Vulnerable Road User (VRU)
Composition of Motor Vehicle Traffic Fatalities, 2018

- **18,714** (51%): VRUs
- **17,846** (49%): Others

**Pedestrians**: 4,936 (28%)
**Pedalcyclists**: 4,985 (28%)
**Motorcyclists**: 6,283 (35%)
**Older Occupants**: 857 (5%)
**Child Occupants**: 785 (4%)
## Changes in VRU Fatalities, 2014-2018

<table>
<thead>
<tr>
<th>VRU Category</th>
<th>2014</th>
<th></th>
<th>2018</th>
<th></th>
<th>2014-2018 % Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
<td>% of Total</td>
<td>Fatalities</td>
<td>% of Total</td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td>4,910</td>
<td>15.0%</td>
<td>6,283</td>
<td>17.2%</td>
<td>+28%</td>
</tr>
<tr>
<td>Pedal-cyclist</td>
<td>729</td>
<td>2.2%</td>
<td>857</td>
<td>2.3%</td>
<td>+17.6%</td>
</tr>
<tr>
<td>Motorcyclist</td>
<td>4,594</td>
<td>14.0%</td>
<td>4,985</td>
<td>13.6%</td>
<td>+8.5%</td>
</tr>
<tr>
<td>Older Occupant</td>
<td>4,218</td>
<td>12.9%</td>
<td>4,936</td>
<td>13.5%</td>
<td>+17%</td>
</tr>
<tr>
<td>Child Occupant</td>
<td>761</td>
<td>2.3%</td>
<td>785</td>
<td>2.2%</td>
<td>+3%</td>
</tr>
<tr>
<td>Others</td>
<td>17,532</td>
<td>53.5%</td>
<td>18,714</td>
<td>51.2%</td>
<td>+6.7%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32,744</td>
<td>100%</td>
<td>36,560</td>
<td>100%</td>
<td>+11.7%</td>
</tr>
</tbody>
</table>
Overview

- NHTSA conducts research to improve the safety of people in and around vehicles that are particularly vulnerable to injury and/or have special considerations
  - Children
  - Pedestrians and pedalcyclists
  - Motorcyclists
  - Older occupants
  - Obese occupants
  - Disabled road users
- Cross-cutting vehicle/equipment and behavioral-based research
  - Crash avoidance
  - Crashworthiness
  - Biomechanics
  - Enforcement
  - Education/Awareness
Overview – Research Programs

• Child Safety
  • Child restraint systems (front & side impact, LATCH ease-of-use)
  • Unattended child reminder systems
  • Large omni-directional child (LODC) ATD development
  • Awareness and availability of child passenger safety resources
  • Factors affecting correct child restraint system installation

• Pedestrian and Bicyclist Safety
  • Pedestrian impact protection (head, upper/lower leg)
  • Pedestrian impact avoidance (PAEB)
  • Integrated crash avoidance and crashworthiness pedestrian testing
  • Pedestrian crash data collection (CIREN)
  • Pedestrian distraction
  • High Visibility Enforcement and compliance with safe bicycle passing laws
  • Use of speed-related programs to improve pedestrian and bicyclist safety
  • Evaluation of “Safety in Numbers” concept
Overview – Research Programs

• Motorcycle Safety
  • Evaluation of motorcycle helmet test procedures
  • Motorcycle helmet safety (rotational injury)
  • Motorcycle conspicuity to light vehicle ADAS capabilities
  • Survey of driver attitudes toward motorcycling
  • Motorcyclists’ attitudes on using high-visibility gear to improve conspicuity
  • Estimating motorcycle travel from State annual safety inspection data

• Older Occupant Safety
  • Injury criteria development - subdural hematoma, thorax
  • Older drivers’ use of rearview video systems
  • Visual scanning training for older drivers
  • Exploring older drivers’ self-regulation and exposure

• Obese Occupant Safety
  • Restraint design for obese occupants

• Disabled Road Users Safety
  • Vulnerable and disabled road users: considerations inside and outside the vehicle
  • Automated restraints systems for wheelchair occupants
1. Pedestrian Protection – Crashworthiness
2. CIREN Pedestrian Pilot Study
3. Pedestrian Distraction
4. Effect of High Visibility Enforcement (HVE) on Driver Compliance with Bicycle Safe Passing Laws
5. Motorcyclists’ Attitudes on Using High-Visibility Gear
6. Motorcycle Conspicuity to Light Vehicle ADAS Capabilities
Pedestrian Protection – Crashworthiness

Jason Stammen, Ph.D.
Background and History
1970s-80s: Seminal research to understand how pedestrian kinematics are affected by vehicle geometry and how head injury risk is affected by underhood clearance.


1970s-80s: Seminal research to understand how pedestrian kinematics are affected by vehicle geometry and how head injury risk is affected by underhood clearance.

1990s: International collaboration to examine the relationship between vehicle contact sources and injuries to various body regions; develop harmonized test procedures to measure head/leg injury risk.

<table>
<thead>
<tr>
<th>Injury Location</th>
<th>US</th>
<th>Europe</th>
<th>Japan</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>32.7%</td>
<td>29.8%</td>
<td>28.6%</td>
<td>30.9%</td>
</tr>
<tr>
<td>Face</td>
<td>3.7%</td>
<td>5.3%</td>
<td>2.4%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0%</td>
<td>1.8%</td>
<td>4.5%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Chest</td>
<td>9.5%</td>
<td>11.6%</td>
<td>8.5%</td>
<td>10.3%</td>
</tr>
<tr>
<td>Abdomen</td>
<td>7.7%</td>
<td>3.8%</td>
<td>4.8%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Pelvis</td>
<td>5.3%</td>
<td>7.9%</td>
<td>4.5%</td>
<td>6.4%</td>
</tr>
<tr>
<td>Arms</td>
<td>7.9%</td>
<td>8.1%</td>
<td>9.0%</td>
<td>8.1%</td>
</tr>
<tr>
<td>Overall Legs</td>
<td>7.9%</td>
<td>0.7%</td>
<td>2.1%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Femur</td>
<td>3.2%</td>
<td>4.0%</td>
<td>9.3%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Knee</td>
<td>3.0%</td>
<td>3.4%</td>
<td>4.2%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Lower Leg</td>
<td>18.1%</td>
<td>19.8%</td>
<td>17.2%</td>
<td>18.8%</td>
</tr>
<tr>
<td>Foot</td>
<td>1.1%</td>
<td>3.4%</td>
<td>2.9%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.0%</td>
<td>0.5%</td>
<td>2.1%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Others</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 2 Global Pedestrian Accident Dataset

<table>
<thead>
<tr>
<th>Region</th>
<th>Cases</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>772</td>
<td>4,191</td>
</tr>
<tr>
<td>Japan</td>
<td>240</td>
<td>901</td>
</tr>
<tr>
<td>United States</td>
<td>518</td>
<td>4,107</td>
</tr>
<tr>
<td>Total</td>
<td>1,550</td>
<td>9,199</td>
</tr>
</tbody>
</table>

1970s-80s: Seminal research to understand how pedestrian kinematics are affected by vehicle geometry and how head injury risk is affected by underhood clearance.

1990s: International collaboration to examine the relationship between vehicle contact sources and injuries to various body regions; develop harmonized test procedures to measure head/leg injury risk.

2000s: Vehicle testing and research to evaluate US fleet performance using newly developed test procedures/tools.

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1990s: International collaboration to examine the relationship between vehicle contact sources and injuries to various body regions; develop harmonized test procedures to measure head/leg injury risk.

2000s: Vehicle testing and research to evaluate US fleet performance using newly developed test procedures/tools.

2010-2015: Testing to assess industry-proposed amendments to test procedures.

RESULTS: FLEXGTR TESTS

Stammen J. “Performance of Bumper Systems with Respect to Pedestrian Protection and Bumper Damageability Requirements” SAE Govt/Industry (2014)

**1970s-80s:** Seminal research to understand how pedestrian kinematics are affected by vehicle geometry and how head injury risk is affected by underhood clearance.

**1990s:** International collaboration to examine the relationship between vehicle contact sources and injuries to various body regions; develop harmonized test procedures to measure head/leg injury risk.

**2000s:** Vehicle testing and research to evaluate US fleet performance using newly developed test procedures/tools.

**2010-2015:** Testing to assess industry-proposed amendment to test procedures.

**2015 – Present:** Research and testing to evaluate, finalize, and document tools and test procedures for US vehicles.

---

**EVALUATION OF TEST TOOLS & PROCEDURES**

**US FLEET ASSESSMENT**

**INJURY DATA STUDIES**
Evaluation of Test Tools & Procedures
Headforms

- Technical evaluation found that the headforms are durable, repeatable & reproducible, sensitive to vehicle design\(^1\)
- Observed HIC improvements in newer vs. older MY vehicles; trying to see if this is consistent with real world U.S. data
- Safety benefit provided by active hoods varies by vehicle in laboratory; unclear from real world data\(^2\)
- Very good lab-to-lab consistency in global platform vehicles tested at VRTC and EuroNCAP\(^3\)


\(^2\)Suntay & Stammen "Assessment of Hood Designs for Pedestrian Head Protection: Active Hood Systems" DOT HS 812 762. (will be posted to research docket soon)

Flex-PLI Lower Legform

• Technical evaluation found that the Flex-PLI is durable, repeatable & reproducible, sensitive to vehicle design\(^1\)
• Observed improvements in newer vs. older MY vehicles; trying to see if this is consistent with real world U.S. data
• Found that front end designs can be both pedestrian-friendly and limit cosmetic damage in low speed bumper impacts\(^2\)
• Determined that global platform vehicles tend to do better than US-only vehicles\(^3\)

\(^2\)Suntay & Stammen “Vehicle Bumper Performance in Part 581 vs. Pedestrian Leg Protection” DOT HS 812 ###. (will be posted to research docket soon)
Upper Legform

- Technical evaluation found that the upper legform is durable, repeatable & reproducible, sensitive to vehicle design\(^1\)
- Smaller vehicles performed better than larger vehicles, reflecting real world trend
- Even though lab-specific measurements & environmental conditions were found to influence test results, VRTC results matched EuroNCAP scores\(^2\)


US Vehicle Fleet Assessment
US Fleet Tests

- EuroNCAP test procedures
  - Head, Flex-PLI, upper leg
- Impact location distribution simulates EuroNCP distribution

Table 1. List and description of U.S. vehicles tested by NHTSA. Rows colored gray have European variants that have been tested by Euro NCAP.

<table>
<thead>
<tr>
<th>Model Year (MY)</th>
<th>Make</th>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>Audi</td>
<td>A4*</td>
<td>Midsize Passenger Car</td>
</tr>
<tr>
<td>2016</td>
<td>Chevrolet</td>
<td>Malibu</td>
<td>Midsize Passenger Car</td>
</tr>
<tr>
<td>2016</td>
<td>Chevrolet</td>
<td>Tahoe</td>
<td>Large SUV</td>
</tr>
<tr>
<td>2016</td>
<td>Ford</td>
<td>Edge</td>
<td>Midsize SUV</td>
</tr>
<tr>
<td>2015</td>
<td>Ford</td>
<td>F-150</td>
<td>Standard Pickup Truck</td>
</tr>
<tr>
<td>2016</td>
<td>Honda</td>
<td>Fit</td>
<td>Small Passenger Car</td>
</tr>
<tr>
<td>2016</td>
<td>Nissan</td>
<td>Rogue</td>
<td>Small SUV</td>
</tr>
<tr>
<td>2016</td>
<td>Toyota</td>
<td>Prius</td>
<td>Small Passenger Car</td>
</tr>
<tr>
<td>2015</td>
<td>Toyota</td>
<td>Sienna</td>
<td>Minivan</td>
</tr>
</tbody>
</table>

*An Audi A4 with an active hood was tested by Euro NCAP. An active hood is standard on European variants of the A4, but is not available on models sold in the U.S.

Suntay & Stammen “Overview of NHTSA Pedestrian Crashworthiness Research” SAE Govt/Industry 2018


https://rosap.ntl.bts.gov/view/dot/41841
SUMMARY - HEAD

• Performance of global vehicles is markedly better
  - Many underpinnings same EU/US

• Larger vehicles had test zones encompassing more hard points and thus did worse

• NHTSA and EuroNCAP scores were similar

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Head Scores (Max 24 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NHTSA</td>
</tr>
<tr>
<td>2017 Audi A4</td>
<td>17.00</td>
</tr>
<tr>
<td>2016 Chevrolet Malibu</td>
<td>16.36</td>
</tr>
<tr>
<td>2016 Chevrolet Tahoe</td>
<td>14.18</td>
</tr>
<tr>
<td>2016 Ford Edge</td>
<td>17.40</td>
</tr>
<tr>
<td>2015 Ford F-150</td>
<td>9.82</td>
</tr>
<tr>
<td>2016 Honda Fit</td>
<td>18.67</td>
</tr>
<tr>
<td>2016 Nissan Rogue</td>
<td>18.00</td>
</tr>
<tr>
<td>2016 Toyota Prius</td>
<td>19.80</td>
</tr>
<tr>
<td>2015 Toyota Sienna</td>
<td>16.67</td>
</tr>
<tr>
<td>Average Score (% of Max)</td>
<td>16.02 (67%)</td>
</tr>
</tbody>
</table>

* Euro NCAP tests performed on an active hood.

SUMMARY – LOWER LEG

- Performance of vehicles somewhat dependent on whether Part 581 applies

- Higher bumper vehicles did worse due to more wrapping of lower leg under bumper beam

- NHTSA and EuroNCAP scores were not as consistent; function of different bumper components

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Is Part 581 Applicable to U.S. Version?</th>
<th>Lower Leg Scores (Max 6 pts)</th>
<th>NHTSA</th>
<th>Euro NCAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017 Audi A4</td>
<td>Yes</td>
<td>2.24</td>
<td>2.24</td>
<td>5.32</td>
</tr>
<tr>
<td>2016 Chevrolet Malibu</td>
<td>Yes</td>
<td>1.99</td>
<td>1.99</td>
<td>--</td>
</tr>
<tr>
<td>2016 Chevrolet Tahoe</td>
<td>No</td>
<td>0.00</td>
<td>0.00</td>
<td>--</td>
</tr>
<tr>
<td>2016 Ford Edge</td>
<td>No</td>
<td>0.40</td>
<td>0.40</td>
<td>6.00</td>
</tr>
<tr>
<td>2015 Ford F-150</td>
<td>No</td>
<td>0.00</td>
<td>0.00</td>
<td>--</td>
</tr>
<tr>
<td>2016 Honda Fit</td>
<td>Yes</td>
<td>0.00</td>
<td>0.00</td>
<td>6.00</td>
</tr>
<tr>
<td>2016 Nissan Rogue</td>
<td>No</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>2016 Toyota Prius</td>
<td>Yes</td>
<td>4.41</td>
<td>4.41</td>
<td>6.00</td>
</tr>
<tr>
<td>2015 Toyota Sienna</td>
<td>No</td>
<td>0.00</td>
<td>0.00</td>
<td>--</td>
</tr>
<tr>
<td>Average Score (% of Max)</td>
<td></td>
<td>1.67 (28%)</td>
<td>5.86 (98%)</td>
<td></td>
</tr>
</tbody>
</table>

SUMMARY – UPPER LEG

• Global vehicles did relatively well – small vehicles especially due to lower test energy & hood involvement

• Larger vehicles did worse due to higher test energy & bumper impact

• NHTSA and EuroNCAP scores were not as consistent; function of different bumper/grille components

---

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Impact Location*</th>
<th>Is Part 581 Applicable to U.S. Version?</th>
<th>Upper Leg Scores (Max 6 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017 Audi A4</td>
<td>BLE</td>
<td>Yes</td>
<td>5.17</td>
</tr>
<tr>
<td>2016 Chevrolet Malibu</td>
<td>BLE</td>
<td>Yes</td>
<td>3.40</td>
</tr>
<tr>
<td>2016 Chevrolet Tahoe</td>
<td>Grille + Bumper</td>
<td>No</td>
<td>0.80</td>
</tr>
<tr>
<td>2016 Ford Edge</td>
<td>Grille</td>
<td>No</td>
<td>0.80</td>
</tr>
<tr>
<td>2015 Ford F-150</td>
<td>Grille + Bumper</td>
<td>No</td>
<td>1.20</td>
</tr>
<tr>
<td>2016 Honda Fit</td>
<td>BLE</td>
<td>Yes</td>
<td>6.00</td>
</tr>
<tr>
<td>2016 Nissan Rogue</td>
<td>Grille</td>
<td>No</td>
<td>6.00</td>
</tr>
<tr>
<td>2016 Toyota Prius</td>
<td>Hood</td>
<td>Yes</td>
<td>5.91</td>
</tr>
<tr>
<td>2015 Toyota Sienna</td>
<td>Grille</td>
<td>No</td>
<td>2.44</td>
</tr>
<tr>
<td>Average Score (% of Max)</td>
<td></td>
<td></td>
<td>3.52 (59%)</td>
</tr>
</tbody>
</table>

* BLE is the bonnet (or hood) leading edge.

Injury Data Studies
Injury Data Studies

- Related frequency of real-world injuries from National Trauma Data Bank (NTDB) to component tests
- When normalized for MAIS 3+, headform and lower legform were 3/8 each while upper legform was 1/4

Current Research
Advanced Legform Evaluation

• Addition of upper body mass provides more accurate femur injury measurement

• Evaluating and comparing two candidate legforms (aPLI, Flex-UBM) that do this

• Replace FlexPLI & upper legform tests with just one test to assess overall leg protection

Project status will be presented at SAE G/I 2020
Injury Data Studies

• Knee cruciate/collateral ligament injury patterns: is there a need for a cruciate injury metric in the FlexPLI or does a collateral injury metric alone adequately protect the cruciate ligaments?

• Prevalence of pedestrian countermeasures in U.S. vehicles: are newer model year vehicles less likely to produce serious/fatal injuries than older model year vehicles?¹,²


²Pfeiffer “Analysis of Pedestrian Injuries by Passenger Vehicle Model Year” DOT HS 812 819.
Thorax Injury Assessment

• Are vehicle countermeasures that protect the head/leg also reducing thoracic injury risk?

• What are the circumstances of a pedestrian collision that lead to a higher chance of thorax injury?

• Can we come up with an experimental approach to evaluate thorax risk?

Integrated Crash Avoidance/Crash Worthiness Tests

- How do crash avoidance technologies (pre-crash systems) and crashworthiness countermeasures work together in a given vehicle to reduce injury severity?

- Assess CW countermeasure performance at various levels of CA effectiveness to help with real-world performance projections
Summary

• NHTSA research in the development and use of pedestrian tools and procedures has contributed to how vehicles are constructed today.

• Existing test tools & procedures can be effectively applied to U.S. vehicles.

• Current research is focusing on improving pedestrian safety even further.

• For more information see Docket ID NHTSA-2019-0112 NHTSA Crashworthiness Research – Pedestrian Protection Documentation.
Crash Injury Research and Engineering Network

• Current program for occupant investigations began in 2017
  • Five enrolling sites and four engineering review centers
  • Emphasis remains on in-depth review of injury causation of motor vehicle occupants
    
    https://www.nhtsa.gov/research-data/crash-injury-research
    https://crashviewer.nhtsa.dot.gov/

• Pedestrian pilot study began in 2018
  • Awards made to two enrollment sites
    • Emory (enrolling at Grady Memorial Hospital in Atlanta, GA)
    • Wake Forest/Virginia Tech (enrolling at Wake Forest Baptist Medical Center in Winston-Salem, NC)
    • Additional engineering support from Medical College of Wisconsin CIREN center
CIREN Pedestrian Pilot Study

Objective and Goals

• Revisit prior investigation protocol (PCDS and Honda Inova CIREN) and update for current and future research needs
  • Injury causation and crashworthiness
  • Crash avoidance and behavioral
• Test new scene and vehicle documentation techniques
• Assess feasibility of fast-response case capture and compare results to follow-on investigation approach
• Adapt injury causation coding (BioTab) for pedestrian crashes
• Develop data collection tools and database
• Acquire data for nine (9) pilot cases total

On-scene evidence collection

- Early observations highlight the importance of strong cooperation with law enforcement for on-scene evidence.
Scene and vehicle documentation

- 3D photogrammetry produces point cloud to more comprehensively capture details
- Rapid data collection via drone

Overhead view for scene diagram
Pedestrian Distraction

• Study Components
  • Literature review (DOT HS 812 256)
  • Crash report analysis
  • Naturalistic observations

• Our List of Observed Distractors
  • Electronic distractors - cell phone, audio device, tablet, GPS, other electronic
  • Non-electronic distractors – other people, reading, eating/drinking, other
Pedestrian Distraction

- Pedestrian Crossing Observations – Observed at curb & during crossing
  - Demographics, distraction(s) before & during, conflict presence & severity, position in group, glances L & R, latency & total time, path keeping

- Driver Observations (paired with pedestrian) – Observed driver/vehicle closest
  - Demographics, distraction(s), conflict presence & severity
Effect of High Visibility Enforcement (HVE) on Driver Compliance with Bicycle Safe Passing Laws

Kristie Johnson, Ph.D.
Effect of HVE on Driver Compliance with Bicycle Safe Passing Laws

• Study Components
  • Literature/program scan
  • Naturalistic observations
    • Staged and random rides
  • HVE Program
    • Grand Rapids, MI and Knoxville, TN

EQUIPMENT CONFIGURATION

- GoPro
- C3FT
- PDL
Effect of HVE on Driver Compliance with Bicycle Safe Passing Laws

- Determine the impact of combined law enforcement and education on bicycle/driver interactions
Motorcyclists’ Attitudes About Using High-Visibility Gear to Improve Conspicuity

Kathryn Wochinger
Presented by Amy Berning
Background and Objective

• NHTSA wants to increase the visibility of motorcyclists
  • Increase use of high-visibility apparel and gear
• Many motorcyclists do not use high-visibility gear
• Understand why riders do not choose high-visibility gear
• Examined attitudes/opinions about gear and conspicuity
Approach and Results

• Focus groups in California, Maryland, Michigan, and Texas
• Most riders do not use Hi-Viz gear; dislike appearance and do not believe Hi-Viz would improve safety
• Expressed belief that driver distraction is the primary safety problem/risk faced by motorcyclists
• More confident riders believe they do not need Hi-Viz as their skill keeps them safe, but Hi-Viz could help novice riders
• Would be more willing to use Hi-Viz if more convinced of safety benefits
Motorcycle Conspicuity to Vehicle ADAS

• Motivation
  • ADAS technology is expected produce a safer environment for all road users

• Research Question
  • Can light vehicle ADAS applications detect and appropriately react to motorcycles?
Motorcycle Conspicuity to Vehicle ADAS

• Develop test metrics & procedures
  • Evaluate ability of light vehicle ADAS technologies to detect, perceive and react to motorcycles

• Assess motorcycle target requirements

• Comparative assessment with corresponding Euro NCAP test procedures

• Comparative tests of ADAS performance against motorcycles and light vehicles

• Emphasize scenarios/conditions that challenge ADAS capabilities in responding to motorcycles