Wyoming DOT
Connected Vehicle Pilot Deployment Program

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SIRWEC 2018
Wyoming CV Pilot Team
Pilot Project

- Using Connected Vehicle (CV) Technology to enable equipped vehicles to transmit and receive data to other equipped vehicles and roadside infrastructure.

- Reduce the impact of adverse weather on truck travel along the corridor through CV-based advisories, roadside alerts, parking notifications, and dynamic traveler information.
Project Phases

Connected Vehicle Pilot Deployment (up to 50 months)

PHASE 1
(up to 12 months)
Concept Dev.

PHASE 2
(up to 20 months)
Design/Deploy/Test

PHASE 3
(minimum 18 months)
Maintain/Operate Pilot

Routine Operations
(ongoing)

Post-Pilot Operations

➢ The Pilot is comprised of three phases

Wyoming Pilot Schedule

Phase 1
• Planning (Sept. 2015 – Sept. 2016)

Phase 2
• Deployment (Oct. 2016 – April 2018)

Phase 3
• Demonstration (May 2018 – Oct. 2019)
Wyoming’s I-80 Corridor
Wyoming’s I-80 Corridor

Heavy Freight Traffic
- Major E/W freight corridor
- Freight = over half of annual traffic

Severe Weather Conditions
- Roadway elevation
- Heavy winds, heavy snow and fog
- Severe blowing snow and low visibility

Adverse Impacts on Trucks
- Higher than normal incident rates
- Multi-vehicle crashes
- Fatalities

Source: WYDOT (Dec 17, 2015)
5 Focus Areas

<table>
<thead>
<tr>
<th>Focus Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manage following speed and distance between vehicles</strong></td>
</tr>
<tr>
<td>• By alerting trucks to slowing traffic ahead to prevent multiple-vehicle crashes</td>
</tr>
<tr>
<td><strong>Provide custom alerts and advisories</strong></td>
</tr>
<tr>
<td>• For vehicles that are at risk due to their weight, profile, or traveling speeds due to high-winds or near work zones, including alerting drivers if vehicles are too tall for bridges</td>
</tr>
<tr>
<td><strong>Provide location-based parking information</strong></td>
</tr>
<tr>
<td>• With a focus on directing drivers to safe parking areas in the event of a road closure</td>
</tr>
<tr>
<td><strong>Allow first responders to be notified of a crash automatically</strong></td>
</tr>
<tr>
<td>• Based on vehicle metrics, such as airbag deployment</td>
</tr>
<tr>
<td><strong>Use data collected from vehicle’s weather sensors</strong></td>
</tr>
<tr>
<td>• Such as the status of windshield wipers and if anti-lock brake systems are activated. This information will be used to develop advisories and forecasts for travel to fleet management centers and the general public.</td>
</tr>
</tbody>
</table>
Why this project is important

1,498 crashes
1,923 vehicles
$773.5M Societal Impact

Response to an incident on I-80

<table>
<thead>
<tr>
<th>Type</th>
<th>No.</th>
<th>Societal Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality</td>
<td>13</td>
<td>$120,891,446</td>
</tr>
<tr>
<td>Injury</td>
<td>253</td>
<td>$110,578,475</td>
</tr>
<tr>
<td>Property Damage</td>
<td>1,232</td>
<td>$542,080,000</td>
</tr>
</tbody>
</table>

Economic impacts listed on figures provided by WYDOT Public Safety. Amounts are moderate injuries and one fatality per crash.

Over the past year...

- 250 Hours Full Lane Closures
- ~180 Hours High Profile Vehicle Restriction
- 37 Days Inclement Weather

10/2/18 CONNECTED VEHICLE (CV) PILOT DEPLOYMENT PROGRAM – PHASE 2
Pilot Elements

CV Environment
- 75 Roadside Units on I-80
- 400 Vehicles with DSRC Connectivity

V2V Applications
- Forward Collision Warning
- Distress Notification

V2I Applications
- Situational Awareness
- Spot Weather
- Work Zone Warning

WYDOT’s CV Pilot System

Vehicle System
- Forward Collision Warning
- Distress Notification
- Situational Awareness
- Spot Weather
- Work Zone Warning

Wyoming CV System
- Roadside Infrastructure
- Back office system

External Interfaces
E-Training
In-Cab Display Unit Layout

- Critical Warnings
- Advisory Warnings
- Speed Limit
- Distress Notification Button
- Settings Button
- Vehicle Speed
- Forward Collision Warning

Note: The notifications will remain on the display until the event is over
Performance Management
Weather as a Confounding Factor

- Weather is a major confounding factor affecting speed and safety performance measures
  - Particularly in the Wyoming CV Pilot, given its focus on operations during adverse weather and the frequency and severity of the weather the corridor experiences

- Not accounting for weather in speed performance measures would make it difficult to detect differences in baseline and post-deployment data
  - Short data collection periods for speed performance measures heighten impact of an single extreme or mild winter season
## Speed and Crash Performance Measures

<table>
<thead>
<tr>
<th>Improved Speed Adherence and Reduced Speed Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. Total vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV Pilot)</td>
</tr>
<tr>
<td>15. Total vehicles traveling within +/- 10 mph of 85th percentile speed (compare before and after CV Pilot)</td>
</tr>
<tr>
<td>16. Speed of applicable connected vehicles are closer to posted speed when compared to non-connected vehicles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reduced Vehicle Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Number of connected vehicles involved in a crash</td>
</tr>
<tr>
<td>Initial crashes</td>
</tr>
<tr>
<td>Secondary crashes</td>
</tr>
<tr>
<td>18. Reduction of the number of vehicles involved in a crash (compare a multi-year average before and after CV Pilot)</td>
</tr>
<tr>
<td>19. Reduction of total and truck crash rates within a work zone area (compare a multi-year average before and after CV Pilot)</td>
</tr>
<tr>
<td>20. Reduction of total and truck crash rates along the corridor (compare a multi-year average before and after CV Pilot)</td>
</tr>
<tr>
<td>21. Reduction of critical (fatal or incapacitating) total and truck crash rates in the corridor (compare a multi-year average before and after CV Pilot)</td>
</tr>
</tbody>
</table>
Speed Performance Measures
Speed Performance Measures

- Speed PMs require linking individual speed observations to weather data from nearby RWIS based on minimizing time and spatial (milepost) differences between observations
  - Speed observations must also be linked with posted speeds from either static signs or VSL data
- 10 RWIS chosen to represent the 402-mile corridor and each speed sensor was linked to closest RWIS
- Initially all available speed data was processed but beginning in May only “priority” speed sensors were processed as more sensors came online

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>April</th>
<th>May</th>
<th>Oct</th>
<th>Nov</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available</td>
<td>1.8</td>
<td>7.7</td>
<td>10.9</td>
<td>11.2</td>
<td>15.4</td>
<td>24.9</td>
<td>21.7</td>
<td>93.8 million</td>
</tr>
<tr>
<td>Processed</td>
<td>1.8</td>
<td>7.7</td>
<td>10.9</td>
<td>11.2</td>
<td>12.0</td>
<td>11.2</td>
<td>9.7</td>
<td>64.6 million</td>
</tr>
</tbody>
</table>

- RWIS Data downloaded from Mesowest archive
Speed Performance Measures

- Previous research on corridor before and after the installation of variable speed limit corridors lead to extensive analyses of speed behavior in various weather conditions.

- Five RWIS variables were determined to be most correlated with speed behavior on the corridor:
  - Road Surface Condition (categorical variable)
  - Visibility (feet)
  - Relative Humidity (%)
  - Wind Speed (MPH)
  - Surface Temperature (°F)
Speed Performance Measures

➢ Further review of the modeling results from earlier work also revealed critical threshold values for each of these weather variables
  • Road Surface Condition - dry (1), wet (2), snow (3), or ice (4)
  • Visibility (feet) – greater than 0.95 miles (1), between 0.57 and 0.95 miles (2), and less than 0.57 miles (3)
  • Relative Humidity (%) – below (1) or above (2) 92%
  • Wind Speed (MPH) – below 30 mph (1), between 30 and 45 mph (2), and above 45 mph (3)
  • Surface Temperature (°F) – above 32°F (1), between 25 and 32°F (2), and below 25°F (3)

➢ Review of these variables with NCAR team member was done to ensure these variables and thresholds made meteorological "sense"

➢ Each of these states for each variable was converted to a categorical variables from 1 to 4 depending on the number of states
  • In all cases, 1 was assigned to the “ideal” or best condition, representing no likely impact on speeds
Speed Performance Measures

- Storm number between 1 and 216 was assigned for each unique combinations of these categorical variables
  - Storm number 1 represents all variables at ideal but beyond that increasing numbers do not represent increasing weather severity

- It was understood that many storm numbers would be unlikely from a meteorological perspective
  - Ice on road but high surface temperatures

- Analysis of data during the baseline period would identify these unlikely conditions

- It was felt that limiting number of storm categories to ~10-12 would be manageable from a performance management standpoint
  - Tradeoff between maximizing potential for seeing difference between baseline and post deployment by limiting variability and having a manageable and meaningful set of performance measure output

- Cluster analysis used to map storm numbers to broader storm categories
Speed Performance Measures

- Speed data from January through May 2017 were linked to RWIS data and each observation assigned a storm number.

- Speed distributions for each storm number were determined based on 2 mph bins and a cluster analysis comparing distributions was performed.
  - Cluster analysis using a bin number of 5
  - Empty white cells represent storm numbers that were never observed.
  - Other white cells have distributions based on fewer than 50 observations.
  - 97 storm numbers remained.
Speed Performance Measures

- Cluster analysis using 9 bins
- Analyses run for 5, 7, 9 and 25 bins to check the stability or some of the larger storm categories
- Results from 9 bin analysis provided starting point for final storm category mapping
- Category containing ideal storm (green cells) divided into three categories to separate high wind and poor surface conditions into their own categories
- 11 final storm categories
## Storm Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Storm Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ideal</td>
<td>1,2,3,10,11,55,56,64,65,82</td>
</tr>
<tr>
<td>2</td>
<td>Wind Event</td>
<td>4,5,7,9,13,16,34,40,52</td>
</tr>
<tr>
<td>3</td>
<td>Snow or Ice Surface Condition</td>
<td>109,110,113,118,127,145,163,164,172,190,208</td>
</tr>
<tr>
<td>4</td>
<td>Low Visibility</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>Wet pavement, moderate wind</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>Ice, high wind</td>
<td>170</td>
</tr>
<tr>
<td>7</td>
<td>Ice, low visibility or moderate wind</td>
<td>211,212</td>
</tr>
<tr>
<td>8</td>
<td>High wind, high RH, wet roads</td>
<td>71,88,107</td>
</tr>
<tr>
<td>9</td>
<td>Mixed Conditions 1</td>
<td>8,12,25,62,76,79,85,94,97,98,103,106,169,175,187,188,193,196,205</td>
</tr>
<tr>
<td>10</td>
<td>Wind Events with Cold Surface Temps</td>
<td>6,63,77,95,176,185,203,206</td>
</tr>
<tr>
<td>11</td>
<td>Mixed Conditions 2</td>
<td>2,28,43,46,49,57,58,59,61,67,68,70,73,80,100,104,111,112,115,119,121,124,136,139,154,157,166,167,178,181,184,202,214</td>
</tr>
</tbody>
</table>
Sample Baseline Results

- Sensor 2372
  - MP 13.45

Graphs showing processed records and percent of processed observations for different storm categories.

Legend:
- Data Quality
- Speed Compliance
- Speed Buffer

Legend for percent observations:
- Percent Compliant
- Percent Buffer
- Total Observations
Speed Performance Measures

- Speed Compliance and Speed Buffer PMs calculated from speed observations in same storm category for baseline and post-deployment periods and compared and tested for statistically significant differences
  - Storm numbers will be retained if it is desired to change the storm categorization mapping
  - Speed data could be parsed between cars and trucks (based on a length based classification) and PMs reported separately by vehicle type
  - Data from priority sensors will be separated and tested for each storm category

- Weather timeline during the baseline period created based on changes in weather categories is created through the analysis and could be used in other PMs
Pikalert ® System
Amanda Anderson, National Center for Atmospheric Research
The Pikalert® System

WYDOT’s CV Pilot System

Vehicle System

Wyoming CV System

Roadside Infrastructure

Back office system

External Interfaces
# Environmental Logs

**WEATHERCLOUD-EQUIPPED**

- Wiper Frequency
- GPS Coordinates/Timestamp
- Ground Temperature
- Ambient Temperature
- Barometeric Pressure
- Relative Humidity

**BASIC SAFETY MESSAGE**

- GPS Coordinates/Timestamp
- Ambient Air Temperature
- Exterior Light
- Wiper Status and Rate
- Brake Status
- Coefficient of Friction
- ABS/Traction/Stability Control Status
- As Available
Vehicle Data Translator

- Environmental logs assigned to WYDOT road segments
  - Updates every one mile and five minutes on I-80
  - Assignment based on location and time of observation

- Both WeatherCloud observations and BSM used as available
Vehicle Data Translator

- Ancillary (traditional) weather observations also matched to road segments
  - Update as available
  - Radius used for non-gridded products

- Data include:
  - Road Weather Information System (RWIS) stations
  - Automated Surface Observing System (ASOS) stations
  - Weather radar
  - Background model analysis
Vehicle Data Translator – Quality Checking

- Environmental logs quality-checked against other segment-matched vehicle and ancillary observations

- Algorithms are:
  - Data Filtering Test
  - Sensor Range Test
  - Spatial Test
  - Model Analysis Test
  - Climate Range Test
  - Persistence Test (Only if ID-ed)
  - Step Test (Only if ID-ed)
  - Neighboring Vehicle Test

- Combined Algorithm Test assigns one final confidence between 0 and 1 based on passing/failing above tests
Vehicle Data Translator – Road Segment Statistics

- Observations of high enough confidence are included in Road Segment Statistics and available for downstream applications.

<table>
<thead>
<tr>
<th>Time</th>
<th>19 Nov 2013, 2030 UTC (2:30pm CST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment ID</td>
<td>481</td>
</tr>
<tr>
<td># Vehicle Messages</td>
<td>12</td>
</tr>
<tr>
<td>Vehicle Mean Heading</td>
<td>127° (southeast)</td>
</tr>
<tr>
<td>Vehicle Mean Speed</td>
<td>10 mph</td>
</tr>
<tr>
<td>Vehicle Mean Air Temp (CAN)</td>
<td>41.9° F</td>
</tr>
<tr>
<td>Vehicle Mean Air Temp (WC)</td>
<td>48.4° F</td>
</tr>
<tr>
<td>Vehicle Mean Surface Temp</td>
<td>43.7° F</td>
</tr>
<tr>
<td>Vehicle Modal Wipers</td>
<td>Off</td>
</tr>
<tr>
<td>Radar</td>
<td>None</td>
</tr>
<tr>
<td>Station Air Temp</td>
<td>44.2° F</td>
</tr>
<tr>
<td>Station Dewpoint Temp</td>
<td>28.2° F</td>
</tr>
<tr>
<td>Station Wind</td>
<td>160° (SSE) at 12.5 mph</td>
</tr>
<tr>
<td>Model Air Temp</td>
<td>44.4° F</td>
</tr>
</tbody>
</table>
Road Weather Hazard Module

- Road segment statistics are used to assess for precipitation, pavement condition, visibility, and blowover hazards.
- Assessments can run without mobile data, but are greatly enhanced by mobile observations.

Poor Visibility: Next five miles.
Road Weather Forecast System

- Blended atmospheric forecast uses multiple input models (e.g., North American Model, High Resolution Rapid Refresh model)
  - Verification history populated at each road segment and RWIS station
  - Models combined based on performance over past several days
  - End result is superior forecast compared to individual models

- Pavement model ingests atmospheric forecast to produce road-specific forecast
  - METRo – Model of the Environment and Temperature of Roads
  - Produces a forecast of pavement temperature and accumulation of snow

- Vehicle data from VDT improves the forecast
Road Weather Forecast System

- Forward Error Correction – Improve forecast using observations

![Diagram showing mobile observation and forecast with forward error correction](image-url)
Road Weather Alert Module

- The RWA serves as a bridge between the Pikalert output and the end-user’s application(s)
- RWH output is converted into notices, advisories, and warnings
  - Alert categories are configurable
  - Messaging from RWA is configurable
- Example:
  - RWH output: heavy snow
  - Alert level: warning
  - Message: Warning: heavy snow ahead. Drive with caution, take alternate route if possible.
- JSON output from RWA are available for downstream applications (e.g., TIM-generation or CVOP)
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Visit CV Pilot and Pilot Site Websites for more Information:
- CV Pilots Program: http://www.its.dot.gov/pilots
- Wyoming DOT: https://wydotcvp.wyoroad.info/