IVBSS Program Overview

Jim Sayer
Program Overview and Purpose

• A 5 year effort to develop and field test integrated safety systems for *passenger vehicles* and *heavy trucks*

• Safety systems provided warnings for *rear-end*, *lane change* and *road departure* crashes in addition to *arbitration of multiple crash threats*

• Included a one-year field test on public roads, and analyses determined system performance, safety benefits, and user acceptance
Development Team
Federal Partners

U.S. Department of Transportation
Intelligent Transportation Systems
Joint Program Office

NHTSA
People Saving People
www.nhtsa.dot.gov

NIST

the VOLPE center

FMCSA
Federal Motor Carrier Safety Administration

October 20, 2010
Timeline - Vehicle Deployment

<table>
<thead>
<tr>
<th>Phase I – 30 months</th>
<th>Phase II – 30 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 2005</td>
<td>Nov 2005</td>
</tr>
<tr>
<td>Engineering</td>
<td>Prototype</td>
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<tr>
<td>Development</td>
<td>Vehicles</td>
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<td>Nov 2006</td>
<td>June 2008</td>
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<td>Vehicles</td>
<td>Pilot</td>
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<tr>
<td>Nov 2008</td>
<td>Nov 2008</td>
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<tr>
<td>Extended</td>
<td>Pilot</td>
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<td>Pilot</td>
<td>FOT</td>
</tr>
<tr>
<td>FOT</td>
<td>Data Collection</td>
</tr>
</tbody>
</table>

Phase I:
- November 2005: Engineering Development Vehicles
- November 2006: Prototype Vehicles
- June 2008: Pilot Vehicles
- November 2008: Extended Pilot

Phase II:
- February 2009: Pilot Vehicles
- November 2010: Data Collection

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IVBSS Passenger Vehicle

Lane-change/Merge (LCM)
Lateral Drift Warning (LDW)
Curve speed Warning (CSW)
Forward Crash Warning (FCW)

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Light Vehicle Integration

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Heavy Truck Sensor Coverage

Radar*

Vision*

Lane-change/Merge (LCM)

Forward Crash Warning (FCW)

Lateral Drift Warning (LDW)

* Sensor field-of-view depth not to scale

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Heavy Truck Integration
Light Vehicle Participants

• 108 drivers
  – younger (20-30 years)
  – middle-aged (40-50 years)
  – older (60-70 years)

• 16 IVBSS vehicles

• 6 weeks of driving per participant
  First 12 days – Warning inhibited (Baseline)
  Next 27 days – IVBSS warnings enabled (Treatment)
Light Vehicle FOT

• April, 2009 to April, 2010

• Data Set
  – 213,000 miles
  – 23,000 trips
  – 6,200 hours
  – 600 data channels
  – 5 video channels
Light Vehicle Video Example

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Heavy Truck Participants

- 20 drivers initially recruited
  - 8 Pick-up and Delivery (daytime, short trips)
  - 10 Line-Haul (nighttime, long trips)
- Average age:
  - P&D – 48 years
  - LH – 50 years
- Average commercial driving experience:
  - P&D – 18 years
  - LH – 25 years

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Heavy Truck FOT

- February, 2009 to December, 2009
- Data Set
  - 602,000 miles
  - 23,000 trips
  - 14,000 hours
  - 500 data channels
  - 5 video channels

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Heavy Truck Video Example
IVBSS Reports and Documentation

• 28 technical reports
  – Over 3000 pages of documentation
  – Functional Requirements and System Perf.
  – Verification Testing
  – Annual reports

• Electronic posting
  – www.umtri.umich/ivbss.php
  – www.nhtsa.gov/research/crash+avoidance

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Structure of Final Reports

Heavy Truck Key Findings Report

Heavy Truck Methodology & Results

IVBSS Final Report

Light Vehicle Key Findings Report

Light Vehicle Methodology & Results

IVBSS Final Report

To be posted before 10/30

In Final Review

Draft 10/27

Draft Submitted Complete 11/12

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Wrap-Up

- Presentations from today will be posted
- UMTRI willing to give presentations on the program
- Data will be made available for research
- Research vehicles located outside
- Representatives from all partners present
Heavy Truck Key Findings

Scott Bogard

Contributors: J. Sayer, D. Funkhouser, A. Blankespoor, S. Bao, M. L. Buonarosa, D. LeBlanc
IVBSS Heavy Trucks

- 10 vehicles with three prototype crash warning systems
- 8 radars, 5 video streams, GPS, >500 other signals at 10 to 50 Hz
- Eaton & Takata with support from Navistar
- Con-way Freight’s Detroit terminal was the fleet

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Heavy Truck Driver Vehicle Interface
Heavy Truck Participants

- 20 drivers initially recruited
  - 8 Pick-up and Delivery (daytime, short trips)
  - 10 Line-Haul (nighttime, long trips)
- 10 months of driving per participant
  - 2 months – IVBSS warnings inhibited (Baseline)
  - 8 months – IVBSS warnings enabled (Treatment)
- Test period: Feb., 2009 to December, 2009
Geographical range of driving by P&D drivers
Geographical range of driving by line-haul drivers
All IVBSS Warnings

- 85,933 warnings (treatment mode, shown below)

- FCW (15397)
- LCM (9317)
- LDW-Imminent (11720)
- LDW-Cautionary (49499)

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Warning Events & Driver Experience

• **Lateral drifts toward unoccupied space:**
  – Accounts for 72%
  – 98% of these warnings are considered valid

• **Lane change merge and Lateral drift warnings toward an occupied space:**
  – 33% are considered valid

• **Forward collision warning (FCW):**
  – 88% of warnings to targets that were seen moving were valid
  – 52% of FCWs were triggered by fixed objects
There was no effect of the integrated system on frequency of secondary tasks.

- 1,980 sampled video clips were coded for secondary tasks
- Slight reduction from 43.5% to 42.1%
- P&D drivers less likely to engage in secondary tasks
HT Comprehensive System Results: 
Driver Behavior

- In multiple threat scenarios, the initial warning was generally enough to get the attention of drivers
  - 83 cases observed were during treatment mode
Drivers believe that the integrated system will increase their driving safety.
HT Comprehensive System Results: Driver Acceptance

- Drivers rated the integrated system fairly well in terms of usefulness and satisfaction.
HT Comprehensive System Results: Driver Acceptance

- 15 of the 18 drivers prefer a truck with the integrated system to a conventional truck.

Driving with the integrated system made me more aware of traffic around me and the position of my car in my lane.

- P&D: Mean = 5.6, St. Dev = 1.6
- LH: Mean = 4.9, St. Dev = 2.0

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HT Lateral Control and Warnings: Driver Behavior

- The integrated system did not have an effect on reducing lane departures
  - But departures decreased for 13 of 18 drivers
- The duration and distance of lane incursions was not affected by the integrated system
- There was no effect of the integrated system on turn-signal use during lane changes
HT Lateral Control and Warnings: Driver Behavior

• The integrated system had a statistically significant, but practically very small, effect on lateral offset
  – Drivers were 1.7 cm closer to the center of the lane
HT Lateral Control and Warnings: Driver Behavior

• The duration and distance of lane incursions was not affected by the integrated system.
• There was no effect on the frequency of lane changes.
LDW/LCM Example Videos
HT Longitudinal Control and Warnings: Driver Behavior

- No effect of the integrated system on forward conflict levels
- Drivers maintained marginally longer average time headways (0.05s)
- No effect on hard-braking events (less than 0.2g [1.96 m/s²])
- Drivers responded more quickly to closing-conflict events in the treatment condition
HT Longitudinal Control and Warnings: Driver Behavior

- No significant effect on gap size when performing lane changes.
FCW Example Videos

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HT Longitudinal Control and Warnings: Driver Acceptance

- Line-haul and P&D drivers specifically mentioned valid FCW warnings and the headway-time margin display to be helpful.
- Driver acceptance, while favorable, would almost certainly have been higher had invalid warnings due to fixed roadside objects and overhead road structures.
Summary – HT FOT

- Drivers generally accepting of the integrated system
- Drivers reported that the LDW system was most beneficial
- Secondary task activity unchanged
- Multiple-threat warning sequences are rare
Independent Evaluation Results – Heavy Truck

IVBSS Public Meeting
October 20, 2010
Presentation Outline

• Evaluation status
• Goals and objectives
• Analysis approach
• Study limitations
• Heavy truck results
  – Safety impact
  – Driver acceptance
  – System performance
Evaluation Status

- Comments received early October, 2010.
Independent Evaluation Goals

**Safety Impact**
- Safety benefits
- Unintended consequences

**Driver Acceptance**
- Ease of use
- Perceived usefulness
- Ease of learning
  - Driving performance
  - Advocacy

**System Performance**
- Sensors
- Alert Logic
  - Interfaces
  - Robustness
Safety Impact Framework

Overall Driving

Driving Conflicts

Near Crashes

Driving Performance

Driver Inattention

Frequency of Occurrence

Driver Response

Frequency of Occurrence

Driver Inattention

Projection of Potential Safety Benefits
Overall Driving Measures

• Driving Performance
  – Travel speed
  – Time headway
  – Lane change maneuvers
  – Lane keeping

• Driver Inattention
  – Secondary tasks
  – Eyes-off-forward-scene
Driving Conflict Measures

• Exposure
  – Rear-end conflicts
    • Lead vehicle decelerating/moving at slower speed
    • Lead vehicle stopped
  – Lateral conflicts
    • Lane change
    • Road departure

• Response
  – Rear-end conflicts: time-to-collision/deceleration level
  – Lateral conflicts: lateral acceleration/lane bust distance
Near Crashes – Thresholds

• Rear-end driving conflicts:
  – $\text{TTC}_{\text{min}} < 3$ sec
  – $A_{x_{\text{min}}} > 0.2g$
  – Brake pedal $> 0.5$ sec
  OR
  – $A_{x_{\text{min}}} > 0.4g$
  – Brake pedal $> 0.5$ sec

• Lane-change conflicts:
  – $A_{y_{\text{max}}} > 0.1g$
  – $0 \text{ m} < d_{LB_{\text{max}}} < 0.9 \text{ m}$

• Road-departure conflicts:
  – $A_{y_{\text{max}}} > 0.1g$
  – $0.3 \text{ m} < d_{LB_{\text{max}}} < 0.9 \text{ m}$
  – $1 \text{ sec} < t_{LB} < 5 \text{ sec}$
  OR
  – $A_{y_{\text{max}}} > 0.3g$
  – $1 \text{ sec} < t_{LB} < 5 \text{ sec}$

$\text{TTC}_{\text{min}}$: minimum time-to-collision
$A_{x_{\text{min}}}$: minimum deceleration level
$A_{y_{\text{max}}}$: maximum lateral acceleration
$d_{LB_{\text{max}}}$: maximum lane bust distance
$t_{LB}$: lane bust duration
## Video Analysis

### All Alerts

<table>
<thead>
<tr>
<th>Video Available</th>
<th>Distraction</th>
<th>Steering Response</th>
<th>Host Vehicle Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash Imminent</td>
<td>Eyes off Forward Scene</td>
<td>Host Vehicle Maneuver</td>
<td>Location</td>
</tr>
</tbody>
</table>

### FCW Alerts
- Target Type
- Target Vehicle Body Type
- Lead Vehicle Maneuver
- Lead Vehicle Position
- In path of host Vehicle
- Lead Vehicle Maneuver Times

### LDW-I/LCM Alerts
- Target Type
- Target Location
- Moving Target Vehicle Relative Speed

### LDW-I/LDW-C
- Lane Excursion Scenario
- Lane Marker
- Road Condition
- Opposing Traffic
- Time of Collision

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**FCW**: Forward Crash Warning  
**LCM**: Lane Change/Merge  
**LDW/I-C**: Lane Departure Warning/Imminent-Cautionary
Study Limitations

• Professional drivers participating in the study were generally very safe, even during the baseline period
• Very low exposure to some near crash types in both test periods prevented safety projections for 4 pre-crash scenarios
• Small sample of test subjects
123,000 heavy trucks were involved in target pre-crash scenarios annually (based on average 2004-2008 GES statistics)
Overall Driving – Turn Signal Use

- Increased turn signal usage for line-haul drivers (speeds over 45 mph)
  - Baseline: 78% of lane changes signaled
  - Treatment: 82% of lane changes signaled
  - 5% increase
Overall Driving – Lane Busts

• Decrease in rate of lane busts to both sides
  – 9% reduction at slower speeds (35 to 55 mph)
    • Baseline: 8.7 per 10 miles, Treatment: 7.9 per 10 miles
  – 15% reduction at higher speeds (above 55 mph)
    • Baseline: 3.5 per 10 miles, Treatment: 3.0 per 10 miles
  – Most improvement to the right side
Overall Driving – Secondary Tasks

- 8 line-haul drivers showed an increase in secondary tasks during the treatment period.
- No negative safety impact is associated with this increase.
## Secondary Tasks – Change from Baseline to Treatment

### Pickup & Delivery

<table>
<thead>
<tr>
<th>Driver</th>
<th>Secondary Task</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Looking outside car</td>
<td>6%</td>
</tr>
<tr>
<td>2</td>
<td>Smoking</td>
<td>8%</td>
</tr>
<tr>
<td>4</td>
<td>Grooming</td>
<td>6%</td>
</tr>
<tr>
<td>5</td>
<td>Reaching for object</td>
<td>3%</td>
</tr>
<tr>
<td>6</td>
<td>Talking on phone</td>
<td>5%</td>
</tr>
<tr>
<td>7</td>
<td>Looking outside car</td>
<td>9%</td>
</tr>
<tr>
<td>8</td>
<td>Grooming</td>
<td>9%</td>
</tr>
<tr>
<td>10</td>
<td>Smoking</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Line-Haul

<table>
<thead>
<tr>
<th>Driver</th>
<th>Secondary Task</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Eating</td>
<td>12%</td>
</tr>
<tr>
<td>22</td>
<td>Looking outside car</td>
<td>13%</td>
</tr>
<tr>
<td>23</td>
<td>Eyes Closed &gt;1s</td>
<td>16%</td>
</tr>
<tr>
<td>24</td>
<td>Eyes Closed &gt;1s</td>
<td>8%</td>
</tr>
<tr>
<td>25</td>
<td>Reaching for object</td>
<td>6%</td>
</tr>
<tr>
<td>26</td>
<td>Smoking cigarettes</td>
<td>9%</td>
</tr>
<tr>
<td>27</td>
<td>Grooming</td>
<td>7%</td>
</tr>
<tr>
<td>28</td>
<td>Talking on Phone</td>
<td>9%</td>
</tr>
<tr>
<td>29</td>
<td>Looking outside car</td>
<td>10%</td>
</tr>
<tr>
<td>30</td>
<td>Talking on bluetooth</td>
<td>19%</td>
</tr>
</tbody>
</table>
Overall Driving – Eyes-Off-Forward Scene

No trend in eyes-off-forward scene behavior with system enabled

<table>
<thead>
<tr>
<th>Change in % of Episodes with Eyes off Forward Scene (T-B)</th>
<th>LH: Line-Haul</th>
<th>P&amp;D: Pickup &amp; Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>-11%</td>
<td></td>
<td>-18% -17%</td>
</tr>
<tr>
<td>-3%</td>
<td></td>
<td>-8%</td>
</tr>
<tr>
<td>-3%</td>
<td>2%</td>
<td>-6%</td>
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<td>0%</td>
<td>2%</td>
<td>-4%</td>
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<tr>
<td>2%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>17%</td>
<td>3%</td>
<td></td>
</tr>
</tbody>
</table>
Overall Driving – Eyes Closed

- 502 instances of “Eyes closed for > 1 second” observed
- 3 line-haul drivers accounted for 90% of instances
  - Driver 21: 7% of baseline alerts, 12% of treatment alerts
  - Driver 23: 19% of baseline alerts, 35% of treatment alerts
  - Driver 24: 5% of baseline alerts, 13% of treatment alerts

![Graph showing proportions of alerts by driver and route type (P&D vs. LH)]
Driving Conflict Results

- No statistically significant reduction in driving conflicts
  - Route type
  - All treatment
  - Last ¼ of treatment mileage
  - Last 2 hours of shift
Near Crash Experience

- 12 drivers experienced a decrease in near crash rates
- Reduction in rates of road departure to left: 2.0 to 1.1 per 1,000 miles (statistically significant)
- Reduction in overall near crash rates: 8.7 to 8.1 per 1,000 miles (not statistically significant)

P&D: Pickup & Delivery
LH: Line-Haul

Decrease
Increase
Near Crash Experience Reported by Subjects

- 8 drivers reported that the system prevented them from getting into a crash or near crash
  - Pickup & Delivery drivers:
    - Lead vehicle cut-in (2 drivers)
    - Slower moving lead vehicle
    - Vehicle in blind spot when attempting lane change
  - Line-Haul drivers:
    - Slower moving lead vehicle
    - When tired and drifting off the road
    - Vehicle in blind spot when attempting lane change
    - Encountered lead vehicle with no brake lights
Driver Acceptance – Key Results

• 15 drivers would prefer to drive a truck with the integrated system.
• 13 drivers felt that driving with the integrated system would increase their driving safety.
• 15 drivers reported that the system made them more aware of their surroundings.
**Driver Acceptance**

What did you like **most** about the integrated system?

<table>
<thead>
<tr>
<th>Pickup &amp; Delivery</th>
<th>Line-Haul</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased awareness</td>
<td>Blind spot monitors</td>
</tr>
<tr>
<td>(3 drivers)</td>
<td>(4 drivers)</td>
</tr>
<tr>
<td></td>
<td>Lane departure warnings</td>
</tr>
<tr>
<td></td>
<td>(3 drivers)</td>
</tr>
</tbody>
</table>
Driver Acceptance

What did you like **least** about the integrated system?

**Pickup & Delivery**
False FCW warnings
(5 drivers)

**Line-Haul**
False side hazard warnings
(4 drivers)
Driver Acceptance

In which situations did you find the integrated system to be most helpful?

Pickup & Delivery
Approaching slower traffic (2 drivers)
Cars in blind spot (2 drivers)

Line-Haul
Drifting (4 drivers)
Driver Acceptance

Reported changes in driving behavior

- Increased alertness/attention (3 P&D, 1 LH)
- Increased headway (2 P&D)
- Improved lane positioning (1 LH)
- None (3 P&D, 8 LH)

LH: Line-Haul
P&D: Pickup & Delivery
Driver Acceptance

Did you rely on the integrated system?

- LH: Line-Haul
- P&D: Pickup & Delivery

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>P&amp;D</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

Number of Responses

0 1 2 4 6 8 10

John A. Volpe National Transportation Systems Center
Driver Acceptance

Did you rely on the integrated system?

• “You find yourself relaxing a bit.”
• “To a small degree, but habit and experience led me to rely on myself most of the time.”
• “For lane changes in bad weather and sunlight, I didn’t check my mirrors until the [BSM] went off.”
• “There were times when I was very tired, the drift warnings were helpful.”
• “I found it helped keep me alert in heavy traffic.”
System Performance – Driver Vehicle Interface

**Center display**

- Positive: 12
- Neutral: 3
- Negative: 3

**Blind spot lights**

- Positive: 11
- Neutral: 2
- Negative: 5

**Blind spot light location**

- Positive: 9
- Neutral: 5
- Negative: 4

Number of Responses

---

John A. Volpe National Transportation Systems Center
System Performance – Auditory Warnings

I could easily distinguish among the auditory warnings:
- Positive: 17
- Neutral: 1
- Negative: 1

The auditory warnings got my attention:
- Positive: 16
- Neutral: 1
- Negative: 1

Number of Responses
9 drivers adjusted the volume more than 5 times

Only 2 drivers used the mute button more than twice
System Performance – Forward Crash Warning (FCW)

- Forward radar characterization
  - 93% of FCW-moving alerts issued for in-path target
  - 3% of FCW-stopped alerts issued for in-path target

(Based on video review of 2,368 FCW alerts)
System Performance – Breakdown of FCW Alerts Issued for Out-of-Path Stationary Objects

(Based on video analysis of 875 FCW-stopped alerts)
System Performance – FCW-M Alert Experience

- 12% reduction in FCW-moving alert rate from baseline to treatment
  - 24% reduction for line-haul drivers (7.0 to 5.2 per 100 miles)
  - Indicates improved headway keeping for all drivers, especially line-haul drivers.
System Performance – Side Imminent Alerts

- 58% of LCM alerts had adjacent target
- 56% of LDW-I alerts had adjacent target
- Side detection more accurate in pickup & delivery driving environment

(Based on video review of 6,861 alerts)

LCM: Lane change/merge warning  LDW-I: Imminent lane departure warning
System Performance – Breakdown of Non-Adjacent Target Types in Side Imminent Alerts

(Based on video analysis of 2,743 alerts)
System Performance – Validity of Cautionary Lane Departure Warning (LDW-C) Alerts

- 90% of LDW-C alerts issued for valid lane departure
- Higher accuracy for line-haul drivers (more freeway miles)

(Based on video analysis of 3,671 LDW-C alerts)
System Performance – LDW-C Alert Experience

• 20% reduction in LDW-C alert rate from baseline to treatment
  • 14% reduction for pickup & delivery drivers (6.9 to 6.0 per 100 miles)
  • 25% reduction for line-haul drivers (7.0 to 5.2 per 100 miles)
• Indicates improved lane keeping for all drivers with the integrated system enabled
System Performance – Steering Intensity

- Increase in corrective steering intensity in response to side alerts when audible warning was issued.
System Performance – LDW Availability

- Lane tracking availability met target performance specifications for all speed bins

![Bar chart showing LDW availability for different speed bins and sides, with target values indicated.](chart.png)
## Projection of Potential Safety Benefits

<table>
<thead>
<tr>
<th>Function</th>
<th>Pre Crash Scenario</th>
<th>Annual Target Crashes</th>
<th>Max Estimated Annual Crash Reduction</th>
<th>Max Estimated Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW-M</td>
<td>Rear end/Lead vehicle decelerating</td>
<td>18,000</td>
<td>5,000</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>Rear end/Lead vehicle moving</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCW-S</td>
<td>Rear end/Lead vehicle stopped</td>
<td>19,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCM</td>
<td>Changing lanes/same direction</td>
<td>53,000</td>
<td></td>
<td>Insufficient field data to estimate</td>
</tr>
<tr>
<td></td>
<td>Turning/same direction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDW-I</td>
<td>Drifting/same lane</td>
<td>7,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDW-C Left</td>
<td>Opposite direction/No maneuver</td>
<td>11,000</td>
<td>3,000</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>Road edge departure/No maneuver</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDW-C Right</td>
<td>Road edge departure/No maneuver</td>
<td>15,000</td>
<td>5,000</td>
<td>36%</td>
</tr>
<tr>
<td>Integrated System</td>
<td>All</td>
<td>123,000</td>
<td><strong>13,000</strong></td>
<td><strong>11%</strong></td>
</tr>
</tbody>
</table>
Recommendations

- System improvements for more accurate detection of:
  - Stationary forward targets
  - Adjacent targets
Questions
Light Vehicle Key Findings
Dave LeBlanc

Contributors: J. Sayer, M. L. Buonarosa D. Funkhouser, S. Bao, A. Blankespoor, S. Bogard
IVBSS Light Vehicles

- 16 vehicles with four prototype crash systems
- 7 radars, 5 video cameras, GPS, >600 channels at 10 to 50 Hz
- Visteon & Takata with support from Honda

Radars behind fascias
Light Vehicle Driver Vehicle Interface

Curve speed warning
- Audible – forward tone
- Text to confirm: “Sharp Curve”

Forward crash warning
- Audible – forward tone
- Haptic – brake pulse
- Text to confirm: “Forward Hazard”

Blind spot detection – vehicle in adjacent lane
- Icon in side mirror

Lane departure – into unoccupied space without turn signal
- Haptic – seat vibration
- Text to confirm, e.g.: “Left Drift”

Lane departure – into occupied space with or without turn signal
- Audible – side tone (directional)
- Text to confirm, e.g.: “Left Hazard”

October 20, 2010
Light Vehicle Experiment

• 108 drivers
  – Younger (20-30 years)
  – Middle-aged (40-50 years)
  – Older (60-70 years)
  – Same number of males and females in each age group

• 6 weeks of driving per participant
  – First 12 days – IVBSS warnings inhibited (Baseline)
  – Next 27 days – IVBSS warnings enabled (Treatment)

• Test period: April 6, 2009 to April 20, 2010
Travel in Light Vehicle FOT

- CSW map coverage:
  - Percent of time in motion: 6.9%
  - 213,309 miles
  - 22,657 trips
  - 6164 hours
  - 2 terabytes
- Non-ADAS map: 15.5%
- No map: 7.6%

October 20, 2010
IVBSS: 7 Crashes (No Injuries)

- One driver struck the rear-end of another vehicle
- One driver ran off the road (~30 mph)
- One driver hit a construction barrel during a last moment move to exit a freeway
- Two drivers backed into stationary objects (a parked vehicle, a fence)
- Two drivers struck running deer at night
- Impact, not crash: curb strike (damages fascia)
Travel in LV FOT

- 213,309 miles (32% in baseline)
- Males accounted for 61% of travel distance

Middle-aged had most travel distance…

- Younger: 29%
- Middle age: 32%
- Older: 39%

Half the travel distance was on limited access & ramps

- Limited access: 42%
- Ramps: 9%
- Surface: 45%
- Unknown: 4%

October 20, 2010
All IVBSS warnings

- 10,617 warnings (baseline)
- 12,202 warnings (treatment mode, shown below).

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDW-Cautionary</td>
<td>70%</td>
<td>8505</td>
</tr>
<tr>
<td>LDW-Imminent</td>
<td>13%</td>
<td>1593</td>
</tr>
<tr>
<td>LCM</td>
<td>7%</td>
<td>915</td>
</tr>
<tr>
<td>FCW</td>
<td>5%</td>
<td>579</td>
</tr>
<tr>
<td>CSW</td>
<td>5%</td>
<td>610</td>
</tr>
</tbody>
</table>

October 20, 2010
Warning Events & Driver Experience

• **Lateral drifts toward unoccupied space:**
  – Accounts for 77% of all warnings in treatment mode
  – Lane tracking is available 63% for both edges (71% for left only) -over the 25 mph minimum operating speed.
  – Left bias: 68% of these warnings occur on left
  – 94% of these warnings are considered valid.

• **Lane change merge warnings:**
  – 94% are considered valid: Adjacent-lane vehicle, and host vehicle is drifting over lane edge, or has initiated a lane change
  – 68% of these warnings occur on left side

October 20, 2010
Warning Events & Driver Experience

- **Forward collision warning (FCW):**
  - 84% of warnings to targets that were seen moving were valid
  - 2% of warnings for always-stopped targets are considered valid
  - 44% of FCWs are triggered by fixed objects

- **Curve speed warning (CSW):**
  - 74% valid: the vehicle traverses a significant curve
  - Invalid warnings for exit ramps that the driver does not take and warnings triggered by map data error and/or its interpretation
Warning Events & Driver Experience

• **Invalid warnings are inevitable**
  – With current technology and are particularly pronounced for “predictive” systems such as FCW and CSW that maintain an “always-available” state
LV Comprehensive System Results:

Driver Behavior

- There was no effect of the integrated system on frequency of secondary tasks.
  - 2,160 sampled video clips were coded for secondary tasks
  - Younger & middle-age drivers had more secondary task involvement than older drivers in their 60s (p=.001)
  - More secondary tasks occurred at night (p=.003)
LV Comprehensive System

Results:

Driver Behavior

• In multiple threat scenarios, the initial warning was generally enough to get the attention of drivers
  – Only six cases of this observed were during treatment mode
Drivers believe that the integrated system will increase their driving safety.

Overall, I think that the integrated system is going to increase my driving safety.

Mean (Y) = 5.0
Mean (M) = 5.5
Mean (O) = 6.1
St. Dev (Y) = 1.5
St. Dev (M) = 1.3
St. Dev (O) = 1.1
LV Comprehensive System

Results:

Driver Acceptance

• Drivers rated the integrated system well in terms of both usefulness and satisfaction.
LV Comprehensive System

Results:

Driver Acceptance

• The majority of drivers reported that they were willing to purchase the system

What is the maximum amount that you would pay for the integrated system?

Response Frequency

Maximum Price

$0  $250-500  $500-750  $750-1000  $1000-1500  $1500-2000  >$2000

October 20, 2010
LV Lateral Control and Warnings: Driver Behavior

- The integrated system had a significant effect on reducing lane departures
  - Decreasing from 14.6 to 7.6 per 100 miles
LDW/LCM Example Videos
LV Lateral Control and Warnings: Driver Behavior

- Drivers 0.9 cm closer to center with the integrated system
- An occupied adjacent lane causes drivers to shift 10 cm away from the object/vehicle

October 20, 2010
LV Lateral Control and Warnings: Driver Behavior

- Drivers use turn signals more often when changing lanes
LV Lateral Control and Warnings: Driver Acceptance

- Not all lateral warnings were considered necessary by drivers

The integrated system gave me left/right hazard warnings when I did not need one.

Mean = 4.2 St. Dev = 2.1
LV Longitudinal Control and Warnings: Driver Behavior

• No effect of the integrated system on forward conflict levels
LV Longitudinal Control and Warnings: Driver Behavior

- No effect on the frequency of hard-braking
- No effect on the curve taking behavior, or behaviors when approaching curves
- Close following, <1 sec HTM, increased slightly
  - 21% to 24%
- Several instances where FCWs prevented a rear-end crash
FCW Example Videos
LV Longitudinal Control and Warnings: Driver Behavior

- No effect on peak sustained lateral accelerations in curves
- No effect on sustained resultant acceleration in curves
  - lateral and longitudinal
- No effect on deceleration approaching a curve
LV Longitudinal Control and Warnings: Driver Acceptance

- Drivers rated the usefulness and satisfaction of FCW lowest
  - But still neutral, to slightly favorable
- Prominent among attributes that drivers did not like was the brake pulse for FCWs
Perceived Benefits

- Eight of 28 drivers that participated in one of the 3 focus groups reported that the system helped them avoid a crash.
- In the individual debriefing sessions, several additional drivers stated the same thing.
Reactions to Warning Frequency and Nuisances

• Drivers noted nuisance warnings in questionnaires, debrief interviews, and focus groups

• Older drivers were more forgiving than middle-aged or younger drivers
  – Invalid rates were relatively constant across age groups
Warning Modalities

• Drivers reported warnings were:
  – attention-getting, not annoying
  – generally predictable and consistent
• Drivers used the visual display to confirm warning type, and found the display useful
• Drivers found volume control useful
• Few drivers used the mute button
• Many drivers disliked the FCW brake pulse
Open-Ended Impressions

• What did you like most about the integrated system? (Top three responses)
  – Blind spot detection icons
  – LDW drift warnings
  – Greater awareness of driving habits

• What did you like least about the integrated system? (Top three responses)
  – False warnings
  – Brake pulse which accompanied FCWs
  – Auditory tones: too startling for some drivers, other drivers wanted “voice warnings” instead of tones
Summary – LV FOT

• Drivers generally accepting of the integrated system
• Drivers reported that blind-spot detection was the most useful and satisfying
• Secondary task activity unchanged
• Fewer lane departures, increased turn signal use
• Multiple-threat warning sequences are rare
Independent Evaluation – Light Vehicle Preliminary Results

IVBSS Public Meeting
October 20, 2010
Presentation Outline

• Evaluation status
• Goals and objectives
• Analysis approach
• Preliminary results
  – Safety impact
  – Driver acceptance
  – System performance
Evaluation Status

• Analysis currently underway
• Draft report due December 12, 2010.
Independent Evaluation Goals

**Safety Impact**
- Safety benefits
- Unintended consequences

**Driver Acceptance**
- Ease of use
- Perceived usefulness
- Ease of learning
- Driving performance
- Advocacy

**System Performance**
- Sensors
- Alert Logic
- Interfaces
- Robustness
Analysis Approach
2,674,000 light vehicles of interest were involved in target pre-crash scenarios annually (based on average 2004-2008 GES statistics)
Safety Impact Framework

Overall Driving

Driving Conflicts

Near Crashes

Driving Performance

Driver Inattention

Frequency of Occurrence

Driver Response

Near Crashes

Driving Conflicts

Overall Driving

Projection of Potential Safety Benefits

Driver Inattention

Frequency of Occurrence
Overall Driving Measures

• Driving Performance
  – Travel speed
  – Time headway
  – Lane change maneuvers
  – Lane keeping

• Driver Inattention
  – Secondary tasks
  – Eyes-off-forward-scene
Driving Conflict Measures

• Exposure
  – Rear end conflicts
    • Lead vehicle decelerating/moving at slower speed
    • Lead vehicle stopped
  – Lateral conflicts
    • Lane change
    • Road departure
  – Curve speed conflicts

• Response
  – Rear end conflicts: time-to-collision/deceleration level
  – Lateral conflicts: lateral acceleration/lane bust distance
  – Curve speed conflicts: deceleration and lateral acceleration
## Video Analysis

### All Alerts

<table>
<thead>
<tr>
<th>Video Available</th>
<th>Distraction</th>
<th>Steering Response</th>
<th>Host Vehicle Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash Imminent</td>
<td>Eyes off Forward Scene</td>
<td>Host Vehicle Maneuver</td>
<td>Location</td>
</tr>
</tbody>
</table>

### FCW Alerts
- Target Type
- Target Vehicle Body Type
- Lead Vehicle Maneuver
- Lead Vehicle Position
- In path of host Vehicle
- Lead Vehicle Maneuver Times

### LDW-I/LCM Alerts
- Target Type
- Target Location
- Moving Target Vehicle Relative Speed

### LDW-I/LDW-C
- Lane Excursion Scenario
- Lane Marker
- Road Condition
- Opposing Traffic
- Time of Collision

**FCW**: Forward Crash Warning; **LCM**: Lane Change/Merge; **CSW**: Curve Speed Warning

**LDW/I-C**: Lane Departure Warning/Imminent-Cautionary
Preliminary Light Vehicle Results
Rear End Conflict Rates

Younger: 20-30 years old
Middle-aged: 40-50 years old
Older: 60-70 years old
Curve Speed Conflict Rates

Younger: 20-30 years old
Middle-aged: 40-50 years old
Older: 60-70 years old
Lane Change/Merge Conflict Rates

- Younger: 20-30 years old
- Middle-aged: 40-50 years old
- Older: 60-70 years old

Test period:
- B
- T1
- T2

Number of conflicts per 100 miles:
- Younger: 0.87
- Middle-aged: 0.66
- Older: 0.57
- All drivers: 0.66

Younger: 20-30 years old
Middle-aged: 40-50 years old
Older: 60-70 years old
Road Departure Conflict Rates

Younger: 20-30 years old  
Middle-aged: 40-50 years old  
Older: 60-70 years old
Conflict Rates

Younger: 20-30 years old
Middle-aged: 40-50 years old
Older: 60-70 years old
Driver Acceptance – Demographic Breakdown

Education Level
- Higher education level → Lower understanding of warnings
- Higher education level → More annoyance with system

Years of Driving Experience
- More experience → Less annoyance with nuisance warnings
- More experience → System made driving easier
Driver Acceptance – Driver Experience Breakdown

- More alerts → Better understanding of warnings
- Shorter average trip length → System made driving easier
- Less freeway driving → System more consistent
  Fewer nuisance warnings
- More nighttime driving → Less distracted by warnings
  Better understanding of warnings

All results significant based on paired t-test
Driver Acceptance – Driver Experience Breakdown

Responses to: “The nuisance warnings were not annoying”

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower alert rates</td>
<td>4.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Higher alert rates</td>
<td>3.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

P-values:
- FCW: 0.01
- CSW: 0.08
- Side Hazard: 0.04
- Drift: 0.26
Alert Rates

The chart illustrates alert rates per 100 miles for different alert types: FCW, CSW, LCM, LDW-I, and LDW-C. The alert rates are divided into baseline and treatment categories.

- FCW: Baseline 0.4, Treatment 0.4
- CSW: Baseline 0.4, Treatment 0.4
- LCM: Baseline 0.7, Treatment 0.6
- LDW-I: Baseline 1.3, Treatment 1.1
- LDW-C: Baseline 11.2, Treatment 5.8
### Alert Rates

<table>
<thead>
<tr>
<th></th>
<th># of Alerts per 100 mi</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Treatment</td>
</tr>
<tr>
<td>All Alerts</td>
<td>15.4</td>
<td>8.4</td>
</tr>
<tr>
<td>Imminent Drift</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Cautionary Drift</td>
<td>12.7</td>
<td>5.9</td>
</tr>
</tbody>
</table>

- All alerts/cautionary drifts significant for all age/gender groups
- Females showed a reduction in imminent drift warnings

All results significant based on paired t-test
Preliminary Secondary Task Results – Most Common Tasks

Secondary tasks present in 57% of alerts

<table>
<thead>
<tr>
<th>Task</th>
<th>Portion of Alerts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talking to/looking at passengers</td>
<td>19%</td>
</tr>
<tr>
<td>Grooming</td>
<td>9%</td>
</tr>
<tr>
<td>Talking on/listening to phone</td>
<td>7%</td>
</tr>
<tr>
<td>Looking to the side/outside car</td>
<td>6%</td>
</tr>
<tr>
<td>Adjusting controls</td>
<td>4%</td>
</tr>
<tr>
<td>Text messaging</td>
<td>3%</td>
</tr>
<tr>
<td>Smoking/lighting cigarettes</td>
<td>2%</td>
</tr>
<tr>
<td>Eating</td>
<td>2%</td>
</tr>
<tr>
<td>Reaching for object in vehicle</td>
<td>2%</td>
</tr>
<tr>
<td>Reading cell phone</td>
<td>2%</td>
</tr>
</tbody>
</table>

(Based on video analysis of 14,860 alerts)
Preliminary Secondary Task Results - Most Common Secondary Tasks by Age Group

- **Older**
  - Talking on/listening to phone: 6%
  - Looking outside car: 8%
  - Grooming: 9%
  - Talking to/looking at passengers: 19%

- **Middle-Aged**
  - Talking on/listening to phone: 7%
  - Grooming: 8%
  - Looking outside car: 8%
  - Talking to/looking at passengers: 17%

- **Younger**
  - Texting: 6%
  - Grooming: 9%
  - Talking on/listening to phone: 10%
  - Talking to/looking at passengers: 23%

(Based on video analysis of 14,860 alerts)
Preliminary Eyes-Off-Forward Scene Results

Most common for LDW-C alerts for all age groups

(Based on video analysis of 14,860 alerts)
Questions
Field Operational Test
Data System Overview

Scott Bogard
UMTRI
Contributors: J. Sayer, D. Funkhouser,
A. Blankespoor, S. Bao
M. L. Buonarosa, D. LeBlanc
### Primary IVBSS FOT Databases

#### Layers and tasks

<table>
<thead>
<tr>
<th>Players</th>
<th>UMTRI</th>
<th>Volpe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Archive</strong></td>
<td>Lv-2.3 TB</td>
<td>Hi-4.5 TB</td>
</tr>
<tr>
<td>Field Operational Test</td>
<td>Hi-Con-way Freight</td>
<td>Lv-General Public</td>
</tr>
<tr>
<td>Extended Pilot Testing</td>
<td>UMTRI</td>
<td>UMTRI</td>
</tr>
</tbody>
</table>

#### IVBSS System

| Lom, Ldw, Fcw, Csw, Dvi, Fusion (Sensors, Radar, Maps, Camera) | UMTRI |

#### Vehicle Platform

| 16-2006 Accords | International Trucks |
| 10-2008 Honda | TransStar |

#### Design optimized for:
- Back-up
- Query efficiency
- Data loading

#### Views relate Radar and Raw to FOT

- Read only
UMTRI Data Guidelines

– All data belongs in a database
  • This includes system definition and collected or derived data

– All databases should be fully normalized
  • Data should not be duplicated
  • Data must have common ‘keys’ which form a unique entry in a database table
    – Driver, Trip, Time (all integer numbers)
    – Additional keys: Index, Unique Id numbers

– If designed correctly a relational database architecture is very efficient and scalable
IVBSS Data Structures

• Database tables (LV 93/741GB; HT 97/1.26TB)
  – Time history
    • Time sequenced data typically at 10 Hz
    • More complex for radar which has multiple targets at any given time creating a one-to-many relationship
    • Transition: logged upon change in state (PRNDL)
IVBSS Data Structures and Archive

- Database tables
  - Summary or Event
    - aggregated data over a period of time
  - Histograms—frequency distributions
  - Reference—mapping between a value and it’s meaning
- 4.5 B records in largest HT table (radar)
- 1.2 B records for LV
- Video—time stamped, mpeg4 compressed in a bitmap format (LV 1.09 TB; HT 2.19 TB)
IVBSS Primary Content

- LV FOT and HT FOT
  - Vehicle—state variables and driver inputs
  - Warning technology
    - Radar and lane tracking camera
  - Diagnostic
    - Faults; heart beats; histograms; odometer; last values
- GPS
- Summary
IVBSS Secondary Content

– LV and HT (256 and 238 tables)
  • Longitudinal/Lateral conflict metrics
  • Traffic surrogates from radar tracks
  • Signal conditioning
  • Events: curve, straight, moving, stopped, road type, dark, braking, following, lane change…

– Supplemental data sources
  • Highway Performance Monitoring Sys.
    – Intersections and nodes, traffic count, signaling,….
  • Weather
Analysis tools and video content

- Most ‘off-the-shelf’ analysis tools can interact with a database… import and export
- Most tools have a programming language for iterative analysis
- All UMTRI derived tools interface directly with the database and video files for efficient/content rich analysis and review of events
Laptop Demonstration

- Live demonstration showing the evolution of SQL queries to find exciting events of braking for slowing vehicles...includes the UMTRI viewer.
Access to Field Operational Test Data and Future Uses

Dave LeBlanc / Jim Sayer
UMTRI
Sharing IVBSS FOT Data

**Goals:**
- Accelerate successful deployment of crash avoidance technologies
  - Light vehicle
  - Heavy vehicle
- Maintain the data archive
  - No support funding is in place - costs of data upkeep are shared by UMTRI & outside investigators

**Constraints:**
- Protecting rights & privacy of test participants
- Protecting commercial interests of industry partners
- Existing research interests
Focus of Discussion

- **Today:** Addressing themes of IVBSS research:
  - Crash warning technologies
  - Driver interaction and adaptations to technology
  - Driver acceptance
  - Generic vehicle-based performance capabilities and limitations

- **Not today:** Other research themes being pursued with this & other data sets
### Application of FOT Data Sets to Subsequent Research: Partners

#### Industry Partners
- GM
- Ford & Volvo Car
- Honda
- Nissan
- Delphi
- Eaton
- Bosch

#### Gov’t/Research Groups
- US DOT
- US DOE
- US Army
- National Academy of Sciences/TRB
- Alzheimer's Ass’n
- SAIC/VTTI
- U. Iowa
- U. Minnesota
- Penn State Univ.
- Iowa State
- George Marshall Univ.
- Chemnitz Inst. of Technology
Data Resources

- IVBSS FOT data
- Four other FOT data sets
- Roadway network data sets
- Weather data
- Crash data – UMTRI Transportation Data Center
- Other data sets can be brought in for specific purposes
Examples*: Simple Access to Data

- Driver lane-keeping data samples
  - Delivered or remote access
- Driver head motion during lane changes
  - Video review by outside or UMTRI staff, remote or on-site
- Frequency and kinematics of lead vehicle turning scenarios (potential false alerts)
- Age differences in driving performance
- Correlating travel patterns & conflict frequency

* Actual and hypothetical examples included
Examples: Fusing Roadway Data

- Speeding (relative to posted speed) and lane change behavior
- Driving behavior at signalized intersections
- Urban driving behavior vs. suburban
- Lateral acceleration on freeway ramps
Examples: Research-Level Use of Data

- V2V: Estimates of possible reduction in unwanted alerts due to V2V information
- Driver acceptance as a function of alert experience and demographics
- Driver style classification and alert design
UMTRI Work Tasks

Naturalistic data-related collaborations often involve:

- ‘Standard’ data processing and packaging tasks
- Customized data work
- Fusing other data sets
- Research collaboration-level work
Process:
Match the Problem and the Data

- Investigator discusses specific interest with UMTRI. For technical issues:
  - Data dictionary is shared & nature of the data products discussed
  - Sample data may be shared
  - Video/numerical data is sometimes reviewed
  - Investigators often discover new possibilities for addressing their issues
    - Data richness (data fusion),
    - Ability to isolate (querying),
    - Statistical techniques.
Process: Identify Deliverables & Tasks

- Identify data products, data access, and tools
  - Data products: raw data, pointers into data, smoothed data, fused data, aggregated data, video possibly with overlays
  - Access to data: delivered to investigator, remote access, on-site access
  - Tools to be provided and/or developed (e.g., viewing/coding video)
- UMTRI work and/or research tasks are identified
Process: Contractual/IP

- Nondisclosure agreements for early conversations, if investigator prefers
- Agreement type usually depends on the nature of the technical work
  - P.O.
  - Research agreement,
  - Research agreement with restricted rights
- All the above include a data sharing agreement addressing the investigator’s access & use of data:
  - Limited time, for specific research purpose, and with a limited number of people
  - Data security (sometimes)
Process: Protecting Individual Identities

- Sometimes investigator gains access to data that allows individual participants to be identified
  - Driver face video
  - GPS coordinates for a set of complete trips (allows residence to be identified)

- If so:
  - Another agreement with UMTRI is usually required, restricting access within the organization
  - Investigator may need approval from a certified board for IRB

- These issues are often avoided by ‘de-identifying’ the data
Process: Protect IVBSS industry partners

- Commercial interests of partners
  - Minimize an outside investigators' ability to observe sensitive information about details of sensor capability, algorithmic approaches, or calibration values.

- Techniques include:
  - Smoothing of signals
  - Non-random sampling of episodes to mask sensitive details of performance
  - Avoiding coupling of algorithm inputs & outputs

- Any techniques used are discussed with potential investigator.
Contacts

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  - (734) 936-1063

- Jim Sayer
  - jimsayer@umich.edu
  - (734) 764-4159