Vehicle Safety Communications 3

Mercedes-Benz
Research & Development North America, Inc.

GM

TOYOTA

HONDA
Honda R&D Americas

Ford

NISSAN

HYUNDAI·KIA MOTORS
Hyundai·Kia America Technical Center, Inc.

VOLKSWAGEN

GROUP OF AMERICA

Intelligent Transportation Systems

Connected Vehicle

V2V Safety Systems Performance

25 Sep 2012
V2V Safety Framework

Maturing the V2V Research
- Initial Crash Problems
- Performance Measures
- Testing Procedures
- Interoperability Requirements
- Initial Security Models
- Driver Vehicle Interface Guidance

Model Deployment
- Benefits Framework
- Driver Clinics
- Performance Testing
- Model Deployment
- Experimental Design

Evaluation
- Evaluation Plan
- Data
- Conduct Evaluation
- Run Simulations

Supporting Policy Elements
- Implementation
- Technical
- Legal

Moving Towards a Decision
- Safety Benefits
- Performance Requirements
- Test Procedures
- Driver Acceptance

Moving Towards an Operation Model
Data Collection
Data Evaluation & Analysis
Establishing an Operational Environment
Results
Systems Performance Testing

Overview
Main Testing Concept

- **Motivation:** Collaborative System Requirements
  - Stakeholder Consensus
  - Some Minimum Performance To be Required (transmitter)

- **Scope:**
  - Assess performance and reliability
    - 5.9 GHz DSRC communications
    - GPS-based positioning
  - Diverse geographic locations
  - Environmental Conditions
Important Subsystems To Evaluate

- **Positioning**
  - Based on Global Navigation Satellite Systems (GNSS)
    - assisted by integrated sensors (vehicle bus)
      - wheel speed only in integrated vehicles
  - Relative Positioning Performance for V2V
    - absolute performance needed for V2I and performance guarantees

- **Communications**
  - DSRC
    - Range and Link Quality (Power, Antenna, Line-of-Sight)
    - (Network Scalability)

- **Applications**
  - Pre-competitive implementations help shape protocols
Previous System-Level Tests (2009)

1. Absolute Positioning Performance Evaluation

<table>
<thead>
<tr>
<th>Category</th>
<th>Time collected</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Urban</td>
<td>1:39:54</td>
<td>3.7%</td>
</tr>
<tr>
<td>Major Urban Thruway</td>
<td>9:50:03</td>
<td>21.8%</td>
</tr>
<tr>
<td>Major Rural Thruway</td>
<td>8:40:09</td>
<td>19.2%</td>
</tr>
<tr>
<td>Major Road</td>
<td>8:10:40</td>
<td>18.1%</td>
</tr>
<tr>
<td>Local Road</td>
<td>6:30:48</td>
<td>14.4%</td>
</tr>
<tr>
<td>Interstate/Freeway</td>
<td>9:04:51</td>
<td>20.1%</td>
</tr>
<tr>
<td>Mountains</td>
<td>1:08:32</td>
<td>2.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45:04:57</strong></td>
<td></td>
</tr>
</tbody>
</table>

2. Real-Time Kinematic (RTK) Navigation
   i. More over-the-air information (pseudoranges)
   ii. Accuracy comparable to non-RTK transmissions for some correction-enabled receivers (WAAS)

3. Cross-channel interference Evaluation

4. Range, Power, Packet Error Rate Evaluation
**Testing during DACs - Overview**

**Types of tests:**

1. **Open-road testing**
   - 8 hrs, 8 vehicles
   - 6 locations

2. **Targeted testing** challenging locations

3. **Closed-road testing** closed track - refined warning timing
   (Intersection Movement Assist, Do-not-pass Warning)

**Performance Metrics**

1. **Positioning** fix quality and availability, positioning errors
2. **Communications** error rates, signal strength, packet gap
3. **Application-level** target lane classification
## Locations 1-6: Trip Overview Totals

### Approximate Totals Per Vehicle Per Group

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>PLANNED TIME</th>
<th>TIME COLLECTED</th>
<th>TIME (%)</th>
<th>DISTANCE (MILES)</th>
<th>DISTANCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Urban</td>
<td>1:39:54</td>
<td>2:02:34</td>
<td>3.76%</td>
<td>30.56</td>
<td>1.17%</td>
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<tr>
<td>Major Rural Thruway</td>
<td>9:50:03</td>
<td>14:28:07</td>
<td>26.63%</td>
<td>826.83</td>
<td>31.68%</td>
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<tr>
<td>Major Urban Thruway</td>
<td>8:40:09</td>
<td>8:16:24</td>
<td>15.23%</td>
<td>419.22</td>
<td>16.06%</td>
</tr>
<tr>
<td>Major Road</td>
<td>8:10:40</td>
<td>9:24:31</td>
<td>17.31%</td>
<td>308.80</td>
<td>11.83%</td>
</tr>
<tr>
<td>Local Road</td>
<td>6:30:48</td>
<td>6:36:01</td>
<td>12.15%</td>
<td>152.93</td>
<td>5.86%</td>
</tr>
<tr>
<td>Interstate/Freeway</td>
<td>9:04:51</td>
<td>8:18:10</td>
<td>15.28%</td>
<td>597.84</td>
<td>22.91%</td>
</tr>
<tr>
<td>Mountains</td>
<td>1:08:32</td>
<td>5:14:33</td>
<td>9.65%</td>
<td>273.69</td>
<td>10.49%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>45:04:57</strong></td>
<td><strong>54:20:20</strong></td>
<td><strong>100.00%</strong></td>
<td><strong>2609.85</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

### Group A

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>PLANNED TIME</th>
<th>TIME COLLECTED</th>
<th>TIME (%)</th>
<th>DISTANCE (MILES)</th>
<th>DISTANCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Urban</td>
<td>1:39:54</td>
<td>1:39:30</td>
<td>3.14%</td>
<td>19.18</td>
<td>0.85%</td>
</tr>
<tr>
<td>Major Rural Thruway</td>
<td>9:50:03</td>
<td>13:14:32</td>
<td>25.05%</td>
<td>739.01</td>
<td>32.84%</td>
</tr>
<tr>
<td>Major Urban Thruway</td>
<td>8:40:09</td>
<td>9:16:49</td>
<td>17.56%</td>
<td>399.69</td>
<td>17.76%</td>
</tr>
<tr>
<td>Major Road</td>
<td>8:10:40</td>
<td>7:54:05</td>
<td>14.95%</td>
<td>189.75</td>
<td>8.43%</td>
</tr>
<tr>
<td>Local Road</td>
<td>6:30:48</td>
<td>5:50:18</td>
<td>11.05%</td>
<td>63.70</td>
<td>2.83%</td>
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<tr>
<td>Interstate/Freeway</td>
<td>9:04:51</td>
<td>9:41:42</td>
<td>18.34%</td>
<td>565.54</td>
<td>25.13%</td>
</tr>
<tr>
<td>Mountains</td>
<td>1:08:32</td>
<td>5:14:33</td>
<td>9.92%</td>
<td>273.69</td>
<td>12.16%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>45:04:57</strong></td>
<td><strong>52:51:29</strong></td>
<td><strong>100.00%</strong></td>
<td><strong>2250.55</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

*Distribution similar to Average driven*
Communications Performance
Open Road Communications Conditions and Metrics

Testing Conditions

- Line-of-sight obstructions
- Weather

Metrics

- Received Power
- Packet Error Rate
- Inter-arrival times (Inter-Packet Gap)
- Evaluate across various inter-vehicle distances
### Range Statistics
*(used for Communications Performance)*

<table>
<thead>
<tr>
<th>Environment</th>
<th>Total Samples per Range Bin per Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Urban</td>
<td></td>
</tr>
<tr>
<td>Major Rural Thruway</td>
<td></td>
</tr>
<tr>
<td>Major Urban Thruway</td>
<td></td>
</tr>
<tr>
<td>Major Road</td>
<td></td>
</tr>
<tr>
<td>Local Road</td>
<td></td>
</tr>
<tr>
<td>Interstate/Freeway</td>
<td></td>
</tr>
<tr>
<td>Mountains</td>
<td></td>
</tr>
</tbody>
</table>

#### Number of samples collected within given range

- $10^7$
- $10^6$
- $10^5$
- $10^4$
- $10^3$
- $10^2$

**Inter-vehicle distance where samples was collected**

(Data from All the Clinics, all vehicle pairs/links)
Communications Performance
(Mean Packet Error Rate overall)
Communications Performance
(Mean Packet Error Rate per environment)
Communications Performance (Inter-packet-gap @10Hz / overall)
Open Road Positioning Conditions and Metrics

Testing Conditions
1. Environments affecting signal reception:

![Environments](image)

2. Geographical, seasonal, and time-of-day variety

![Weather](image)

Metrics
- Positioning Fix *availability* and constellation use
- Signal *reliability* and relative positioning *accuracy*

Five (5) different GPS receivers giving numerous combinations
Positioning Equipment Configuration

Standard Clinics Configuration

- Antenna (Signal Split)
- GPS 1 (main)
- Wireless Radio & Applications Box

Additional Test Vehicle Equipment

- GPS 2
- GPS 3
- Data Acquisition System (DAS)
# Positioning Fix Availability

Data from All the Clinics, all vehicles,  
*Rounded to nearest 1%*

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Deep Urban</th>
<th>All Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>† SG₁</td>
<td>77</td>
<td>97</td>
</tr>
<tr>
<td>† SG₀</td>
<td>82</td>
<td>99</td>
</tr>
<tr>
<td>† SG₂</td>
<td>94</td>
<td>88</td>
</tr>
<tr>
<td>*AG₃</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>*AG₂</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>*AG₁</td>
<td>98</td>
<td>100</td>
</tr>
</tbody>
</table>

† **Survey-Grade (SG)** receivers designed for *high SNR, selectivity, SG₂ better at lower speeds*

* **Automotive-Grade (AG)** receivers designed for *high availability in challenging environments*
Single Vehicle Position Discrepancy when reported by 2 GPS units

Portion of available solutions

Receiver Discrepancies:
- Across Error
- Ahead (Along) Error
- Range (2D) Error

Half Lane Width

Discrepancy between Receivers on Absolute Vehicle Position
Ublox (Reference GPS) vs. Novatel in Deep Urban Environment

AG₁ - SG₀
(Deep Urban)

AG₁ - AG₂
(Local Road)

AG₁ - SG₀
(Major Rural Thruway)
### Single Vehicle Position Discrepancy when reported by 2 GPS units†

**% of time** \(\text{AG}_1\) **is within 1.8m (Across Path):**

<table>
<thead>
<tr>
<th>Rcv/Env</th>
<th>Deep Urban</th>
<th>Mountain</th>
<th>Major Urban Thruway</th>
<th>Interstate Freeway</th>
<th>Major Road</th>
<th>Local Road</th>
<th>Major Rural Thruway</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{AG}_3)</td>
<td>41</td>
<td>61</td>
<td>61</td>
<td>71</td>
<td>52</td>
<td>46</td>
<td>64</td>
</tr>
<tr>
<td>(\text{AG}_2)</td>
<td>56</td>
<td>70</td>
<td>81</td>
<td>76</td>
<td>81</td>
<td>81</td>
<td>86</td>
</tr>
<tr>
<td>(\text{AG}_2)</td>
<td>44</td>
<td>72</td>
<td>82</td>
<td>90</td>
<td>87</td>
<td>81</td>
<td>87</td>
</tr>
<tr>
<td>(\text{SG}_1)</td>
<td>67</td>
<td>79</td>
<td>84</td>
<td>81</td>
<td>84</td>
<td>88</td>
<td>91</td>
</tr>
<tr>
<td>(\text{SG}_3^*)</td>
<td>64</td>
<td>-</td>
<td>83</td>
<td>61</td>
<td>91</td>
<td>92</td>
<td>91</td>
</tr>
<tr>
<td>(\text{SG}_0)</td>
<td>74</td>
<td>87</td>
<td>95</td>
<td>97</td>
<td>96</td>
<td>91</td>
<td>96</td>
</tr>
</tbody>
</table>

**% of time** \(\text{AG}_1\) **is within 5m (Across Path):**

<table>
<thead>
<tr>
<th>Rcv/Env</th>
<th>Deep Urban</th>
<th>Mountain</th>
<th>Major Urban Thruway</th>
<th>Interstate Freeway</th>
<th>Major Road</th>
<th>Local Road</th>
<th>Major Rural Thruway</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{AG}_3)</td>
<td>81</td>
<td>95</td>
<td>96</td>
<td>99</td>
<td>98</td>
<td>90</td>
<td>99</td>
</tr>
<tr>
<td>(\text{AG}_2)</td>
<td>79</td>
<td>96</td>
<td>98</td>
<td>98</td>
<td>98</td>
<td>97</td>
<td>99</td>
</tr>
<tr>
<td>(\text{AG}_2)</td>
<td>80</td>
<td>97</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>(\text{SG}_1)</td>
<td>83</td>
<td>99</td>
<td>98</td>
<td>99</td>
<td>99</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>(\text{SG}_3^*)</td>
<td>88</td>
<td>-</td>
<td>99</td>
<td>98</td>
<td>99</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>(\text{SG}_0)</td>
<td>92</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>99</td>
<td>100</td>
</tr>
</tbody>
</table>

† Rounded to 1%

* \(\text{SG}_3^*\) Only used in 1st Clinic
Applications Performance

Lane classification of leading vehicles in each group.
SG₀-SG₀ Target Classification

SG₀ Connected - Distribution of Target Classifications

Legend

A  Ahead
A-L  Ahead Left
A-R  Ahead Right
A-F-L  Ahead Far Left
A-F-R  Ahead Far Right
UC  Unclassified

% samples of target classification output

Unexpected classifications lasted one sample, 100ms (as part of total time)

% samples of target classification output

Unexpected classifications lasted 2-to-5 samples (200-500ms).

Criteria for Data:
GPS valid
Above 5mph
No Left/Right turn sig.
**AG₁-AG₁ Target Classification**

% samples of target classification output

---

**AG1 Connected - Distribution of Target Classifications**

- **Deep Urban**: Total Classifications = 54573
- **Major Rural Thruway**: Total Classifications = 522016
- **Major Urban Thruway**: Total Classifications = 347873
- **Major Road**: Total Classifications = 384721
- **Local Road**: Total Classifications = 357860
- **Interstate/Freeway**: Total Classifications = 726357
- **Mountains**: Total Classifications = 472522

---

**Unexpected classifications lasted one sample, 100ms (as part of total time)**

% of Total Target Classifications vs. Consecutive Unexpected Classifications

Unwanted classifications lasted 2-to-5 samples (200-500ms).

% samples of target classification output
Conclusions

1. **Positioning & Application** performance
   - Lane-level target classification in most environments
   - Road-level achievable in all environments
   - Deep urban most challenging

2. **Communications** performance
   - Very reliable

Upcoming Work

1. **Positioning** performance
   - Improvement of relative positioning performance
   - Relate to absolute performance

2. **Communications** performance
   - Evaluate network scalability / congested environment performance