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Connected Vehicle Program Manager FHWA (HRT-01)

Development of Vehicle-to-Infrastructure Safety Applications in the United States
The U.S. Department of Transportation ITS Strategic Plan 2010-2014 established an objective to:

“Develop V2I active safety applications that address some of the most critical crash scenarios, particularly using the signal phase and timing (SPaT) capability.”

The Progress Update 2012 reaffirmed the goal of selecting, developing and evaluating V2I Safety Applications
Background

- Report FHWA-HRT-11-040: Provided an analysis of possible impact of potential V2I safety applications
- USDOT and State DOT representatives prioritized a list of V2I safety applications for further development
- A systems engineering process was used to develop Concepts of Operation, Systems Requirements, and Performance Requirements for potential applications
Background

• The Federal Highway Administration awarded a Cooperative Agreement to the Crash Avoidance Metrics Partners, LLC (CAMP) to:

  Provide a basis for CAMP and various Automotive Original Equipment Manufacturers (OEMs) and suppliers to work cooperatively on pre-competitive projects to develop crash avoidance and driver information applications

• The CAMP V2I Consortium consists of 10 Automotive OEMs: FCA, Ford, GM, Honda, Hyundai-Kia, Mazda, Nissan, Subaru, Volvo Truck, and VW/Audi
Background

- System requirements were developed for following five applications:
  - Stop Sign Gap Assist (SSGA):
    - Warn in case of potential hazard at non-signalized intersections
  - Red Light Violation Warning (RLVW)
    - Warn in case of potential red light violation
  - Curve Speed Warning (CSW)
    - Warn in case of over speeding on a curve
  - Reduced Speed Zone Warning / Lane Closure (RSZW/LC)
    - Provide warnings when warranted in work zones
  - Spot Weather Information Warning (SWIW)
    - Provide advisories of unsafe conditions due to inclement weather at specific location on the roadway
Assessment of Safety Applications

- Conducted technical assessment of prioritized list of safety applications
- Three were chosen for development and testing

<table>
<thead>
<tr>
<th>Safety Applications Technical Assessment</th>
<th>Intersection</th>
<th>Speed</th>
<th>Traffic Anomalies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop Sign Gap Assist (SSGA)</td>
<td></td>
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<td>Red Light Violation Warning (RLVW)</td>
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<tr>
<td>Reduced Speed Zone / Lane Closure Warning (RSZWL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spot Weather Information Warning</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Application Development Attributes

- Need for Infrastructure Component
  - No
- Cost of Development, Setup & Maintenance
  - High
- Additional Benefits to the Drivers
  - Low
- Scalability and Deployability
  - Low

<table>
<thead>
<tr>
<th>Application Development Attributes</th>
<th>Intersection</th>
<th>Speed</th>
<th>Traffic Anomalies</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>High</td>
<td>Low/Med</td>
<td>Low</td>
<td>Low/Med</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Project Development & Testing Impact

- Vehicle Component
  - Low
- Infrastructure Component
  - High

<table>
<thead>
<tr>
<th>Project Development &amp; Testing Impact</th>
<th>Intersection</th>
<th>Speed</th>
<th>Traffic Anomalies</th>
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<tr>
<td>Vehicle Component</td>
<td>Low</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Infrastructure Component</td>
<td>High</td>
<td>Low/Med</td>
<td>Low/Med</td>
</tr>
</tbody>
</table>
Information Exchange Between Infrastructure Subsystem and Vehicle

An RSU at a signalized intersection interfaces with:

- a traffic signal controller
- a DGPS/RTCM correction base station
In-vehicle System Architecture

DSRC/GPS Antenna

GPS Data

On Board Equipment (OBE)

SA Processing Unit

Vehicle Data

SA Processing Unit

eGUI

Data Logging

Safety Applications

API

DSRC Wireless Services

OS / Device Drivers

API – Application Programming Interface

eGUI – Engineering Graphical User Interface

OS – Operating System
OTA Message Development

- Basic Information Message (BIM) was designed to support CSW and RSZW/LC
- Message structure is based on the European Telecommunications Standards Institute (ETSI) standard for the Decentralized Environmental Notification Message (DENM)
Safety Application Algorithm Flow

- Relevance of surrounding zones based on host vehicle (HV) approach for determining the relevant event

- Use map information from the RSU to determine if the vehicle is approaching the event

- Application-specific threat assessment algorithm to determine the appropriate warning level

- Event specific Inform / Warning messages for output to the vehicle DVI
Overview of Developed Safety Applications

- **RLVW** warns the driver of a potential to run a red light
- **CSW** informs the driver of an approaching curve and warns when the speed is too high
- **RSZW/LC** informs the driver of an approaching lane closure and/or speeding in a work zone
Seven OEMs Built Test Vehicles

- GM – Buick LaCrosse
- Honda – Acura RLX
- Hyundai-Kia K-900
- Nissan – Infiniti M37
- Subaru Legacy
- Volvo Truck VNL 670S
- VW / Audi Audi A4

All 7 vehicles implemented all 3 applications
RLVW Test Scenarios

- Tested 10 scenarios on 2- and 4-lane intersections
### CSW Test Scenarios

- Tested 6 scenarios at various approach speeds, road surface conditions, and curve geometries

<table>
<thead>
<tr>
<th>Test #</th>
<th>Approach Speed [mph]*</th>
<th>Curve Radius [m]</th>
<th>Surface Condition</th>
<th>Bank Angle</th>
<th>Test Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55 / 40</td>
<td>100</td>
<td>Dry</td>
<td>5</td>
<td>Basic functionality</td>
</tr>
<tr>
<td>2</td>
<td>35 / 20</td>
<td>100</td>
<td>Dry</td>
<td>5</td>
<td>Slow speed, no warnings</td>
</tr>
<tr>
<td>3</td>
<td>55 / 35</td>
<td>100</td>
<td>Icy</td>
<td>5</td>
<td>Icy road, earlier warnings</td>
</tr>
<tr>
<td>4</td>
<td>55 / 40</td>
<td>100</td>
<td>Dry</td>
<td>5</td>
<td>Reduced visibility</td>
</tr>
<tr>
<td>5</td>
<td>40 / 40</td>
<td>100 =&gt; 50</td>
<td>Dry</td>
<td>5</td>
<td>Two radii curve</td>
</tr>
<tr>
<td>6</td>
<td>40 / 40</td>
<td>100 =&gt; 50</td>
<td>Icy</td>
<td>5</td>
<td>Icy road, earlier warnings</td>
</tr>
</tbody>
</table>

* Approach Speed: Approach Speed / Curve Radius
RSZW/LC Test Scenarios

- Tested 6 scenarios for multiple lane closures and presence of workers at two approach speeds

### Layout for 70mph Approach Speed

<table>
<thead>
<tr>
<th>Lane 1</th>
<th>720m</th>
<th>Lane Closure 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 3</td>
<td>0-2mph</td>
<td>Inform (110m, ~10s)</td>
</tr>
</tbody>
</table>

225 60 250 60 125 20 90 60 125 20 170

- Reference Point: Start of work zone
- Warning for LC2

### Layout for 45mph Approach Speed

<table>
<thead>
<tr>
<th>Lane 1</th>
<th>420m</th>
<th>Lane Closure 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 3</td>
<td>0-45 (120m, ~3s)</td>
<td>Inform (160m, ~6s)</td>
</tr>
</tbody>
</table>

100 40 120 40 100 20 110 40 100 20 170

14-Oct-2016
Safety Application Testing

- Conducted over 20 distinct scenarios and more than 100 test runs

RLVW Setup

CSW Test Run

Volvo Truck

RSZW/LC Test Runs

Passenger Car
Test Results and Lessons Learned

RLVW:
- Address map matching based on vehicle turn signal indicator and signal phase association for lanes with multiple movements

CSW:
- Adjust warning when the vehicle speed is slightly above the computed $V_{max}$
- Additional information is needed to assure approach leads to the curve
- For truck, data analyses verified the need for warnings based on stability criteria along with the stability evaluation

RSZW/LC:
- For proper map matching, first map data point for approach lane and work zone lane should be placed close to each other
- Need a data element that links an approach lane to a work zone lane
Future Activities

• Further refine and enhance safety applications
• For RLVW, conduct a feasibility study to incorporate actuated and coordinated traffic signals
• For CSW, conduct further testing on public roads to measure application performance on single- and multiple-radii including s-curves
• For RSZW/LC, test and evaluate the application in live work zones of varying complexities
For further information:

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