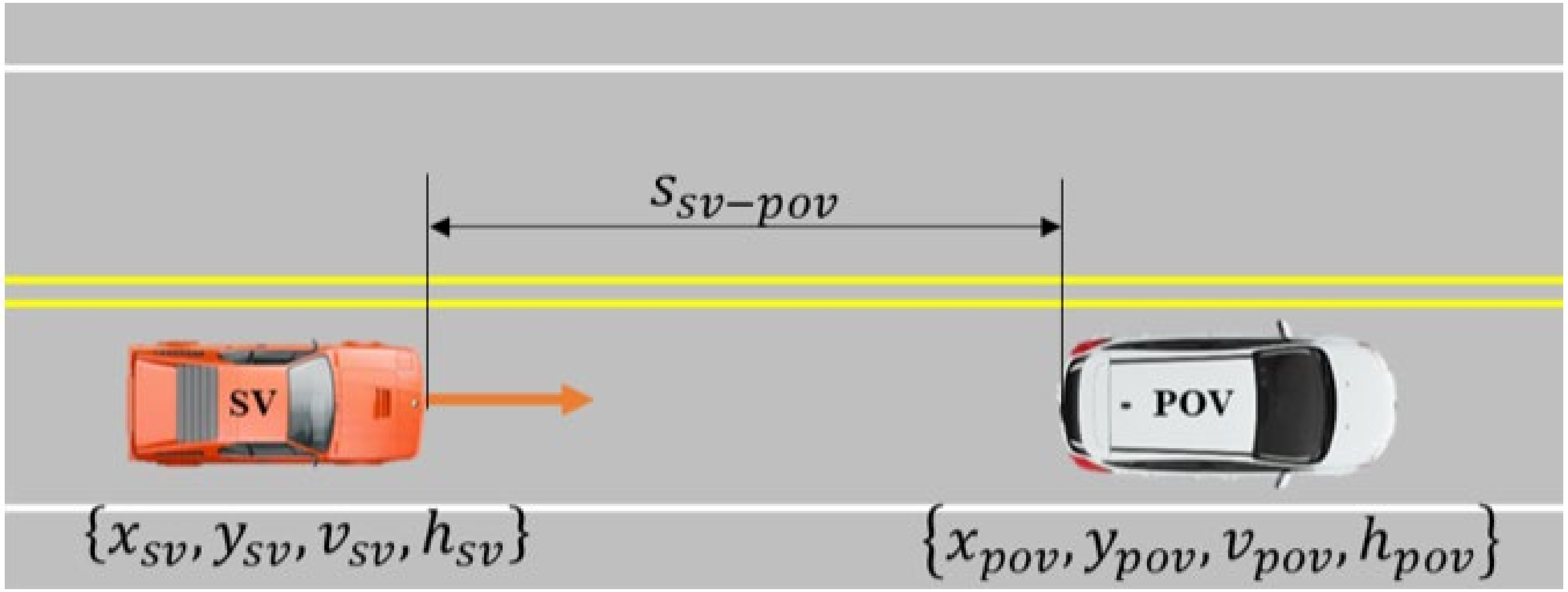
- An initial literature review of simulation frameworks and standards
- The work pivoted to explore elements and properties used to characterize scenarios in a repeatable and reproducible manner
- Additional work on validating vehicle dynamics model fidelity using subjective analysis with simulation and test track data

Simulations Performed

- Three scenarios were implemented in five different simulation software packages
- Existing research tests were leveraged due to their precise scenario definition and validation requirements to assess simulation capability
- Goal: Validate that the test procedure can be implemented in simulation

Simulations Performed

- Lead Vehicle Interactions
  - Scenarios: lead vehicle stopped, moving, decelerating
  - 66 simulations varying speed and deceleration rate

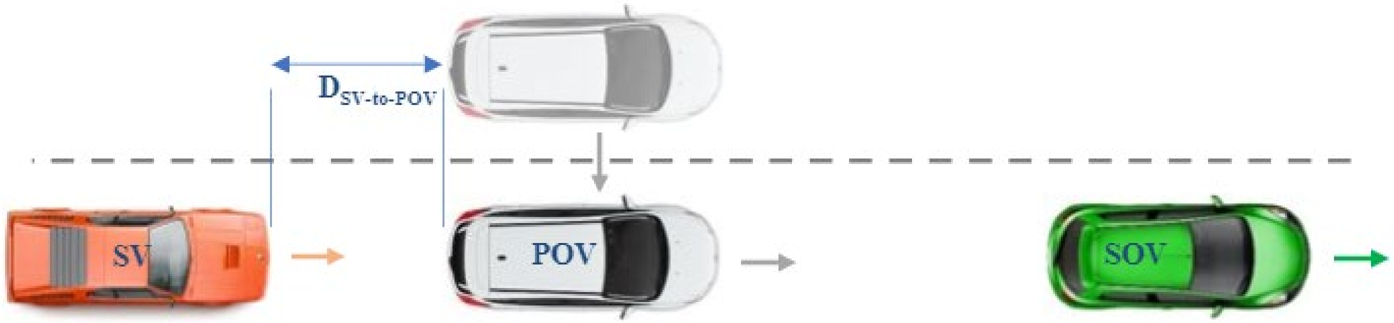


Validity Requirements:

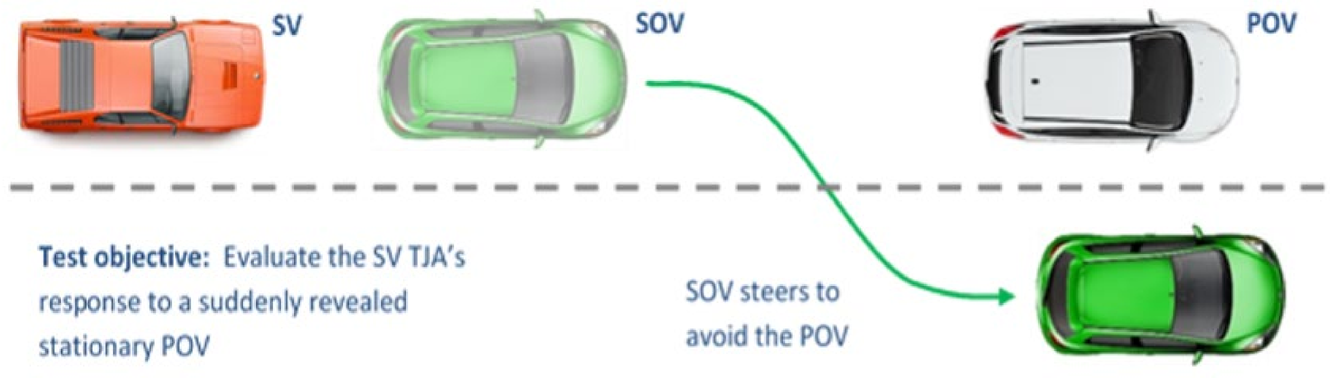
- POV
  - Lane Position
  - Velocity
  - Heading
  - Deceleration
- Timing
  - Relative Distance
  - Relative Speeds

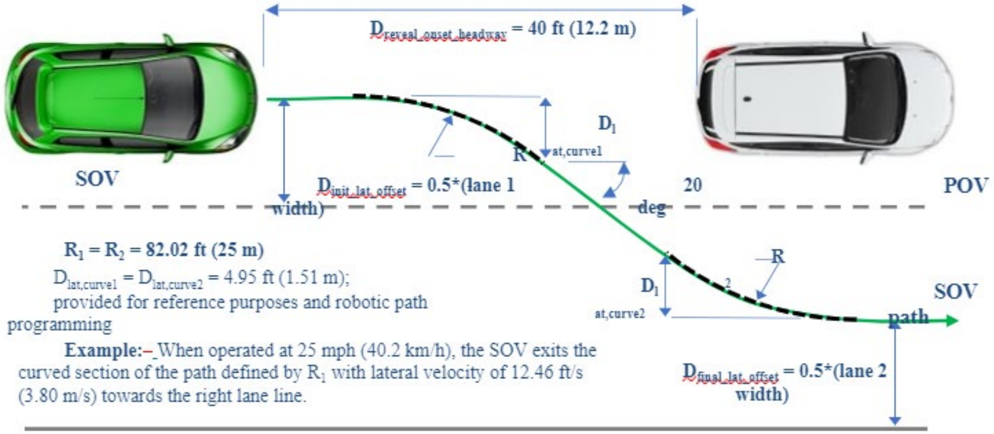
Simulations Performed

- Lane Change Interaction
  - Cut In: 49 simulations varying speed and cut in range



  - Cut Out: 30 simulations varying speed and range





Simulations Performed

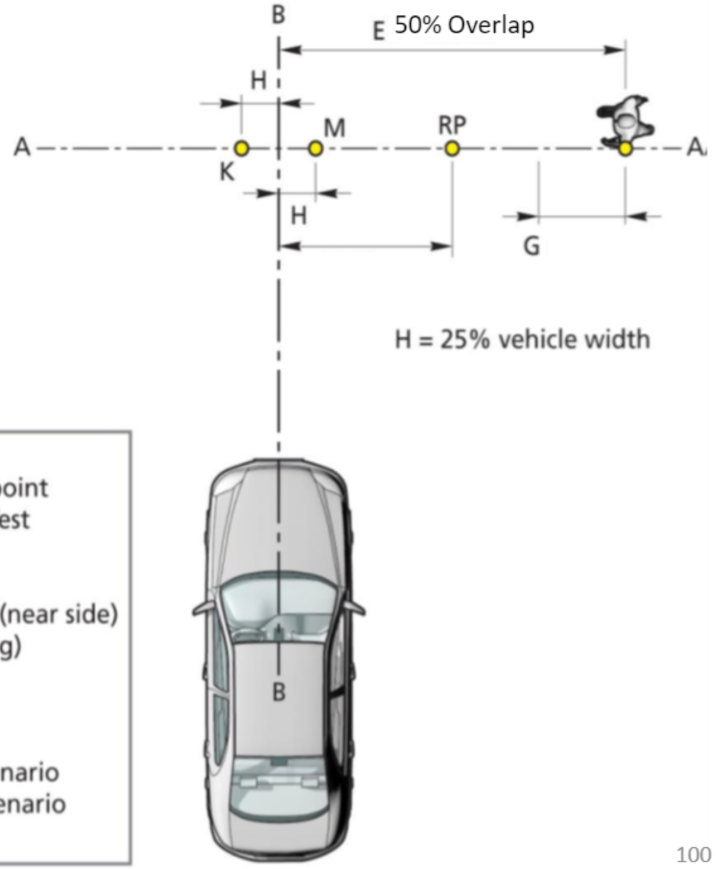
- Vulnerable Road User (VRU) Interaction
  - 96 simulations varying and validating speed, heading angle, position, timing, and overlap

- **Prescribed overlap:** -25%, 0%, 25%, **50%,** 75%, 100%, 125%, and 225%
- **Initial SV speeds**: 20 km/h and 40 km/h.
- **VRU constant speed**:
  - Pedestrian Adult/Child: **5, 7.9 km/h**
  - Bicycle: **10, 15 km/h**
- **Environment**
  - Occlusion with two parked vehicles
  - Obstruction wall (Bicyclist only)
- **Total Tests**
  - Adult - **32**
  - Child – **32**
  - Bicyclists – **32**
  - **Total - 96**

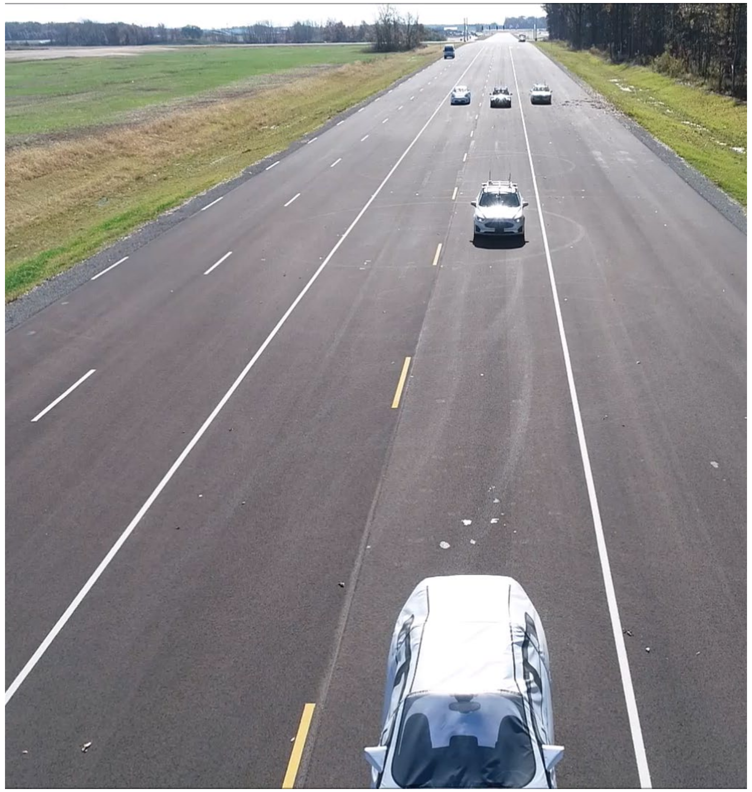
Axes
AA – Trajectory of pedestrian dummy H-point
BB – Axis of centerline of Vehicle under Test

Distances
E – Dummy H-point, start to 50%-impact (near side)
G – Dummy acceleration distance (walking)
H – Impact point offset for 25% or 75%

Points
K – Impact position for 75% near-side scenario
M – Impact position for 25% near-side scenario
RP – Reference Point (dummy hip-point)

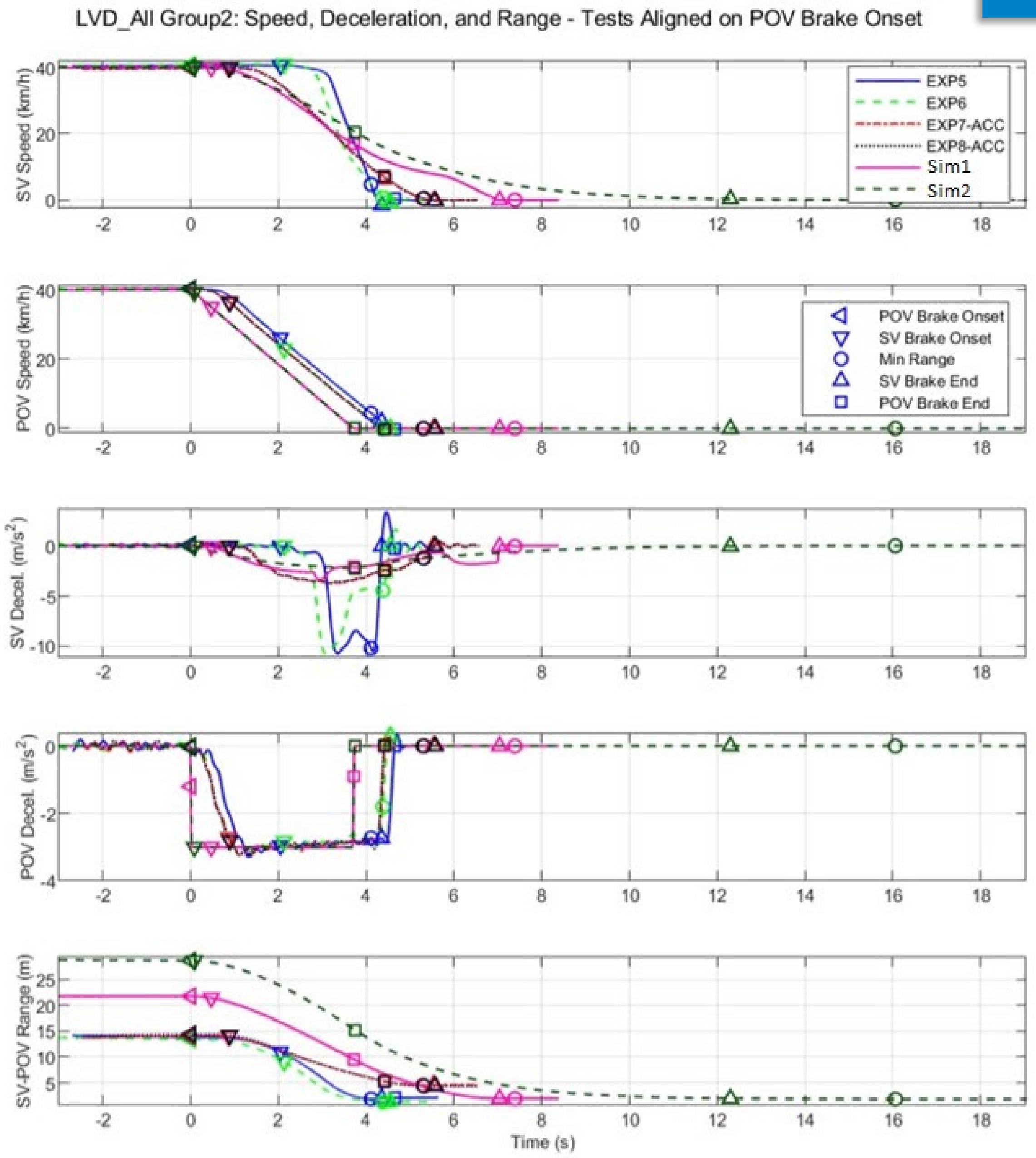


Simulations Performed



Results

- Both test track and simulation tests were able to meet the validity requirements set forth in the test procedures
- However, the plot comparing the test track and simulation results reveal different trends
    - Simulation instantaneously achieving the desired deceleration vs test track actual dynamics
    - Varying performance of the SV during the scenario
- Most difference are attributed to differences in model fidelity and devices under test



Results

- Total of 241 scenarios were ran in 5 simulation software packages = 1205 total scenarios
- All five of the simulation packages were eventually able to meet the validity requirements for scenario choreography
- Automated data summary tables and graphs were generated for validity criteria and vehicle performance

Lessons Learned from Implementing Test Procedures in Simulation Packages

- Hard to specify tolerances for subject vehicles with higher-levels of automation
- Only have control over inputs to the scenario
- A few simulators claimed they support open standards

ADS Test Track Testing Methods Research

Devin Elsasser

Objectives

Objectives:

- Enable coordination and more precise control of other actors around a vehicle that is equipped with ADAS or ADS.
- Study of more complex driving maneuvers and scenarios
- Experiment with testing methodologies

Methodologies:

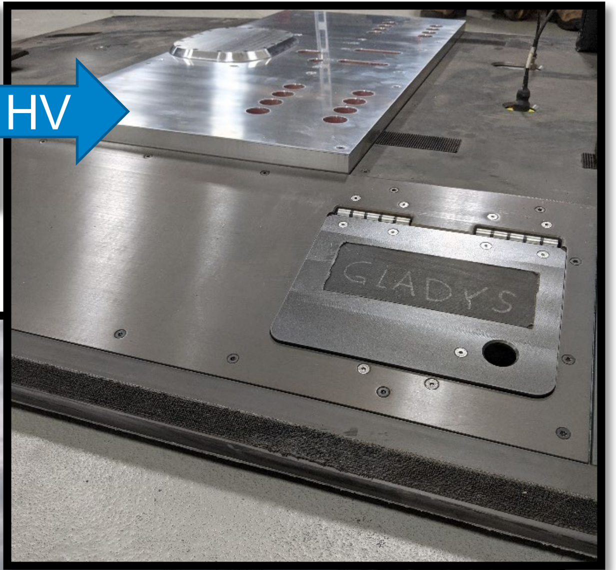
Performing research on potential test methodologies that enable data collection and may contribute to performance assessment

Advanced Test Tools for ADAS and ADS

Published report titled “Advanced Test Tools for ADAS and ADS” in May 2021

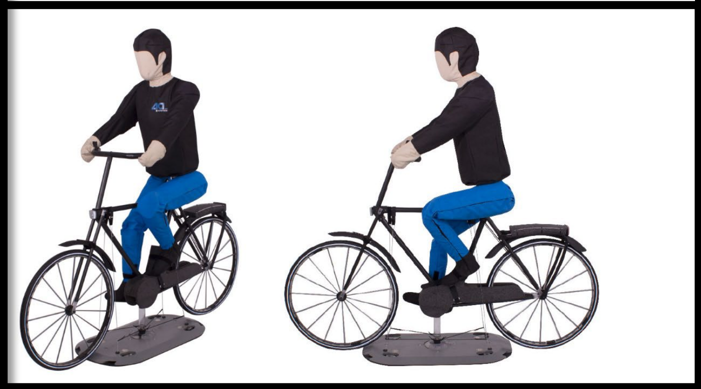
https://rosap.ntl.bts.gov/view/dot/55991/dot_55991_DS1.pdf

Covers test methods and tools for researching the safety performance of advanced driver assistance systems and Automated Driving Systems in a closed-course setting.



Strikable Vehicles and VRUs

- Low Profile Robotic Vehicles
- 360 degree Guided Soft Targets/Global Vehicle Targets
- Pedestrians and Pedalcyclists
  - 50% adult male
  - 7-year-old child



Test Track Driving Scenario Actors

Steering Robot

Brake and Throttle Robot

Main Controller steering/brake/throttle

Power Pack

GPS/IMU/Range

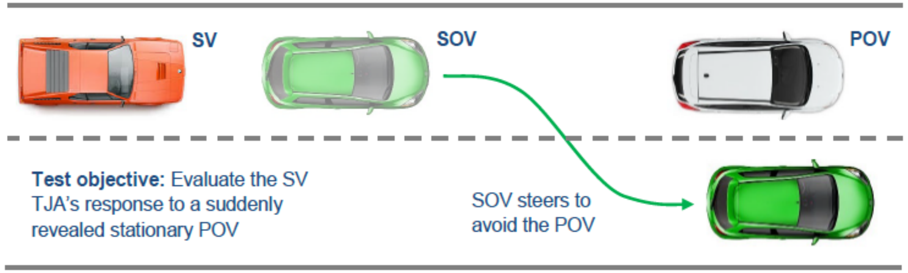


Figure 24. TJA Suddenly Revealed Stopped Vehicle (SRSV) Test Procedure Scenario

Experimental Test Vehicle

- Planning to use a production vehicle equipped with an open-source software, controllers, and sensors to help enable applied research in this area
  - Autoware open-source system
  - Drive-by-wire system
  - Sensors
    - Radar
    - Lidar
    - Cameras
    - GNSS
- Enable preliminary test track methodology research with some driving applications
- Enable research on simulation-to-test track driving scenario testing methods

Upcoming ADS Research

Jay Chen

FY21 ADS Research Contracts

Core ADS Elements

Project Overview	Project Objectives
Performance Assessment of ADS Perception Systems	• Determine extent to which ADS perception system performance can be assessed in isolation • Develop test method(s) for assessment
Performance Assessment of ADS Control Systems	• Determine extent to which ADS control system performance can be assessed in isolation • Develop test method(s) for assessment

FY21 ADS Research Contracts

Heavy Trucks

Project Overview	Project Objectives
Safety Assessment of Heavy Truck ECBS and Electronic Steering Systems	• Identify available electronically controlled braking systems (ECBS) and electronic steering systems for heavy trucks • Assess potential safety hazards and risks of available systems • Conduct SOTIF and FMEA
On-Road Driving Performance Evaluation of ADS Heavy Trucks	• Develop a “ground truth” data recording system for heavy trucks • Identify and characterize driving scenarios • Evaluate driving performance metrics

FY21 ADS Research Contracts
Operational Safety

Project Overview	Project Objectives
ADS Durability and Preventive Maintenance	• Assess ADS risks related to durability and wear-and-tear • Establish "state of the art" knowledge in ADS preventive maintenance and prognostics to help mitigate risks
Operational Safety Responsibilities of L4 ADS MaaS Fleet Operators	• Conduct risk analysis and catalog operational safety responsibilities of L4 ADS Mobility-as-a-Service (MaaS) fleet operators • Identify activities and enablers to help mitigate fleet operational safety risks and achieve responsibilities

FY21 ADS Research Contracts
Simulation and AI

Project Overview	Project Objectives
Simulation Use and Best-Practices for ADS Development	• Identify and characterize the uses of simulation and modeling throughout the ADS development cycle • Document best practices for simulation use
Use of Artificial Intelligence (AI) / Machine Learning (ML) Techniques in Driving Automation Technologies	• Research and analyze available sources, developments, and practices into the use of AI / ML techniques in driving automation technologies

Thank you for your time and attention

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