V2I Safety Application Development Program
Tasks 13, 14 & 15 Final Briefing
October 30, 2019
Acknowledgement and Disclaimer

This material is based upon work supported by the U.S. Department of Transportation under Cooperative Agreement No. DTFH6114H00002. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the Author(s) and do not necessarily reflect the view of the U.S. Department of Transportation.
Agenda

- Safety Application Project Extension #2
  - Task 13: Adaptation of RSZW/LC in TxDOT I-35 Construction
  - Task 14: Work Zone Mapping
  - Task 15: SPaT/RLVW Intersection Verification
## Timeline of Completed V2I SA Project Tasks

Tasks 2 through 12 – Final report submitted to FHWA on July 27, 2017

<table>
<thead>
<tr>
<th>Task</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>Safety Applications Extension #2 Tasks</th>
<th>Task Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adaptation of RSZW/LC in TxDOT I-35 Construction - COMPLETED</td>
<td></td>
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</tbody>
</table>

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V2I SA Project Tasks and Timeline

- Task 1: Technical Project Management
- Task 2: Coordination with Stakeholders
- Task 3: SA Technical Assessment
- Task 4: Develop Criteria for V2I-SA Selection
- Task 5: Application Development Plan
- Task 6: Application Development
- Task 7: Vehicle Build
- Task 8: Infrastructure Build
- Task 9: Testing
- Task 10: Map Support

- Developed V2I Safety Applications
  - Red Light Violation Warning (RLVW)
  - Curve Speed Warning (CSW)
  - Reduced Speed Zone Warning with Lane Closures (RSZW/LC)
V2I SA Project Tasks and Timeline

• SA Project Extension – 1
  – Task 11: Feasibility Study-Actuated Signal
  – Task 12: On-road Testing

• Final Report for Tasks 1 – 12 submitted to FHWA on July 27, 2017

• SA Project Extension – 2
  – Task 13: Connected Work Zone Deployment Guideline (Internal report to FHWA June 6, 2019)
  – Task 15: SPaT/MAP Verification for RLVW (Internal report to FHWA Dec. 15, 2017)
Task 13
Adaptation of RSZW/LC in TxDOT I-35 Corridor Construction Project
I-35 Connected Work Zone

FHWA Final Briefing Update

October 30, 2019

In cooperation with:
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  Jianming Ma, Ph.D., P.E. (TxDOT)
**GOAL**

Deploy and test the Reduced Speed Zone Warning / Lane Closure (RSZW/LC) application

- on Real-world work zone situations
- on Interstate 35
High-level Objectives to Get to Goal

*Establish methodologies to create, deliver, and test work zone information to connected vehicles*

1. Utilize CAMP software base
2. Utilize existing I-35 lane closure information
3. Utilize high-fidelity and low-fidelity pathways
4. Operate RSZW/LC application / collect data / analyze
5. Provide real-world application deployment experience input for CAMP guidance document
I-35 Connected Work Zone

- Work Zone Ahead
- Slow Down To 55 mph
- Right Lane Closed Ahead
- Lane Ends Merge Left

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Challenges

Equipment assemblies are not off-the-shelf and requires specialized knowledge and parts

Leading manufacturers and developers in this space are still shaking out

Disparity in support, standards implementation, capabilities, ease of use, etc.

Software solutions are developing and are not transferrable across equipment

Different information levels (available vs. desired) exist
The Path Forward

- Set of Work Zone Information
- Deployment and Data Collection
- High-Fidelity
- Low-Fidelity
- Input to National Guidance
Deployed and tested the Reduced Speed Zone Warning / Lane Closure (RSZW/LC) mapping and application from CAMP

1. Test work zone mapping application
2. Lonestar™ connected vehicle module
3. Integrate I-35 lane closure information
4. Built connected work zone (RSU deployment)
5. Built reference vehicle(s)
6. Conducted CWZ (using reference vehicle)
7. Operations via Lonestar™
8. Conducted test of high-fidelity RSZW/LC application
9. Developed deployment guidelines
## Field Test

### RSU Deployment
- 9 RSUs
- 8 miles of I-35 in Temple
- ~1 mile spacing

### Closure Scenarios
- Single closure
  - Multiple lanes
- Multiple closures
  - Alternate lanes
  - Same lane

### RSU Deployment
- Mapping
- High fidelity CAMP OBU Application
- Low-fidelity SwRI application

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*Source: Map image from Google. Used with permission. Plotted data from Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium October 30, 2019*

*CAMP – Vehicle-to-Infrastructure (V2I) Consortium Proprietary
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High-Fidelity Mapped Work Zone on I-35
Findings and Lessons Learned
The Need for Linkages

Task 13

Contractor coordination for lane closure data
- Appropriate detail
- In advance
- Procedures for emergency situations

Integrate work zone mapping and closures
- Work zone mapping not yet commonplace
- Correlations of data are not automatic

Multiple systems / endpoints within the IOO
- Traveler information
- ITS
- TMC operations

IOO to roadway
- Vehicles
- Infrastructure

CAMP To IOOs
- Guidance
Two-Tiered Solution

**High-fidelity scenario**
- Detailed lane-level mapping of the roadway and work zone is possible
- Reference point (beginning of lane closure taper) can be accurately defined
- Full information load for RSZW/LC application is supported

**Low-fidelity scenario**
- Less detailed mapping of the roadway and work zone
- Reference point is estimated
- Reduced information load for RSZW/LC application is supported
<table>
<thead>
<tr>
<th>Location</th>
<th>Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Work zone setup differs by state/region</td>
</tr>
<tr>
<td></td>
<td>Overall, mapping and applications work</td>
</tr>
<tr>
<td></td>
<td>Hardware suffers from inconsistency, specialized knowledge, and lack of standardization</td>
</tr>
<tr>
<td></td>
<td>Integration of lane closure information in a systemic fashion is in early stages</td>
</tr>
<tr>
<td></td>
<td>Required linkages with multi-agencies can be complex</td>
</tr>
<tr>
<td></td>
<td>IOO’s will have to chart an appropriate path and fidelity level</td>
</tr>
</tbody>
</table>
Potential Lab-to-Market Research Areas

• **Field Hardware Maturity, Lack of Adherence to Standards**
  – Hardware utilized in the field deployment for testing suffered from lack of maturity
  – Lack of adherence to standards vary widely between vendors of the same equipment type
    • No support for broadcasting multiple messages from RSU at a specified time interval
  – Lack of uniform easy-to-setup process for field equipment.
    • Setup process varies significantly from one vendor to another and differ from one version to another within the same vendor

• **WZ Mapping Requirements**
  – Spatial and temporal mapping requirements for high- med- low-resolution work zone maps to support
    • Different levels of fidelity
    • Quick changes to WZ map as the configuration changes
  – Consistent techniques for managing infrastructure information for:
    • Local vs backend approaches to managing data
    • Integration with other traveler information systems
      • 511 systems
      • DMS consistency
    • Manage set up / take down transitions
  – Guidelines for intended in-vehicle information / alert for drivers
Potential Lab-to-Market Research Areas

• Support GPS Enabled Barrels/Arrow Board for Lane Closures
  – Need for availability of lane closure information
    • The standardization of work zone information elements required to support the CWZ applications for broad-scale application
  – Develop uniform and consistent method to access location from GPS enabled barrels / cones / arrow boards
    • Integrate into work zone mapping
    • Integrate into Work Zone Data Initiative (WZDi)

• RSU Placement in Field
  – Establish guidelines for placement of RSUs in field for maximum signal coverage
    • Height and orientation of antenna for maximum coverage
    • Antenna requirements and potential signal interferences and obstructions in field
Task 14

Work Zone Mapping
Work Zone Mapping

Scope:
• Develop an effective dynamic mapping technique to rapidly generate work zone map for the RSZW/LC application
• Evaluate efficacy of the technique in live work zones

Outcomes:
• WZ Mapping using a reference vehicle equipped with:
  – Suitable positioning and recording capabilities
  – OBU and an on-board processing unit (Laptop) for transmitted work zone message verification
• WZ mapping and message builder “software tool chain:”
  – Rapidly construct work zone map with work zone relevant data for RSZW/LC application
  – RSZW/LC application verification
• Make the “software tool chain” and required components for building the map as part of “tool chain” available to IOOs
Infrastructure Map for CV Applications

- Map convey many types of geographical data of the roadway
- Three levels of “Map” (region) information needed:
  - Low fidelity: only a region
    - Ex. Hurricane evacuation
  - Medium fidelity: limited road level
    - Ex. Road closures due to flooding
  - High fidelity: lane level details
    - Lane closure(s)
    - Speed limit change(s)
    - Workers present
    - ...

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October 30, 2019
What We Need

- Proper and accurate infrastructure maps are crucial for the desired functioning of many V2I applications
- The ability to easily generate, validate and transmit accurate high-fidelity lane-level digital maps
- Wide-scale implementation using consistent mapping technology
  - to easily produce digital maps in standard format
  - for stable and dynamically changing road environment at a lane level
  - which is beneficial for both vehicle manufacturer and infrastructure owner operators (IOO)
Mapping for Connected Work Zone Applications

For a work zone:

– Lane geometry represented by node points that describe:
  
  • Start of work zone
  • Layout of each lane
    – Lane closure location(s) – Start and end of tapers
    – Workers presence zones(s) – area(s) where the workers are present
  • Posted speed limit(s)
Equidistance Node Points

- Map can be generated by:
  - Conducting survey
    - costly and time consuming
  - Selecting node points on a map
    - manual process can be less accurate and error prone
  - Convert to specified format in a standard
- In-vehicle map matching
  - Creates a virtual bounding box equal to the lane width and two consecutive node points of the lane geometry to determine vehicle lane
  - Placement of node points for lane geometry has direct implications on the performance of the vehicle lane determination
Software Toolchain for Work Zone Mapping and Message Building

RSU Agnostic Software Toolchain

Vehicle Path Data Collection → Vehicle Path Data → WZ Configuration → XML Visualizer → Map Visualizer → ASN.1 CV Message Builder

Road Side Unit (RSU) → IEEE Protocols → Work Zone Map Message Broadcast

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Steps for Building a Work Zone Map and Message for Transmission

1. Vehicle Path Data Acq.
2. Work Zone Configuration
3. Map Builder
4. Map Visualizer
5. Message Builder

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Plotted data from Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium.

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Software Toolchain Status

• Used by TxDOT with TTI for Connected Work Zone Project on I-35 corridor in Texas
• U. of Arizona (Larry Head)
  – Used for mapping CVISN* Freight Vehicle Work Zone Project
• FHWA Saxton Transportation Operations Laboratory (STOL)
  – For integrating into a larger map making tool
• VTTI for incorporating into WZ software for use in Virginia Connected Corridor (VCC)
• In the process of:
  – Developing clickable ‘free software’ license to download the toolchain from CAMP websites
  – Promoting broader IOO utilization and feedback on system deployment and mapping tools through IOO/OEM forum

CVISN - Commercial Vehicle Information Systems and Networks
Task 15
SPaT/RLVW Intersection Verification
Verification of SPaT/MAP for RLVW

Scope:

• Conduct verification of selected signalized intersections in SE Michigan to confirm DSRC messages (SAE J2735-201603) transmitted by the RSE will support the RLVW application
• Develop SPaT/MAP verification process and refine as needed based on SPaT Challenge

Outcome:

• Develop SPaT/MAP verification process document

Deliverable:

• Updated verification process document including satellite-based position correction as task interim report
Findings from Tested Intersections for RLVW

- SPaT and MAP messages contain different intersection IDs
  - Failed association between SPaT and MAP
- Incomplete MAP (map data) of an intersection
  - Map of only right 2 out of 4 SB lanes in the MAP message
- In some cases, intersection map contained absolute GPS coordinates and other offset from previous node for mapped node points
- Pedestrian cross walk phase and time used in SPaT for signal phase and time
  - Incorrect red phase time
  - Very high (random) \textit{minEndTime} in SPaT message until crosswalk button is pressed or “don’t walk” timer is activated
- Inconsistencies in time remaining in current phase in SPaT message for actuated signalized intersections
Steps for SPaT/MAP Verification

1. Get SPaT MIB object data from signal controller
2. Convert user input to vendor-specific configuration file (e.g., XML file)
3. Compare SPaT MIB objects from RSU
4. Compare: 1. User input and XML file 2. XML file and DSRC MAP message from RSU
5. Compare SPaT MIB objects from controller and DSRC SPaT Messages from RSU

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Satellite-based Positioning System Error and Techniques for Correction
Position Correction Study

• In addition to SPaT / MAP verification, FHWA suggested to include study for vehicle position correction for:
  – Do all intersections are required to equip with RTCM correction for RLVW application?
  – NYC pilot experienced significant position errors in urban canyon areas
  – Suggest recommendations
Need for Position Accuracy

• For the vehicle to accurately identify the approach and associate with signal phase using the MAP/SPaT message, it is critical that the location of the vehicle (determined by the on-board GPS) is within required accuracy.

• Satellites broadcast their signals in space with a certain accuracy, but what is received depends on additional factors.

• This can be accomplished by a broadcast of position correction information.
GNSS Systems

• “GNSS” (Global Navigation Satellite System) describes the collection of satellite positioning systems
  – GPS (United States)
  – Galileo (European Union)
  – QZSS (Japan)
  – GLONASS (Russia)
  – BeiDou (China)
  – IRNSS (India)

• GNSS satellite systems consist of three major components or “segments:”
  – space segment
  – control segment
  – user segment

Source: https://www.novatel.com
User Equivalent Range Error (UERE)

- Error **components** in the distance from a satellite to the receiver
  - Signal arrival time measurement
  - Atmospheric effects (changes slowly)
    - Ionosphere - affects speed of the signal as they pass through earth’s atmosphere
      - Effects are smaller when satellite is directly overhead and greater for satellites near horizon
    - Troposphere - humidity also causes a variable delay
      - Effects are localized and changes quickly
      - Atmospheric pressure - affects signal reception delay
  - Ephemeris and clock errors
  - Receiver Noise
  - Multipath
  - Geometric dilution of precision
    - Satellites have smaller angular separation (close together) in the sky – DOP value is high
    - Satellites have wider angular separation – DOP is low, better positional accuracy

<table>
<thead>
<tr>
<th>Contributing Source</th>
<th>Error Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Clocks</td>
<td>~ ± 2m</td>
</tr>
<tr>
<td>Orbit Errors</td>
<td>~ ± 2.5m</td>
</tr>
<tr>
<td>Ionospheric Delays</td>
<td>~ ± 5m</td>
</tr>
<tr>
<td>Tropospheric Delays</td>
<td>~ ± 0.5m</td>
</tr>
<tr>
<td>Receiver Noise</td>
<td>~ ± 0.3m</td>
</tr>
<tr>
<td>Multipath</td>
<td>~ ± 1m</td>
</tr>
</tbody>
</table>

Source: [http://www.gps.gov](http://www.gps.gov)
Resolving Errors

• Many techniques are used to resolve errors
  1. Averaging of repeated observations at the same location (the least efficient method)
  2. Modeling of the phenomenon that is causing the error and predicting the correction values
  3. Differential Corrections
• What is the ideal technique for error correction?
  – There really is no “best way,” it all depends on the positioning performance required for the application
• There are trade-offs between the different methods of removing errors
GNSS Measurement
Code Phase Vs. Carrier Phase

• Code-phase measurement
  – Compares the *pseudo random code* with an identical code in the signal from the satellite
  – A wide pseudo random code is used
  – Measurement can be off by 3 to 6 meters
  – Results in positioning accuracies of a few meters

• Carrier-phase measurement
  – a measure of the range between a satellite and receiver in units of cycles of the *carrier frequency*
  – Real-time Kinematic (RTK)
  – Precise Point Positioning (PPP)
Differential GNSS

- A commonly used code-based technique for improving GNSS performance
For applications where the rover stations are spread over a large area
Include reference stations, master stations, uplink stations and geosynchronous satellites
Corrections are uplinked to the satellite then broadcast to GNSS/GPS receivers
User equipment receives the corrections for range calculations

WAAS Positioning Accuracy
- 15 m: Typical GPS position accuracy without selective availability
- 3-5 m: Typical differential (DGPS) position accuracy
- < 3 m: Typical WAAS position accuracy
“RTK” Real-time Kinematic

• Carrier-phase ranging technique
  – More precise than code-phase positioning
  – The concept reduces and removes errors common to a base station and rover pair
  – Provides centimeter-level positioning

Source: https://www.novatel.com
“PPP” Precise Point Positioning

- Removes GNSS system errors to provide a high level of position accuracy
- Solution depends on GNSS satellite clock and orbit corrections generated from a network of global reference stations
  - Does not require base station
  - Corrections are delivered via satellite or over the Internet
  - A typical PPP solution requires time to converge to high accuracy in order to resolve any local biases
- Generally a fee to access base service from the providers

Source: https://www.novatel.com

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Which Correction Method?

A comparison of the accuracy and practical range of use for each of the method
## Comparison of Various Position Correction Techniques

<table>
<thead>
<tr>
<th></th>
<th>Base Station</th>
<th>Rover Station</th>
<th>Positioning Technique</th>
<th>Cost</th>
<th>Correction Source</th>
<th>Coverage</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGNSS</td>
<td>Receiver at known location</td>
<td>Requires one or more Constellations</td>
<td>Code-phase</td>
<td>Less expensive than RTK $</td>
<td>Receive correction from base station</td>
<td>~ 10s of Km</td>
<td>± 1m</td>
</tr>
<tr>
<td>SBAS</td>
<td>Reference station and Master station</td>
<td>User: SBAS capable receiver and a GNSS antenna</td>
<td>Code-phase</td>
<td>Free</td>
<td>Receive corrections from satellites.</td>
<td>Wide area or regional augmentation</td>
<td>± 2m</td>
</tr>
</tbody>
</table>
| PPP    | Network of global reference stations | User:  
• PPP compatible receiver
• Antenna capable of receiving GNSS and L-Band frequencies | Carrier-phase | Subscription based $ | Receive corrections from satellites | Worldwide | ± 3cm | Long convergence time, ~ 20–30 min |
| RTK    | Receiver at known location | Requires two or more constellations | Carrier-phase | Subscription based $ | Receive correction from base station | ~ 50 Km | +/- 2cm or so | Available immediately |
Radio Technical Commission for Maritime for Position Correction

• What is RTCM?
  – Message standard and data format for GNSS
  – **RTCM Special Committee 104** was formed to draft a standard format for the correction messages to ensure an open real-time DGPS system
  – The format is generally known as **RTCM SC 104**
  – RTCM is not instrument specific
RTCM SC-104 Versions

- RTCM - 2.0 (Code correction -> DGPS)
- RTCM - 2.1 (Code + Phase correction -> RTK)
- RTCM - 2.2 (...+ GLONASS)
- RTCM - 2.3 (....+ GPS Antenna Definition)
- RTCM - 3.0 (....+ Network RTK & GNSS)
  - Message type 1001 – GPS L1 observations at 5 Hz
  - Message type 1005 – Antenna Reference Point (ARP) coordinates at 2 Hz
Position Correction for Different Intersection Configurations
Open Sky Clear Visibility Satellite Intersections

Intersection Configuration:
- Multiple lanes in each direction
- Near-far traffic lights in all direction

Complexity - Low:
- Simple – Straight through and right turn
- Maximum 2 signal phase associations – Straight and right turn movements
- Positioning challenge - Low

Position correction may not add significant benefit
- Limited lane-level map matching is required
Low/Poor Satellite Visibility Intersections

Intersection Configuration:
• Typical no Near-far traffic lights

Complexity - High:
• Multiple lanes in each direction
• Multiple signal phases in each direction
• Urban canyon, obstructed satellite visibility, makes it difficult to use correction
• Positioning challenge - High

Position correction would not provide required benefits
Positioning Challenge in Urban Canyon

- Lack of direct line-of-sight (LOS) signals from GNSS satellite constellations
- Forced to use signals that have multipath in them
- Surrounded by buildings that are parallel to the street,
  - which means that it is more likely to receive LOS signals from satellites that are along the street than across the street
Open Sky Clear Visibility Satellite Intersections
Complex SPaT/MAP

Intersection Configuration:
• Typical, no near-far traffic lights

Complexity - High:
• Multiple lanes and multiple signals phases in each direction
• Lane-level positioning is required

Position correction would certainly provide required benefits
## Benefits from Position Correction

<table>
<thead>
<tr>
<th>Satellite Visibility</th>
<th>Open Sky High Satellite Visibility</th>
<th>Obstructed Satellite Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Configuration</td>
<td>Some benefit can be achieved</td>
<td>May not achieve desired benefit</td>
</tr>
<tr>
<td>Combination of Less Complex SPaT/MAP Configuration</td>
<td>Most benefit can be achieved</td>
<td>Cannot achieve desired benefit</td>
</tr>
</tbody>
</table>
Questions / Discussion