Overview of Automated Driving System Research

• Support Updating and Modernizing Regulations
  (removing assumption of a driver from current regs)

• System Safety Performance
  (tests, test methods, safety performance metrics)

• Human Factors
  (signaling, telltales, disabled user needs)

• Occupant Protection
  (alternative cabin configurations)

• Functional Safety, ADS Subsystems, Cybersecurity
  (covered in previous session)
1. **Support Updating and Modernizing Regulations**
   - FMVSS Considerations for Vehicles with ADS

2. **System Safety Performance**
   - Test Methodology for Test Track Testing
   - Development of Simulation Methods
   - Testing & Evaluation of Low Speed L4 Shuttles
   - Research on Candidate ADS Performance Measures
   - ADS Safety Assessment Metrics
   - ADS Testable Cases & Scenarios
   - On-Road Assessment Methods

3. **Human Factors**
   - Vulnerable and Disabled Road Users Research

4. **Occupant Protection – Alternative Cabin Configurations**
   - Rear-facing Occupant Kinematics
   - Forward-facing Reclined Seating
   - Rear seat safety for ADS occupants
FMVSS Considerations for Vehicles with ADS

Ellen Lee
FMVSS Considerations for Vehicles with ADS

• Identify unnecessary/unintended regulatory barriers to self-certification and compliance verification of innovative vehicle designs with Automated Driving Systems (ADS)

• Provide technical translation options of FMVSS and related compliance test procedures for ADS-equipped vehicles

• Focus is on ADS-Dedicated Vehicles (ADS-DVs) that lack manually operated driving controls (e.g. steering wheel, brake pedal)
FMVSS Considerations for Vehicles with ADS

- **Phase 1 FMVSS of focus**
  - Detailed evaluation performed on both FMVSS regulatory text and compliance test procedures

- **Test Methods: Crash Avoidance**
  - Investigate the equipment, methods, and/or procedures to perform compliance testing
  - Evaluate functionalities required to execute compliance test procedures using several potential test methods

- **Phase 2 Focus:**
  - Technical translations for FMVSS not covered in Phase 1
  - Refinement of crash avoidance test methods
  - Additional research that stemmed from Phase 1
Test Methodology for Test Track Testing ADS

Tim Johnson
Testing Methodology for Test Track Testing ADS

Motivation

• Test track work that will simulate multi-vehicle test scenarios (from any direction)
  • E.g. Intersection Crash Avoidance

• Test infrastructure and scalable actors (targets) necessary to stress an ADS
  • Varying complexity
  • Density (multi-vehicle)
  • Specialized instrumentation

• ADS system performance research considers tests inclusive of track and simulation assessments
  • Practical, minimum
  • Complex variable or randomized methods
Guided Soft Targets

- 2 ABD low profile robotic platforms
- 1 DRI robotic platform (with heavy vehicle capacity)
- 2 Global Vehicle Targets (GVT rev f)
- Multiple misc. soft cars
Throttle/Brake/Steering Controllers

• 4 complete ABD “drop-in” systems
• 2 combined Brake and Accelerator Robots (CBAR)
• 2 steering robots
Soft Pedestrian System

- System consists of:
  - ABD (SR60-based steering robot)
  - Support vehicle retrofitted with steering robot controller
  - Multiple 4a mannequins
  - 4a bicycle and rider
Multi-Actor Testing and Support

- 2 support vehicles retrofitted with base station hardware
- Current software supports choreography of up to 5 actors
- Real-time data telemetry
- Remote control for manual driving
- Safety (system override)
Multi Actor Example
ADS Testing and Evaluation of Low Speed L4 Shuttles

Tim Johnson
Testing two Low Speed Automated Driving Shuttles (LSADS)

- Navya
- Ridecell
  - Based on Dataspeed Vehicle (Ford Fusion)

Shuttles are operating in SAE Level 4
- Run on pre-defined path
- 12 mph or less
Objectives

• Understand how to test low speed L4 vehicles.
  • Understand current state of the art performance
  • Understand limitations of the tests
• Perform ADAS tests
  • AEB, PAEB, BSI, etc.
  • Recognize areas needed to perform additional research for testing.
• Systems Testing
  • Low speed challenges
  • Sensor Failure
    • Blocking a laser, blocking a RADAR, etc.
  • General performance when localization degrades
  • Operation Robustness (how many bugs, glitches, problems do we find over time)
Test Examples
Development of Simulation Methods

Tim Johnson
Development of Simulation Methodologies

• Background
  • Objective methods and a open simulation framework could benefit the process of validating performance of Automated Driving Systems in scenarios encountered in the United States.

• Motivation and Project Focus
  • Such a framework could enable scenario exchanges among stakeholders and facilitate more rapid development of a knowledge base around safety relevant scenarios.
  • Performing research on elements needed to describe a driving scenario in a simulation environment and open file formats.
  • Drafting a paper that covers scenario elements to describe 5 sample scenarios.
Simulation Example
Automated Driving System Metrics

Tim Johnson
Alrik Svenson
Automated Driving Systems Safety Assessment Metrics

• Background
  • Innovative driving performance assessment models have been proposed by industry that could potentially serve a role in understanding the safety performance of an ADS equipped vehicles
  • Various “leading indicators” of safety performance have also been studied.

• Approach
  • Review candidate safety assessment models
  • Synthesize and review potential leading indicators of safe driving behavior.
  • Catalogue data needs and sources used for assessing safety
  • Assess strengths and weaknesses of identified approaches through both analysis and stakeholder outreach efforts.

• Expected Results
  • Better understanding of currently proposed safety assessment models.
  • Potential data needs for assessing the safety of an ADS.
  • Project initiated in October 2019.
Applied Research on Candidate ADS Performance Measures for Utility Assessment

- Research to evaluate various safety measures that have been identified to date (e.g. ISM, DIST, RSS, RII) to characterize the safety performance of Automated Driving Systems (ADS).

- These measures will be applied to both real world data and simulated data. Safety margins will be observed as well as sensitivity to crashes, false positives, and other outcomes that are indicative of performance.

- The results of this research will contribute to better understanding these measures and how they can be applied assess the safety performance of ADS.
Metric Development
ADS Testable Cases and Scenarios

Paul Rau
OBJECTIVES:
• Develop a preliminary objective testing and assessment approach, which may contribute to industry approaches to understand ADS safety performance.
• Take the first steps of partitioning the ADS performance space as a test framework of independent factors.

OUTCOMES:
• Identify sample list of candidate maneuver/competency behaviors from various sources.
• Identify factors that define the ADS Operational Design Domains (ODD)
• Develop a Model Framework of Assessment Factors
Test Scenarios and Test Procedures

• Define key elements of a scenario (e.g., maneuver behaviors, ODD, OEDR)
• Develop candidate scenario tests for specific competencies
• Operational scenarios can be composed of multiple behavioral competency tests
• Can add fault/failure behaviors to scenario tests
Testing Framework

- **Modeling & Simulation**
  - Controlled, predictable, repeatable
  - Opportunity to run large number of simulations very quickly
  - Opportunity to perform sensitivity analysis of ODD and OEDR variability, and identify candidate scenarios for further testing

- **Closed-Track Testing**
  - Controlled, predictable, repeatable
  - Opportunity to assess full system performance

- **Open-Road Testing**
  - Uncontrolled, unpredictable
  - Exposure to variety of environmental conditions (e.g., weather) and other ODD elements (e.g., local traffic patterns and infrastructure conditions)
  - Exposure to variety of real-world scenarios that may be difficult to replicate on a test track or simulator
Development of Tools & Methods to Record ADS Data During On-Road Testing

Sebastian Silvani
Development of Tools & Methods to record ADS data during On-Road Testing

• Background
  • Collection of data during “normal” and “challenging” on-road operations is fundamental to assessing driving performance

• Approach
  • Identify sample (concept) driving scenarios
  • Determine data needed for assessing performance
  • Develop a prototype Ground Truth Trip Recorder (GTTR) that will not interfere with vehicle sensor systems.
  • Test and refinement of: data needs; GTTR; and, analysis methods

• Expected Results
  • Sample scenarios and metrics
  • GTTR prototype
  • Concept of operations
  • Feasibility and practicality assessment
Vulnerable and Disabled Road Users: Considerations Inside and Outside the ADS Vehicle

Eric Traube
Presented by Dee Williams
Population Addressed in this Study

• Disabled Road Users (DRUs)
  • 18.5 million with mobility disabilities
  • 19 million with vision or hearing disabilities
  • 28 million with cognitive or psychiatric disabilities (e.g., autism, intellectual, learning, and mental health disabilities, traumatic brain injuries)

• Vulnerable Road Users (VRUs)
  • Pedestrians
  • 47.5 million bicyclists
  • 8.4 million motorcyclists
Project Objectives

- Identify vehicle-side needs for ADSs to interact with
  - Disabled Road Users.
  - Vulnerable Road Users.
- Prioritize the most pressing needs and identify possible interaction techniques and communication strategies that could facilitate trust, efficiency, and safety.
- Assess a subset of possible solutions with end-users in an experimental setting.
Research Questions

• What are the travel needs of DRUs?
• What information do DRUs require to maximize confidence, trust, efficiency, and safety?
• What are effective display/communication options for users within each category of disability?
• What feedback is desirable, including when the route or destination is unavailable at different points in the trip?
• What other concerns may need to be addressed to ensure a satisfactory end-to-end user experience for all levels and types of disabilities?
• What are the information needs and expectations of VRUs?
• What are the best ways to communicate this information to VRUs?
Research Phases

Phase 1: User Needs Analysis
- Literature Review & Synthesis of Existing User Needs
- Technology Scan
- Stakeholder Engagement

Phase 2: Design and Testing
- Use Case Development
- User Centered Design Activities
- Empirical Research

Phase 3: Reporting
- Technical Reports
- NHTSA Briefing
- Stakeholder Outreach
ADS-Equipped Vehicle Occupant Kinematics: Rear-facing Reclined

Jason Stammen
Motivation

- NHTSA is investigating existing computational models and crash test dummies in the most likely scenarios in Automated Driving Systems (ADS)-equipped vehicles reclined seating for both forward and rear-facing occupants for different impact severities.
- Biofidelity of tools to be modified as needed to provide optimal injury risk assessment given new post-mortem human surrogate (PMHS)-based biomechanical data.
- NHTSA is sponsoring three research projects to generate new biomechanical data: (1) rear-facing, (2) forward-facing, (3) forward-facing for occupants vulnerable to submarining/abdominal injury.
Test Setup: Rear-facing

- Repeatability: rigidized support to prevent seatback rotation – eliminates variation due to rotational stiffness when testing different seats
- Instrumentation: load cells to measure forces & moments at head restraint, seatback, and seat anchor points to floor
- Adjustability: can accommodate various recline angles, seats, PDOF, and speeds

2018 Honda Odyssey 2nd Row Seat
- ABTS: most likely for reclined ADS
- Availability
Test Matrix: PHMS

- Subject selection: anthropometry close to 50th male ATD, no physical issues preventing sensor installation
- Positioning: approximate volunteer postures from UMTRI study\(^1\)
- Head restraint location: follow FMVSS 202a backset for standard seatback angle; maintain HR position relative to seatback when reclined

<table>
<thead>
<tr>
<th># of Tests</th>
<th>Seat</th>
<th>Delta V (kph)</th>
<th>Seat Back Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2018 Honda Odyssey, 2nd Row (w/ABTS)</td>
<td>56</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>56</td>
<td>45</td>
</tr>
<tr>
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<td>24</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>TBD</td>
<td></td>
</tr>
</tbody>
</table>

PMHS, 25° Seatback

PMHS, 45° Seatback
Test Matrix: ATD

- Positioning: approximate volunteer postures from UMTRI study\(^1\) (when possible)
- Head restraint location: same as PMHS, with some adjustment to accommodate ATD posture limitations when reclined

<table>
<thead>
<tr>
<th>Seats</th>
<th>ATDs</th>
<th>Delta V (kph)</th>
<th>Seat Back Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 2018 Honda Odyssey, 2(^{nd}) Row (w/ABTS)</td>
<td>THOR-50M, Hybrid III 50th</td>
<td>56</td>
<td>25</td>
</tr>
<tr>
<td>(2) 2018 Honda Accord, 1(^{st}) Row (standard belt)</td>
<td>THOR-50M, Hybrid III 50(^{th}), BioRID</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

THOR-50M, 45° Seatback
Instrumentation

- Kinematics: head, spine, pelvis, legs
- Forces & Moments: seat, seatbelt, legs
- Strains (PMHS only): ribs, pelvis, legs
- Deflections: ribcage

<table>
<thead>
<tr>
<th>ATD/PMHS/Seat</th>
<th># of Channels</th>
</tr>
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<tbody>
<tr>
<td>Seat (11 Load Cells)</td>
<td>52</td>
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<tr>
<td>Belt Load Cells</td>
<td>2</td>
</tr>
<tr>
<td>PMHS</td>
<td>186</td>
</tr>
<tr>
<td>THOR-50M</td>
<td>104</td>
</tr>
<tr>
<td>Hybrid III 50th Male</td>
<td>81</td>
</tr>
<tr>
<td>BioRID-II</td>
<td>89</td>
</tr>
</tbody>
</table>
Results: 25 deg, 56 kph

PMHS\textsuperscript{1}  \hspace{150pt}  THOR 50\textsuperscript{th} Male  \hspace{150pt}  Hybrid III 50\textsuperscript{th} Male

\textsuperscript{1}Kang Y. “Biomechanical Responses and Injury Assessment of PMHS in Rear-facing Seating Configurations” SAE Govt/Industry 2019
Results: 45 deg, 56 kph
Results: Findings to Date

- Cable routing changes are needed for the frontal ATDs due to posterior interaction with the seatback
- Difficulties encountered getting ATDs into reclined posture
- ATD chest deflections higher with upright than reclined seatback
- Extensive PMHS injuries in high speed testing: fractures observed in posterior ribs, thoracic/lumbar spine, pelvis, scapula, tibia
  - Combination of rigid seatback and localized structures needed for ABTS
Current Work

- SAE Gov’t/Industry 2020
- Derive Biomechanical Targets and Assess ATD Biofidelity
- Injury Mechanisms for Various Body Regions
- Test Other Seats
- Evaluate LODC
Summary

- NHTSA is generating biomechanical data in high and low speed rear-facing, reclined seating scenarios so that ATDs and models can be evaluated and refined
- Results indicate potential for injuries to posterior ribcage, lower spine, pelvis, and lower extremities
- ATDs will need to be revised for reclined seating and protection of rear-mounted instrumentation
- More details on our testing so far will be presented at SAE G/I 2020

For more information see Docket ID NHTSA-2019-0123 NHTSA Crashworthiness Research - Occupant Protection for ADS-Equipped Vehicles Documentation
ADS-Equipped Vehicle Occupant Kinematics
Forward-facing Reclined

Dan Parent
ADS-Equipped Vehicle Occupant Kinematics Overview

Phase I: 50th Percentile Male Occupants

Phase II: Vulnerable Occupants
Test Setup: Forward-facing Reclined

- **Test Apparatus**
  - Spring-controlled seat (Uriot et al., 2015)
  - Adjustable, open seatback
  - Adjustable, padded knee bolster

- **Crash Pulse**
  - Representative of vehicle pulse in frontal rigid barrier crash test
  - High-speed: 56 kph
  - Low-speed: 15 kph or 32 kph (scaled)

- **Subject positioning**
  - Target volunteer postures (Reed et al., 2018)
    - 25, 45, 60 degree posture predictions
Instrumentation: Forward-facing Reclined

- **PMHS Instrumentation**
  - 6DOF sensors
    - head, T1, T8, T12, L4/L5, iliac wings, femurs, tibias
  - Uniaxial strain gages
    - left clavicle, sternum, ribs 4-7, left and right ASIS
  - 3D triad targets (TEMA or VICON)
    - All 6DOF sensors
    - skeletal landmarks
    - 4 locations on anterior ribcage
**Test Matrix: Forward-facing Reclined**

### Phase I: 50th Male
- **Subject Inclusion Criteria**
  - Age $\geq 18$ years
  - $170 \leq$ Height $\leq 181$ cm
  - $18.5 \leq$ BMI $\leq 30$ kg/m$^2$
  - qCT BMD $\geq 80$ mg/cc
- 24 PMHS tests (+12 optional)

<table>
<thead>
<tr>
<th># of Tests</th>
<th>Delta V (kph)</th>
<th>Seat Back Angle</th>
<th>Restraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>32</td>
<td>25°</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>25°</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>45°</td>
<td>force-limited belt knee bolster initially out of contact</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>45°</td>
<td></td>
</tr>
</tbody>
</table>

### Phase II: Vulnerable Occupant
- **Obese Occupants**
  - Male or female
  - BMI $\geq 30$ kg/m$^2$
- **Small Female Occupants**
  - $143 \leq$ Height $\leq 157$ cm
  - $38 \leq$ Weight $\leq 62$ kg
- 24 PMHS tests (+12 optional)

<table>
<thead>
<tr>
<th># of Tests</th>
<th>Occupant</th>
<th>Delta V (kph)</th>
<th>Seat Back Angle</th>
<th>Restraints</th>
</tr>
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<tbody>
<tr>
<td>3</td>
<td>Obese</td>
<td>1) 15 km/h</td>
<td>25°</td>
<td>force-limited belt knee bolster initially out of contact</td>
</tr>
<tr>
<td>3</td>
<td>Obese</td>
<td>2) if no injury, 56 km/h</td>
<td>45°</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Small Female</td>
<td></td>
<td>25°</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Small Female</td>
<td></td>
<td>45°</td>
<td></td>
</tr>
</tbody>
</table>

12 TBD

Detailed Task Implementation Plans: [http://mreed.umtri.umich.edu/AV_Safety_TIP/](http://mreed.umtri.umich.edu/AV_Safety_TIP/)
ADS-Equipped Vehicle Occupant Kinematics

- **Additional Tasks**
  - Biofidelity Corridor Creation
  - ATD Matched Pair Tests
  - Human Body Model Evaluation/Improvement
  - Injury Criteria Development

- **Status/Schedule**
  - Work underway since September 2018
  - Sled bucks complete, PMHS testing ongoing
  - PMHS data due to NHTSA 30 days after each test
    - Targeting posting to NHTSA Biomechanics Database within 10 days of delivery
    - Processed data, reports added on rolling basis
ATD Seating in Highly Reclined Seats

Objective
- Examine the range of positions that the ATD could assume in a current production seat

Test Apparatus
- 2018 Honda Odyssey driver seat
- Reclined from standard up to 75° in 5° increments

ATDs Evaluated

Observations
- Current ATDs exhibit limitations when positioned in reclined seats
  - Gaps between head, headrest
  - Gaps between pelvis, abdomen, thorax
  - Excessive extension of flexible spine elements

More information
- Prasad, 2019 SAE Government-Industry Meeting

Hybrid III 50th

THOR-50M
THOR-50M Modifications for Reclined Seating

• **Objective**
  - Design and fabricate modified parts to address limitations in THOR-50M static positioning in reclined seats

• **Tasks**
  - Baseline static positioning assessment in 3 seats
    - 2 production, 1 generic
    - Follow procedure from VRTC study
  - Design and fabricate prototype parts
  - Incorporate design in THOR-50M FE model
  - Repeat baseline positioning assessment with modified THOR-50M
  - (Optional) Fabricate 3 additional sets of parts

• **Key Outputs**
  - 3D CAD package for modified parts
  - Static positioning assessment data
  - Updated THOR-50M FE model
Integrated Seat Modeling

• **Objective**
  - Develop and validate model of seat with integrated seat belt system

• **Tasks**
  - Seat selection (‘18–’19 Honda Odyssey 2nd row)
  - Seat tear-down, scanning, model development & validation
  - Destructive quasi-static testing (forward, rearward)
  - Frontal impact sled test with THOR-50M
  - Rear impact sled test with BioRID
  - (Optional) Additional sled tests with reclined seatback

• **Key Outputs**
  - Seat validation data (quasi-static, sled test)
  - Finite element model of integrated seat
Automated Wheelchair Securement System

- **Objective**
  - To develop a prototype automated wheelchair tiedown and occupant restraint system (AWTORS) that can be used without assistance in an ADS-equipped vehicle by a person traveling in a wheelchair

- **AWTORS Design Concept**
  - Incorporate Universal Docking Interface Geometry (UDIG)
  - Automated seat belt donning system
  - Consider advanced belt features that could improve fit, ease of use, and occupant protection (e.g. Active Buckle Lifter)
  - Include airbag restraints as part of occupant protection system (e.g. Self Conforming Rearseat Air Bag – SCaRAB)

- **Key Outputs**
  - Volunteer usability testing data
  - Design demonstration
Rear Seat Occupant Protection

Ellen Lee
Motivation and Project Overview

- Current emphasis of frontal crash tests is on the front seats.
- Expectation is that Automated Driving Systems-Dedicated Vehicles (ADS-DV) occupants may be more likely to self-select a rear seat.
- Initial focus of research effort was to evaluate rear seat occupant crash protection for conventional seating.
- A range of rear seats were evaluated using finite element (FE) modeling and ATD sled tests (both Hybrid III and THOR-50M)
Project Overview

1. REAL-WORLD PROBLEM SCOPING
   • Estimate the extent to which individuals will self-select the rear seat in ADS-DVS
   • Estimate injury risk in rear seat

2. FE MODELING, VEHICLE SELECTION
   • Simulate NCAP tests using ATD models to assess the related safety performance
   • Select a range of late model vehicles for physical testing

3. TEST BUCK PREPARATION

4. ATD SLED TESTING
   • Conduct ATD sled tests using THOR-50M and Hybrid III
   • Assess submarining and injury risk in the rear seats
   • PMHS testing
   • Finite element (FE) modeling
   • Parametric analysis to determine key vehicle design parameters that affect safety

5. ANALYSIS AND NEXT STEPS
Discussion and Next Steps

• To date, submarining and injury risks in head, neck, chest, femur and abdomen have been documented in five vehicles
• PMHS testing will be used to corroborate ATD results and to determine the efficacy of the ATDs for assessing rear seat safety
• Future analysis will seek to define some key vehicle design parameters (e.g. pretensioner/load limiter, seat pan geometry, anti-submarining ramp, seat cushion stiffness) that could improve rear seat passenger safety
Clarification or Questions?