Government-Industry Cooperation to Develop Objective Test Procedures and Performance Requirements for Crash Imminent Braking Systems and Pedestrian Crash Avoidance/Mitigation Systems

Michael G. Carpenter,
General Motors Company
On Behalf of the Crash Avoidance Metrics Partnership (CAMP)
CAMP’s goal is to facilitate industry consensus on what future crash avoidance countermeasure systems should do and how to test them. Conducting cooperative research with USDOT balances perspectives and leverages resources to address common needs.

**COOPERATIVE R&D**

ongoing **USDOT efforts**

NHTSA / FHwA / ...

**NEED**: Identify, Evaluate and Promote Solutions to Improve Safety through Crash Avoidance

**CONTRACT R&D**

Efforts to develop the science of crash avoidance in order to improve safety & satisfy societal needs

• CALSPAN
• UMTRI
• ...

**emerging **CAMP activities**

‘Crash Avoidance Metrics Partnership’

**NEED**: Establish a Common Basis for Evaluating Product Opportunities which Improve Automotive Safety

**INDUSTRY R&D**

Efforts to define crash avoidance products to improve automotive safety & satisfy market demands

**BALANCED SOLUTIONS**

SOCIETAL & MARKET PERSPECTIVES

- COMMON PROBLEM DEFINITIONS
- STANDARD PERFORMANCE METRICS & TEST PROCEDURES
- JOINT DEFINITION OF COMMON FUNCTIONS & MINIMUM PERFORMANCE SPECIFICATIONS
- JOINT EVALUATION OF POTENTIAL SOLUTIONS
Crash Imminent Braking – Summary

Objectives:
- Develop and validate performance requirements and objective tests for crash imminent automatic braking systems that may improve the safety of the U.S. light vehicle fleet
- Develop a CIB benefits estimation methodology based upon injury risk data and test results from prototype CIB systems

Key Aspects of Project:
- OEM and supplier participating team members
- Multiple USDOT agencies and offices
- Interdependent collaboration throughout the project
- Prototype CIB systems used for test method development, not further development of the technology
CIB Analysis Process
Joint Volpe/CIB Analysis

Prioritize scenarios by fatalities & FYL (FARS/GES/CDS)

Analyze pedestrian crashes (GES)

Analyze pedestrian crashes (CDS)

Select dominant scenarios

Filter dominant scenarios

Apply EDR data

Select other target scenarios

Apply EDR data

Establish harm functions

Determine CIB applicability

Analyze applicable CIB scenarios

Determine CIB applicability

Analyze applicable CIB scenarios

Build simulation models

Estimate potential safety benefits

Top-Down Analysis

Bottom-Up Analysis

- Functional requirements
- Performance specifications
- Test scenarios

Analyze pedestrian crashes (GES)

Analyze pedestrian crashes (CDS)

Establish harm functions
Priority Crash Scenarios Identified

• **Vehicle-to-Vehicle Crashes:**
  - Opposite Direction – Front to Front
  - Rear End – Front to Back
  - Left Turn Across Path / Opposite Direction (Front to Front and Front to Right Side)
  - Straight Crossing Path (Front to Left Side and Front to Right Side)
  - Turning – Front to Left Side

• **Vehicle-to-Object & Vehicle-to-Pedestrian Crashes:**
  - Pedestrian
  - Road Departure – Pole
  - Road Departure – Tree
  - Road Departure – Ground
  - Road Departure – Structure
CIB Test Vehicles

• Simulate the capabilities of various CIB systems for the development of test procedures

• Vehicles included:
  • Various arrays of radar & camera sensors
  • Brake controllers with adjustable parameters
  • System controls capable of supporting varying configurations
Functional Test Method Development Process

Initial prove-out tests - used representative baseline CIB systems to assess preliminary test methods & evaluate various test target types

Prove-out tests - used the project test vehicles to further refine the test methods & targets

Validation - finalized CIB test methods / target designs & confirmed the ability of the tests to differentiate performance among assorted CIB systems
CIB Target Correlation Studies
Each Test Method Was Categorized As Follows

Test Methods Validated
- Lead Vehicle Moving (LVM)
- Lead Vehicle Decelerating (LVD)
- Lead Vehicle Stopped (LVS)

Test Methods Not Validated → Further Development Required
- Pedestrian In-Path
- Pedestrian Crossing Path

Test Methods Not Validated → Not Addressed By CIB

Systems Tested
- Straight Crossing Path (SCP)
- Left Turn Across Path – Opposite Direction (LTAP-OD)
- Opposite Direction (OD)
- Pole & Tree
The Real-world Operational Assessment Data (ROAD) Trip was Used to Assess CIB System Reliability

- Positive performance tests only show one aspect of a CIB system’s performance
- Performance levels expected for CIB systems make understanding potential unintended consequences in real-world operation important to assess
- In order to have a balanced assessment of CIB system performance, test methods are required that can assess system performance with regard to false events
- Test scenarios were designed to mimic the phenomena observed in the field
What did the ROAD Trip look like?

6 weeks of continuous data, covering 10 major cities and various roadways and driving situations across the US in approximate proportion to that of a typical customer vehicle’s lifetime.
Example Radar Only Scenarios

*Same approach used for camera-based sensors*
Example Radar Only Operational Tests
*Same approach used for camera-based sensors

Objects-in-Roadway

Constant Speed

Test Vehicle

Bott's dots

Curve Exit

Curve Entry

Stationary Vehicles

Test Vehicle

Roadside Objects

Overhead Objects

Short Radius Turn

Crash Imminent Braking Consortium

Ford
Continental
GM
Mercedes-Benz
Minimum Performance Recommended to NHTSA for Validated Functional Test Methods

Three measures defined for final minimum specifications
- Priority of validated functional test scenarios
- Minimum speed reduction (related to crash energy)
- CIB activation rates

<table>
<thead>
<tr>
<th>Measure</th>
<th>Recommended Minimum Performance Value</th>
<th>Ways to “Raise the Bar”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Condition Priorities</td>
<td>LVD, LVM</td>
<td>+LVS</td>
</tr>
<tr>
<td>Activation Rate</td>
<td>80% of 10 tests</td>
<td>&gt;80% of 10 tests</td>
</tr>
<tr>
<td>Average Host Speed Reduction for Samples with CIB Activation</td>
<td>6 kph</td>
<td>&gt;6 kph</td>
</tr>
</tbody>
</table>
CAMP-CIB Remarks on Benefit Estimation

- **BENEFIT** = CIB Applicable “Harm Reduction Opportunity Pool” \( \times \) CIB Effectiveness
- Limited data to exercise/support Benefit Estimation Method (& limited time to explore data limitations via alternative techniques/approaches)
  - Under- & over-estimation of Pool (Ex: “Vehicle Did Not Brake” filter)
  - Overlap with other systems such as FCW
  - Limited crash data after “CIB Applicability” filters
  - System performance assumptions
- CAMP-led Summary provided a constructive review and identified opportunities to support the shared goal of improving “State-of-the Art” for estimating Safety Benefits (including CAMP follow-on ideas)
Pedestrian Crash Avoidance/Mitigation (PCAM) Project Proposal

- CAMP and NHTSA have developed a follow on research project proposal
- Proposed 24-months for technical work
- Would include driver initiated and/or autonomous activations of braking technologies capable of avoiding and/or mitigating pedestrian crashes
- Builds upon work initiated in CIB
  - Same participating companies
  - Continued collaboration w/ NHTSA Research & VRTC
- Added collaboration w/ ASSESS, vFSS and related projects through NHTSA/BASSt Memorandum of Cooperation, including preliminary visit by CIB TMT members to Europe
  1. Reviewed existing test methods & equipment
  2. Participated in ASSESS & vFSS consortium meetings
Back-Up
Objective Tests for Crash Imminent Braking Systems

CIB Program Manager
Ray Kiefer

USDOT
Stephen Summers

Management Committee
Ford
Mike Shulman

Delphi
Bill Shogren

GM
John Capp

Continental
Phil Headley

Daimler
Joerg Breuer

Technical Team
Tim Zwicky

Tom Fornari

Mike Carpenter
Principal Investigator

Chris Walker

Frank Baumann
M. Feldmann

CAMP
Crash Imminent Braking Consortium

SAE International™
Vehicle to Vehicle Scenario Priorities

Based on *Functional Years Lost* measure computed based on AAIS 2+ of all persons involved in crashes of Light Vehicles Model Year ≥ 1998 w/ Front Damage from First Harmful Event

<table>
<thead>
<tr>
<th>FARS (by Impact Type)</th>
<th>GES (by Pre-Crash Scenario / Impact Type Combination)</th>
<th>CDS (by Pre-Crash Scenario / Impact Type Combination)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front – Front</td>
<td>Rear End – Front to Back</td>
<td>OD – Front to Front</td>
</tr>
<tr>
<td>36.7%</td>
<td>24.8%</td>
<td>22.4%</td>
</tr>
<tr>
<td>Front – Lt Side</td>
<td>OD – Front to Front</td>
<td>Rear End – Front to Back</td>
</tr>
<tr>
<td>20.5%</td>
<td>13.8%</td>
<td>12.7%</td>
</tr>
<tr>
<td>Front – Rt Side</td>
<td>SCP – Front to Lt Side</td>
<td>LTAP/OD – Front to Front</td>
</tr>
<tr>
<td>17.2%</td>
<td>9.2%</td>
<td>9%</td>
</tr>
<tr>
<td>Front - Rear</td>
<td>SCP – Front to Right Side</td>
<td>SCP – Front to Lt Side</td>
</tr>
<tr>
<td>11%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td></td>
<td>Turning - Front to Lt Side</td>
<td>Turning - Front to Lt Side</td>
</tr>
<tr>
<td></td>
<td>6.2%</td>
<td>7.3%</td>
</tr>
<tr>
<td></td>
<td>LTAP/OD – Front to Rt Side</td>
<td>SCP – Front to Rt Side</td>
</tr>
<tr>
<td></td>
<td>6.1%</td>
<td>7.2%</td>
</tr>
</tbody>
</table>

CDS
Crash Imminent Braking Consortium

FARS
SAE International™
### Vehicle to Object & Vehicle to Pedestrian Scenario Priorities

Based on *Functional Years Lost* measure computed based on AAIS 2+ of all persons involved in crashes of Light Vehicles Model Year ≥ 1998 w/ Front Damage from First Harmful Event

<table>
<thead>
<tr>
<th>FARS (by specific obstacle)</th>
<th>GES (by Pre-Crash Scenario / Object Combination)</th>
<th>CDS (by Pre-Crash Scenario / Object Combination)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian</td>
<td>Pedestrian – Person</td>
<td>Road Departure – Ground</td>
</tr>
<tr>
<td>26.5%</td>
<td>22.7%</td>
<td>17.8%</td>
</tr>
<tr>
<td>Tree</td>
<td>Road Departure – Ground</td>
<td>Road Departure - Pole</td>
</tr>
<tr>
<td>14%</td>
<td>12.7%</td>
<td>17.6%</td>
</tr>
<tr>
<td>Guardrail Face</td>
<td>Road Departure – Structure</td>
<td>Road Departure – Structure</td>
</tr>
<tr>
<td>6%</td>
<td>11.9%</td>
<td>16.8%</td>
</tr>
<tr>
<td>Ditch</td>
<td>Cyclist – Person</td>
<td>Road Departure – Tree</td>
</tr>
<tr>
<td>5.1%</td>
<td>10.1%</td>
<td>14.6%</td>
</tr>
<tr>
<td></td>
<td>Road Departure – Tree</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.7%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road Departure – Pole</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.7%</td>
<td></td>
</tr>
</tbody>
</table>
Data Filtering for Case Reviews

* V-V & V-O indicate #'s of Vehicle-to-Vehicle & Vehicle-to-Object Cases

Target vehicles light vehicles AND
Model Year ≥ 1998 AND
Front Damage from 1st Impact

At least 1 person suffering AAIS2+
(AAIS ≠ 0, 1, 7, N, or U)

YES

Braking Maneuver Attempted?
(MANEUVER ≠ 2, 3, 4, 8 or 9)

NO

Longitudinal ΔV ≤ 45 mph

YES

NO

Control Lost Due to Evasive Maneuver?
(PREISTAB ≠ 0, 2, 3, 4, or 7)
## PIP Vehicle Minimum Performance Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>System Specification</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle-to-Vehicle Crash Scenarios</strong></td>
<td>Address crash scenarios:&lt;br&gt;  - Lead Vehicle Stopped (LVS)&lt;br&gt;  - Opposite Direction (OD)&lt;br&gt;  - Turning – Left Turn in Path (LTIP), Right Turn in Path (RTIP)&lt;br&gt;  - Left Turn Across Path – Opposite Direction (LTAP-OD)&lt;br&gt;  - Straight Crossing Path (SCP)</td>
<td>Task 2 results</td>
</tr>
<tr>
<td><strong>Vehicle-to-Object Crash Scenarios</strong></td>
<td>Address crash scenarios:&lt;br&gt;  - Pedestrian&lt;br&gt;  - Poles&lt;br&gt;  - Trees&lt;br&gt;  - Structure</td>
<td>Task 2 results</td>
</tr>
<tr>
<td><strong>Vehicle Impact Speed Reduction</strong></td>
<td>Approx. 16kph (10 mph)</td>
<td>Surface with a high coefficient of friction (high mu, greater than 0.8) such as dry concrete or dry asphalt.</td>
</tr>
<tr>
<td><strong>Wheel Slip Control</strong></td>
<td>Maintain wheel slip control on all road surfaces</td>
<td>Ensure ABS control works when CIB system goes active and ABS is required to prevent wheel lockup. Only test high mu condition.</td>
</tr>
<tr>
<td><strong>Yaw Control</strong></td>
<td>Maintain yaw control on split mu surfaces</td>
<td>All PIP vehicles will include a yaw control algorithm in the antilock brake system.</td>
</tr>
<tr>
<td><strong>Apply CIB on Any Surface Mu</strong></td>
<td>CIB active on all road conditions</td>
<td>CIB must work on all road conditions. On low mu, the impact speed reduction can be less than the maximum expected on a high mu surface.</td>
</tr>
</tbody>
</table>
Pugh Analysis

- Ranking in 3 categories
  - Overall
  - Ability to Detect
  - Ability to Classify

| Assessment                                      | Weight | A  | B  | C  | D  | E  | F  | G  | H  | I  | J  | K  | L  | M  | N  | O  | P  | Q  | R  | S  | T  | U  | V  |
|------------------------------------------------|--------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Relative cost                                   | 3      | +  | +  | +  | +  | +  | +  | +  | +  | +  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Package size                                    | 1      | +  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Electrical/communication interface              | 2      | +  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Compatibility with data acquisition system      | 3      | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Technical support from supplier                 | 3      | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Mechanical interface with vehicle               | 1      | +  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Fusion algorithm risk                            | 5      | +  | +  | -  | +  | +  | +  | +  | +  | +  | +  | +  | +  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Production field expertise/technical maturity   | 3      | -  | +  | -  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Component lead time                             | 3      | +  | +  | +  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Variation in range measurement                  | 1      | $  | $  | $  | $  | $  | $  | $  | $  | $  | +  | +  | +  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Variation in range rate measurement             | 1      | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Variation in field of view (FOV) measurement    | 1      | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Environmental performance                      | 1      | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| Working relationship w/CIB Technical Team       | 3      | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  | $  |
| **Σ +**                                         |        | 6  | 7  | 2  | 5  | 2  | 7  | 6  | 1  | 2  | 1  | 1  | 5  | 7  | 0  | 5  | 5  | 5  | 5  | 0  | 0  | 0  | 0  |
| **Σ -**                                         |        | 3  | 1  | 3  | 1  | 3  | 3  | 3  | 1  | 2  | 5  | 5  | 1  | 3  | 0  | 3  | 6  | 6  | 4  | 3  | 2  | 2  |
| **Σ $**                                         |        | 5  | 6  | 9  | 8  | 9  | 4  | 5  | 12 | 10 | 8  | 8  | 4  | 14 | 6  | 3  | 3  | 5  | 11 | 12 | 12 | 12|

Datum

Pugh Analysis Key
- = Much Worse than Datum
$ = About the Same as Datum
+ = Much Better than Datum
Test Results: Lead Vehicle Moving

Average Speed Reduction vs. Target Speed

- 0% - 100%
- Braking/No Braking
- Standard Deviation (±1σ)
- Average Speed Reduction [m/s]

Test Vehicle Speed
- 30mph
- 40mph
- 10mph
- 20mph

Target Speed
- Mono Cam
- Orange Balloon Car
- Fusion
- Blue Balloon Car
- Vehicle E
- Vehicle F
- Vehicle G

Average Speed Reduction and Standard Dev. based on runs which had brake activation

TTC: 0.6sec; Decel: 0.9g
TTC: 1.6sec; Decel: 0.4/0.9g
TTC: 1.0sec; Decel: 0.6g

Vehicle E
Vehicle F
Vehicle G