WYDOT CV PILOT DEPLOYMENT RESULTS AND TRANSITION PLAN

Kate Hartman, USDOT; Vince Garcia and Brian Peel, WYDOT; Nayel Urena Serulle ICF; Rhonda Young, Gonzaga U; Mohamed Ahmed, UW; Tony English, Neaera
AGENDA

- Webinar Content
  - ITSA Logistics and Opening Remarks
  - CV Pilot Big Picture Overview, Operational Showcase and Accomplishments
  - Summary of Performance Findings
  - Lessons Learned
  - Transition Plan
  - Q&A

- Webinar Protocol
  - Please mute your phone during the entire webinar.
  - You are welcome to ask questions via chatbox at the Q&A Section.
  - The webinar recording and the presentation material will be posted on the CV Pilots website.
Opening Remarks

Kate Hartman, USDOT
CV PILOT DEPLOYMENT PROGRAM GOALS

- Spur Early CV Tech Deployment
- Measure Deployment Benefits
- Resolve Deployment Issues
- Wirelessly Connected Vehicles
- Safety
- Technical
- Mobile Devices
- Mobility
- Institutional
- Infrastructure
- Environment
- Financial
THE THREE PILOT SITES

Wyoming DOT

New York City DOT

THEA
Tampa Hillsborough Expressway Authority
CV Pilot Big Picture Overview, Operational Showcase and Accomplishments

Vince Garcia, WYDOT
INTERSTATE 80 CORRIDOR

- Runs 402 miles along Wyoming’s southern border

- I-80 in Wyoming is one of the busiest freight corridors in the region
  - More than 32 million tons of freight per year.
  - Truck volume is 30-55% of the total traffic on an annual basis—can be as much as 70% on a seasonal basis.

- Difficult environment and terrain
  - Elevations above 6,000 feet across the entire corridor.
CONNECTED VEHICLE PILOT

75 ROADSIDE UNITS

Receive and broadcast messages using DSRC technology along sections of I-80. The units will be installed at locations along the corridor based on identified hotspots.

400 INSTRUMENTED FLEET VEHICLES

Equipped with DSRC-connected onboard units that broadcast basic safety messages, share alerts and advisories, and collect environmental data through mobile weather sensors.

WYDOT TRAVELER INFORMATION

The data collected by fleets and roadside units gives drivers in Wyoming improved travel information through services like the Wyoming 511 app and the commercial vehicle operator portal (CVOP).
The showcase took place at WYDOT’s office at 5300 Bishop Boulevard, Cheyenne, WY on Tuesday, October 30, 2018.

The Operational Capability Showcase illustrated to the media, along with other invited attendees, the capabilities, intent, and value of this pilot for WYDOT’s TMC and all drivers of I-80.

The intent of the Showcase was for the media to grasp the importance of this project, not just for Wyoming, WYDOT, or the trucking industry, but for the general public and for future interoperability efforts with other connected vehicles around the country.
Operational Showcase

- The Operational Capability Showcase successfully demonstrated the performance of the CV system, including the suite of V2V, V2I, and I2V applications.
- The Showcase also demonstrated the real-time data flow of the system.
- The Showcase included a discussion on interoperability, touching on a key goal of the CV Pilots program itself from a national perspective.
The CV pilot is fully integrated into TMC operations.
No additional personnel or changes to workload.
Improvement of back-office processes and monitoring capabilities.
Integration of the Operational Data Environment (ODE) with the V2X Hub.
Integration of the Security Credential Management System with the TMC, RSU, and OBU.
Research and Testing

• 50+ research documents identifying successes, findings and gaps in research.
• Creation of a testbed for new technologies and software.
• Moved forward the hardware, firmware, and software.
Standards and Freight

• Serve as ground proof / empirical data for improving guidelines and standards for freight vehicles and rural environments.
• Successful implementation of Distress Notifications and Weather Cloud.
• Engage with security.
Overarching Outcomes

• Creation of expertise.
• Help identify improvements in how States provide information to drivers (e.g., construction information).
• Development of a Situational Data Exchange (SDX) and expanding it statewide—in combination to the transition to satellite.
• Development of an expandable and easy to replicate Alexa Skill leveraging CV data.
Performance Measurement Approach

Nayel Urena Serulle, ICF
System Performance Measurement Approach

1. Understand current situation
2. Establish the Pilot’s hypothesis
3. Define measures of success
4. Analyze pilot data and results
Baseline Situation

- **Connected Vehicle Pilot Deployment Program Phase 2, Final System Performance Report, Baseline Conditions – WYDOT CV Pilot (FHWA-JPO-17-474)** documents the data collected and analysis performed to assess the current situation at the time and support the establishment of the pre-deployment (baseline) conditions.

- Pre-deployment data collection focuses on December 2016 through November 2017, including work zone data in the summer of 2017.

- Crash data before December 2016 is also included in the report given the natural variations inherent in these data.

- The 2016-17 winter was one of the most severe on record, especially the number and intensity of strong wind events in the corridor.
  - Forty-one (41) separate significant weather events were documented between December 2016 and May 2017.
Hypotheses and Performance Metrics

- **Increase Road Weather Condition Reporting**
  1. Number of Road Condition Reports
  2. Number of Road Sections With At Least One Report
  3. Average Refresh Time of Road Reports

- **Enhance Information Dissemination**
  4. Percentage of TIMs received by at least one RSU
  5. Percentage of TIMs received by at least one OBU on I-80 through satellite
  6. Percentage of TIMs received by at least one Friendly Fleet vehicle from RSUs
  7. Percentage of TIMs received by at least one OBU, through either satellite or RSU

- **Improve Safety**
  8. Total vehicles traveling at no more than 5 mph over the posted speed
  9. Total vehicles traveling within +/- 10 mph over the posted speed
  10. CVs Speed compliance compared to non-CVs
  11. Connected Vehicles Involved in Initial or Secondary Crash
  12. Reduction of the number of vehicles involved in a crash
  13. Reduction of total and truck crash rates within a work zone area
  14. Reduction of total and rates of truck crash along the corridor
  15. Reduction of critical total and truck crash rates in the corridor
  16. CVs that likely took action following receipt of an alert
  17. CVs that likely took action following receipt of a V2V alert
Data Collection

- The complete dataset consists of data collected and/or produced by:
  - **WYDOT** (e.g., road reports, crash, and weather)
  - **CV System** (e.g., data produced by OBUs, RSUs and backoffice systems).

- While the first data type is accessible through WYDOT’s database and public records available upon request through inter-agency agreements, CV system data is stored and managed through the Secure Data Commons (SDC).

  - The SDC is a USDOT-sponsored cloud-based analytical platform designed to create wider access to sensitive transportation data sets, with the goal of advancing the state of the art of transportation research and state/local traffic management. The SDC stores sensitive transportation data made available by participating data providers, and grants access to approved researchers to these datasets.
WYDOT accesses the CV Pilot data (historic and near real time) stored at the SDC.

The SDC enables the use of tools and functionalities to perform data queries, preprocessing, analytics and to collaborate and share code across the other CVP team members.

The project team uses of SDC to perform the following type of data analysis:

1. Develop, and host a custom tool (using Python), called “Data Tool”, to enable analysts to (a) query BSM, driver alert, and speed data, (b) perform geospatial based conversions, (c) convert unprocessed speed data, generate speed reports from processed speed data, and (d) export data out of the SDC.

2. Use R to develop ad hoc data analysis to estimate performance metrics and performance measures based of BSMs, TIM, and driver alert data.

3. Use SQL Workbench and LibreOffice to perform additional data queries and analysis based on the BSM, TIM, and driver alert data.
Summary of Performance Findings

Nayel Urena Serulle, ICF
Rhonda Young, Gonzaga University
Period of analysis: Jan’ 2021 – Apr’ 2022.

Background statistics are provided for:

- Road Condition and Events
  1. Weather events
  2. I-80 incidents highlights
  3. I-80 work zone related events

- CV System Operations
  1. Connected vehicles count summary
  2. Statistics of the BSM data
  3. Statistics of the driver alerts
  4. CV hours of operation
A total of **499 severe weather events lasting 5,807 hours** were recorded around I-80 between January 2021 and April 2022.

While the number of events during winter could be lower, the event may continue for a significantly longer period.
Between December 2020 and February 2022, **1,964 crashes** occurred within the I-80 corridor, **56% involved a truck** vehicle.

Between January 2021 and April 2022, **17 work zones** impacted traffic within I-80, **covering about 123 miles** out of the 402 miles of I-80.
Towards the end of April 2022, the WYDOT CV Pilot had deployed over 320 OBUs to be equipped in Friendly and Partner fleets.

- **Friendly Fleet** is composed by vehicles over which the pilot had more access to and is able to identify in the data, as they have unique IDs. This group includes WYDOT Plows (WY), Trihydro Vehicles (TH), and Highway Patrol Vehicles (HP).

- **Partner CV Fleet** is composed by all other vehicles, namely from partners of the pilot. Note that for security and privacy reasons, these vehicles have dynamic IDs and therefore cannot be tracked and accurately counted.

- WYDOT only had control over its own fleet of vehicles. Partners Fleets were responsible for installing and maintaining their equipment—with support from WYDOT when requested.
**CV System Operations – BSM and Alerts**

- **412 Million BSMs**
  - 4.5 Million BSMs/wk (by Friendly Fleet)
  - 1.5 Million BSMs/wk (by Partner Fleet)
  - Vehs/wk: 8 WY, 9 TH, and 32 HP
  - BSMs/Vehs*wk: 22k WY, 29k TH, and 122k HP

- **635k Driver Alerts**
  - 100 /wk FCWs
  - 55 /wk SVAs
  - 9k/wk TIMs

*Between January 1, 2021, and April 30, 2022, within the I-80 corridor*
Two HPs parked near each other, producing most of the alerts generated in January (roughly 90k SVAs).

- **Data anomalies occurred in 31 days** out of the near 484 days of operation analyzed.
- These occurrences account for roughly 6.4% of the total days of CVP operation, but amount to **600k redundant alerts**.
Road Weather Condition Reporting

- A total 499 severe weather events from Jan’ 2021 to Apr’ 2022. For each, we look at:
  - Number of unique reporting sections.
  - Hours of each weather event.

- The CV Pilot successfully and consistently:
  - **Increased** the number of road condition reports.
  - **Expanded** the coverage of road condition reports.
  - **Reduced** the refresh time of road condition reports.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Target</th>
<th>Post Deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of reports</td>
<td>4.3</td>
<td>+30%</td>
<td>16.88 (+293%)</td>
</tr>
<tr>
<td>Number of sections</td>
<td>5</td>
<td>+25%</td>
<td>6.4 (+29%)</td>
</tr>
<tr>
<td>Refresh time</td>
<td>3.9</td>
<td>-25%</td>
<td>3.2 (-13.5%)</td>
</tr>
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</table>
One TIM package logs the transmission of a single TIM as it is disseminated across different RUSs and/or OBUs.

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>No. TIM Packages</th>
<th>No. TIM Records</th>
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<tbody>
<tr>
<td>01.2021</td>
<td>1,860</td>
<td>36,784</td>
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<tr>
<td>02.2021</td>
<td>9,956</td>
<td>48,053</td>
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<td>6,236</td>
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<td>05.2021</td>
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<td>2,173</td>
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<td>09.2021</td>
<td>936</td>
<td>39,135</td>
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<td>10.2021</td>
<td>5,152</td>
<td>38,777</td>
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<tr>
<td>11.2021</td>
<td>2,995</td>
<td>38,957</td>
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<tr>
<td>12.2021</td>
<td>13,239</td>
<td>40,117</td>
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<td>01.2022</td>
<td>10,989</td>
<td>46,134</td>
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<td>02.2022</td>
<td>9,121</td>
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<td>03.2022</td>
<td>6,754</td>
<td>16,861</td>
</tr>
<tr>
<td>04.2022</td>
<td>5,791</td>
<td>35,602</td>
</tr>
</tbody>
</table>
Reliable / Efficient Dissemination of Information

- Average of ~90% of TIMs received by at least one OBU on I-80, through Satellite or RSU.

- Average of ~ 92.1% of the TIM packages were received by at least one RSU within the CVP network.

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>No. TIM Packages</th>
<th>% TIMs received by at least one OBU via Satellite</th>
<th>% TIMs received by at least one OBU via Satellite or RSU</th>
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<tbody>
<tr>
<td>01.2021</td>
<td>1,860</td>
<td>91.8%</td>
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<td>93.0%</td>
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<td>03.2021</td>
<td>6,236</td>
<td>89.2%</td>
<td>89.3%</td>
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<td>4,835</td>
<td>90.6%</td>
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<td>86.0%</td>
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<td>87.6%</td>
<td>87.7%</td>
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<td>1,405</td>
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<td>5,791</td>
<td>91.0%</td>
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</tr>
</tbody>
</table>
Improvements in Speed Compliance

- Mixed condition storms presented improvement in vehicles traveling <+5mph above speed limit (~4-5% increase in compliance).
  
  - However, overall speed compliance was shown to decrease from 77.1% to 65.8%, a reduction of 11.3%, across all weather conditions.

- Generally, percentage vehicles traveling +/- 10mph within speed limit was shown to increase from 58.9% to 66.4%, a 7.5% improvement, across all weather conditions.

- Speed data distribution indicates that CVs slightly favors speed below the posted speed with 44% of the observations occurring in speeds below the limit, compared to 38% of the Non-CVs.
No CV Crashes

- This performance measures tracks the number of initial and secondary crashes that connected vehicles were involved in during the post deployment stage.

- **No crashes involving a connected vehicle were reported** to WYDOT during the period from December 2020 through February 2022.

  - This PM requires self notification by the CV fleets managers (Friendly and Partner).
Driver Compliance After Alert

Three snapshot analyses were done to evaluate the driver reactions after receiving an alert:

- High wind alerts for a wind event on June 22, 2021
- Work zone alerts for a construction zone during the month of June 2021
- Winter storm event on February 2, 2022
Reactions seem to be in line with expectations

**High wind** alerts for a wind event on June 22, 2021

<table>
<thead>
<tr>
<th>Event</th>
<th>Speed (MPH)</th>
<th>Driver Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21.74</td>
<td>Vehicle Stopped</td>
</tr>
<tr>
<td>2</td>
<td>77.40</td>
<td>No Action</td>
</tr>
<tr>
<td>3</td>
<td>69.88</td>
<td>No Action</td>
</tr>
<tr>
<td>4</td>
<td>13.96</td>
<td>Vehicle Stopped</td>
</tr>
<tr>
<td>5</td>
<td>54.27</td>
<td>Vehicle Reduced Speed</td>
</tr>
<tr>
<td>6</td>
<td>77.31</td>
<td>Vehicle Reduced Speed</td>
</tr>
<tr>
<td>7</td>
<td>77.67</td>
<td>No Action</td>
</tr>
<tr>
<td>8</td>
<td>75.70</td>
<td>No Action</td>
</tr>
<tr>
<td>9</td>
<td>33.33</td>
<td>Vehicle Reduced Speed</td>
</tr>
<tr>
<td>10</td>
<td>78.69</td>
<td>Vehicle Reduced Speed</td>
</tr>
</tbody>
</table>

**Work zone** alerts for a construction zone during the month of June 2021

<table>
<thead>
<tr>
<th>Event</th>
<th># of Alerts</th>
<th>Driver Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>Vehicle Exited</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>No Action</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>No Action</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>No Action</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Reduced Speed</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>No Action</td>
</tr>
<tr>
<td>14</td>
<td>3</td>
<td>No Action</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>No Action</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>No Action</td>
</tr>
</tbody>
</table>

**Winter storm** alerts during the month of Feb 2, 2022

<table>
<thead>
<tr>
<th>Event</th>
<th># of Alerts</th>
<th>Alert Types</th>
<th>Driver Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>Icy Patches (2), Snow, Blowing Snow, Ice</td>
<td>Vehicle Reduced Speed</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Snow (2)</td>
<td>Vehicle Reduced Speed</td>
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<tr>
<td>3</td>
<td>1</td>
<td>Snow</td>
<td>No Action</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Icy Patches</td>
<td>No Action</td>
</tr>
</tbody>
</table>

Winter storm alerts during the month of Feb 2, 2022
Human Machine Interface Development, and Assessment
Simulation Analysis of Driver Behavior to CV Applications

Mohamed M. Ahmed, University of Wyoming
ADAS Human Machine Interface

Forward Collision Warning (FCW) – V2V

Situational Awareness (SA) – I2V

Work Zones Warning (WZW) – I2V

Distress Notification (DN) – V2I & V2V

Spot Weather Impact Warning (SWIW) - I2V
ADAS Human Machine Interface

Ride-along with WHP
Emphasis on Training

- Truck driving simulator with CV HMI at University of Wyoming Driving Simulator Lab (WyoSafeSim)
- 23 snowplow truck drivers from WYDOT and WHP troopers participated in the experiment.
- Highway Patrol officers are often required to drive at high speeds under enormous workload regardless of the road and weather conditions which increases the risk of crashes.
  - CV warnings are easy to understand (average Likert score 6.2 out of 7).
  - Adverse weather, work zones and surface conditions noted as priority.

https://www.youtube.com/watch?v=JLaS-s1OvCl&feature=youtu.be
Emphasis on Training

- Hands-on and Online Training on the WYDOT CV Applications to Participants
- Feedback improved HMI and CV Acceptance
Emphasis on Training

YouTube Video: https://youtu.be/JLaS-s1OvCI
Eye Tracking/ Data Visualization


Best Paper Award: Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, Truck and Bus Safety (ACS60) Deborah Freund Paper Award, 2021.
Benefits of Simulator Studies

Learning early about HMI effectiveness and driver responses

Impact of warnings on driver behavior, and distraction → Microsimulation

Make rapid adjustments to algorithms, HMI displays
Microsimulation Modeling

✓ SHRP2 and Driving Simulator Data to calibrate and validate;

Cumulative Effect of Weather Warnings

Gradual Reduction in Speed

Abrupt Reduction in Speed

Mean Driver Speed (MPH)

In clear conditions
Following fog warning
Following advisory speed warning
When encountered with fog

Baseline Scenario

Gradual Reduction in Speed

Speed Variations at the Icy Road Segment

Advisory Speed Limit

Baseline Scenario

CV Scenario

Baseline Scenario vs Gradual Reduction in Speed

Baseline Scenario vs Abrupt Reduction in Speed
Microsimulation Modeling

✓ Microsimulation modeling to derive Surrogate Measures of Safety;
✓ VISSIM simulation model for a 23-mile segment of the I-80 Cheyenne-Laramie VSL corridor;
✓ Surrogate Safety Assessment Model (SSAM) to analyze the number of traffic conflicts generated by VISSIM simulation model.
Over 50 research papers developed between baseline, simulation and deployment analysis.

- **Best Paper Award:** Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, Truck and Bus Safety (ACS60) Deborah Freund Paper Award, 2021.

- List of key journal publications available at the end of the presentation.
Lessons Learned

Tony English, Neaera Consulting
LESSONS LEARNED

- SCMS Integration
- Radio Integration
- Log File Size
- OBU Failing at Scale
- Network Security
- DSRC Shadow and Heavy Freight Vehicles
ISSUE – WHEN TO ADD SCMS TO PROJECTS

SCMS Integration

- Use from start of project
- Consider CRL and Misbehavior Detection

Mitigation Strategy

Vendors for TMCA, RSU, and OBU hardware should be integrated before any testing starts.
ISSUE – RADIO INTEGRATION

Radio Integration

- Needed an updated firmware
- WYDOT had no direct relationship with OBU component vendors

Mitigation Strategy

OBU Vendors should have better service agreements with their component vendors
Log File Size

• DSRC off-leading and over-the-air update speed
  o At highway speeds, contact time with vehicles is short and off-loading of data is a challenge
  o We are collecting performance data for evaluation purposes

Mitigation Strategy

Trim logged messages and have over-the-air updates be restartable. Consider time needed for cert top off and CRL/MB reports.
ISSUE – OBU FAILING AT SCALE

OBU Failing at Scale

- Maintaining an OBU fleet is hard
- Security obfuscation makes it harder
- General code stability (crashing, GPS not coming online, HMI disconnecting, offloading random)
- HSMs are essential

Mitigation Strategy

- Periodically touch OBUs to review fleets
- Have spare units with cables/antennas
Network Security

- We went for the big play with full IPv6 end-to-end
- Public sector networks typically do not think about or support IPv6
- This resulted in firewall updates
- Router configuration changes

Mitigation Strategy

- Continuously upgrade, patch, lock, probe, and analyze
- Monitor/report/alert essential
ISSUE – 5.9 GHZ AND FREIGHT VEHICLES

DSRC/C-V2X Shadow

- Line of sight requirements
  - Single antenna on cab issues
  - Vehicle dynamics concerns

Mitigation Strategy

- Antennas on mirrors
- BSM part 2 data
- Trailer interface for drivers
- SAE J2735 clarity for heavy freight
Transition Plan

Brian Peel, WYDOT
Transition Approach Overview

- It is just not RSUs and OBUs, it is an entire ecosystem.

- WYDOT plans to continue use of the CV Pilot’s infrastructure in the TMC used to create and disseminate TIMs.

- With the Federal Communications Commission (FCC) removing the lower 45 MHz and pushing for cellular vehicle to everything (C-V2X) communications, WYDOT will not continue use of DSRC after July 2022.
  - This removes solutions currently in place for log offloads from vehicles, certificate updates, TIM dissemination from RSUs, FCW, distress notification, and OTAs for OBUs.

- Satellite delivery of TIMs will remain in effect for the foreseeable future for the entire state.

- The Alexa Skill deployed through the situation data exchange (SDX) will also continue and WYDOT will continue to populate the SDX so third-party vendors can use WYDOT data.
Post Pilot Operations

- **Core Applications and Services that will remain include:**
  - OBUs
  - TIM generation and distribution (through Satellite).
  - Internal databases for CV data storage.
  - Pikalert

- **Planned / Future Enhancements**
  - Construction Information
  - SDX
  - Potential Integration of WYDOT CV Data with OEMs
  - Conversion to C-V2X RSUs and OBUs
  - New Applications
Potential outcome of future FCC and USDOT decisions for spectrum and communication protocol. The current indecision is a risk for all CV deployers.

C-V2X or other technologies need to be thoroughly tested and validated at scale.

Future funding to support satellite delivery of TIMs is an unknown at this time.

Sirius XM (SXM) currently allows free distribution of TIMs over satellite. If this changes, WYDOT will need to evaluate the benefit/cost of operating over SXM.

No contingency is available to WYDOT at this stage on the previous risks as these are outside of WYDOT’s control.
Q&A
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Visit CV Pilot and Pilot Site Website for more Information:

- CV Pilots Program: http://www.its.dot.gov/pilots
- Wyoming DOT: https://wydotcvp.wyoroad.info/