CONNECTED VEHICLE PILOT
Deployment Program

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.

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Opening Remarks

Kate Hartman, USDOT

Wyoming DOT

New York City DOT

Tampa (THEA)
Tampa Hillsborough
Expressway Authority

WYOMING DOT

NEW YORK CITY DOT

THEA
Tampa Hillsborough
Expressway Authority

U.S. Department of Transportation
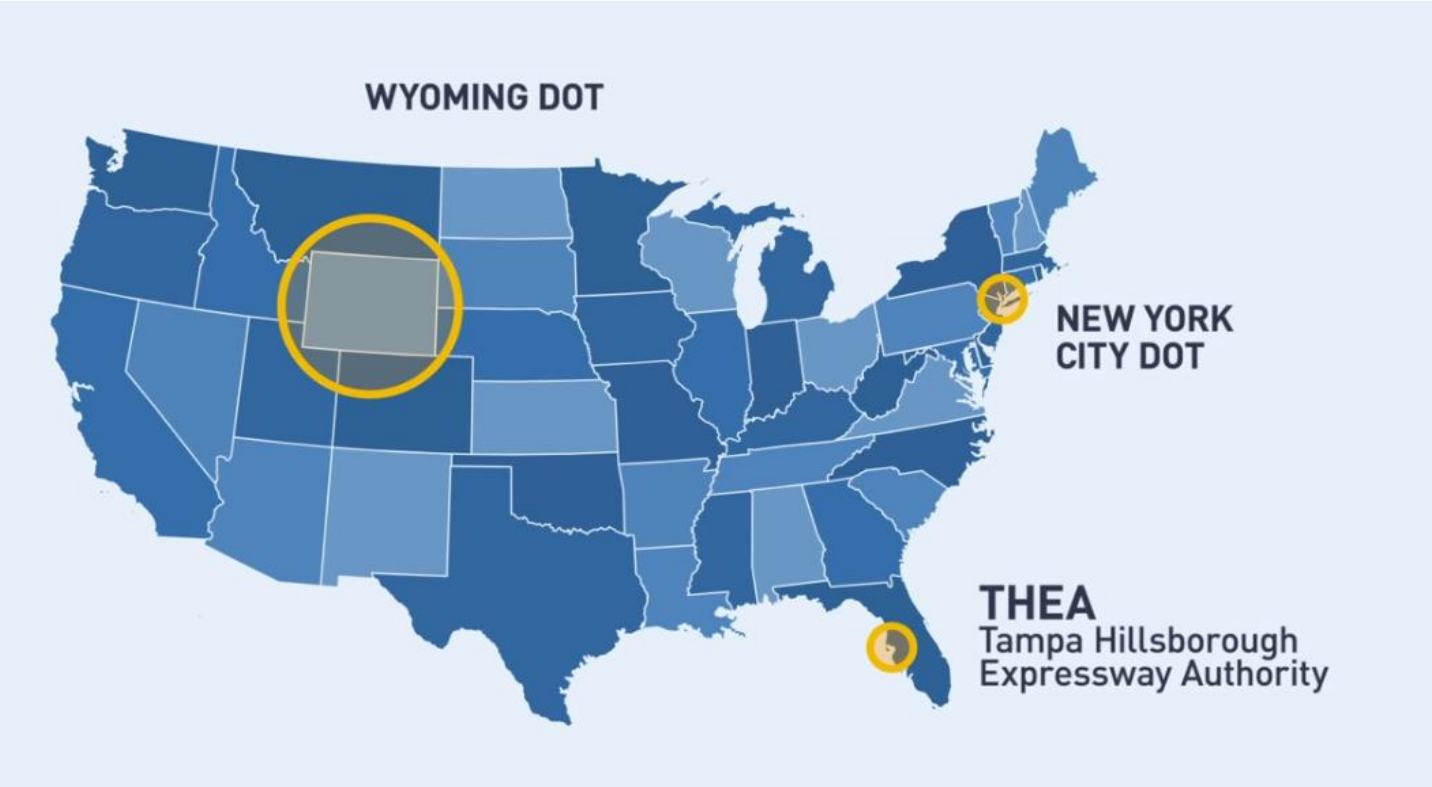
CV Pilot Big Picture Overview, Operational Showcase and Accomplishments

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

  o More than 32 million tons of freight per year.

  o 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

  o Elevations above 6,000 feet across the entire corridor.

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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).
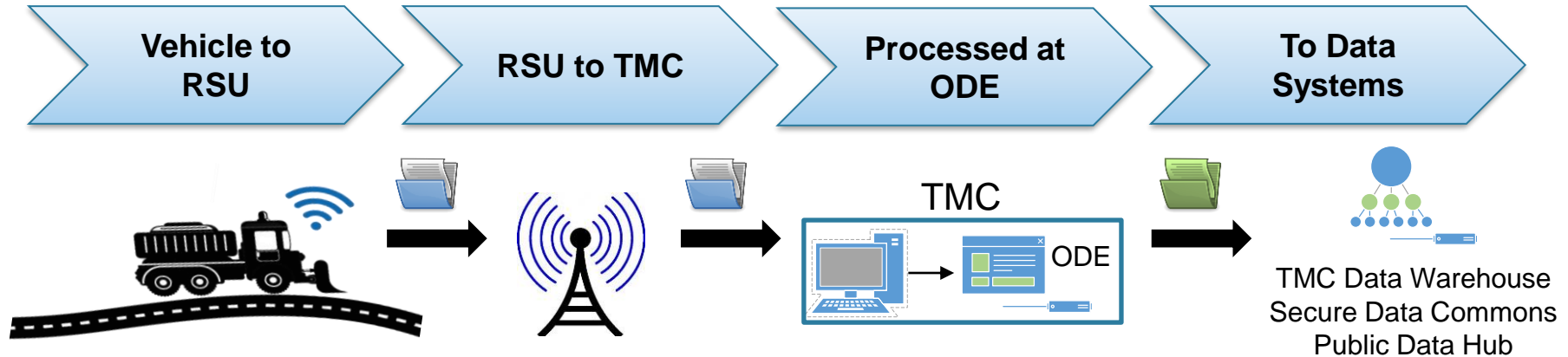
Operational Showcase

- **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.

Vehicle to RSU	RSU to TMC	Processed at ODE	To Data Systems

TMC

ODE

TMC Data Warehouse
Secure Data Commons
Public Data Hub

WYDOT CV Pilot Accomplishments

Integration and Operations

- 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.

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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.

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WYDOT CV Pilot Accomplishments

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.
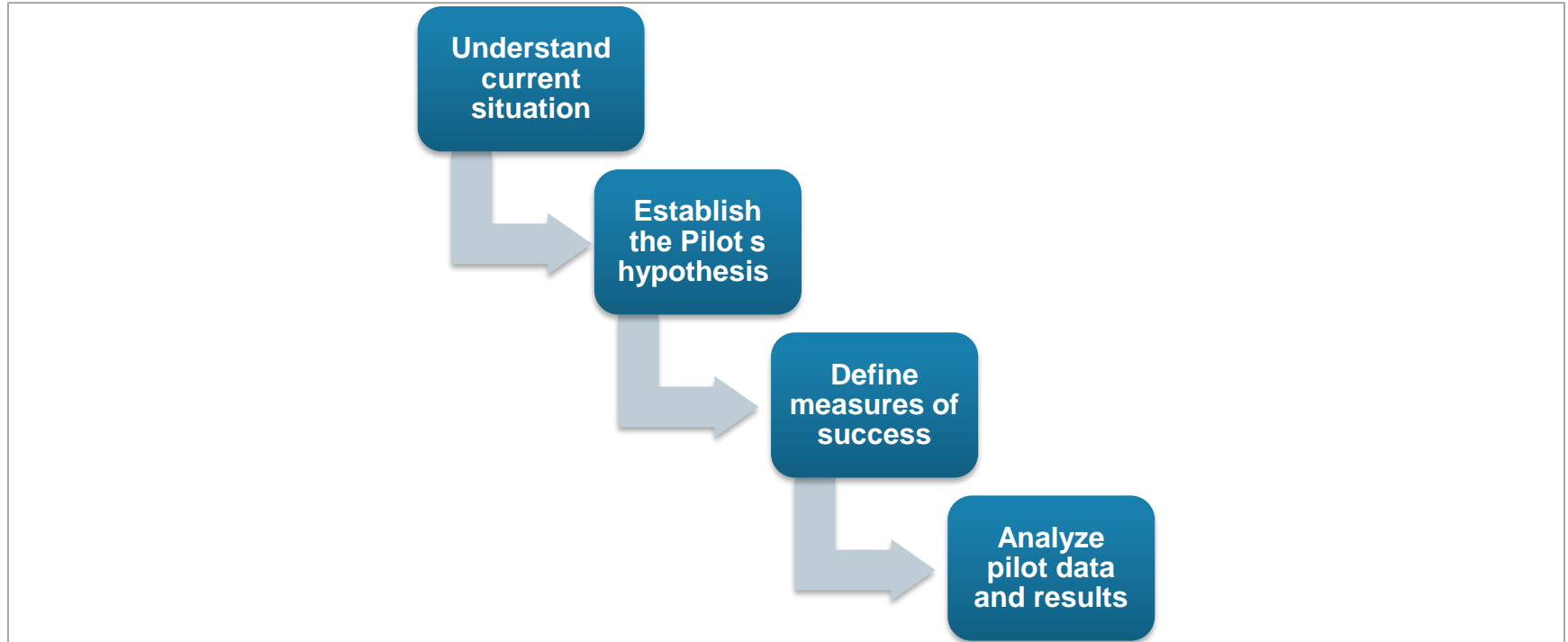- Development of an expandable and easy to replicate Alexa Skill leveraging CV data.

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Performance Measurement Approach

Nayel Urena Serulle, ICF

System Performance Measurement Approach

Understand current situation

Establish the Pilot s hypothesis

Define measures of success

Analyze pilot data and results

- **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.

Connected Vehicle Pilot Deployment Program Phase 2

Final System Performance Report, Baseline Conditions – WYDOT CV Pilot

www.its.dot.gov/index.htm
Final Report – July 30, 2018
Publication Number: FHWA-JPO-17-474

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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

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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.

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Data Analysis

- 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.
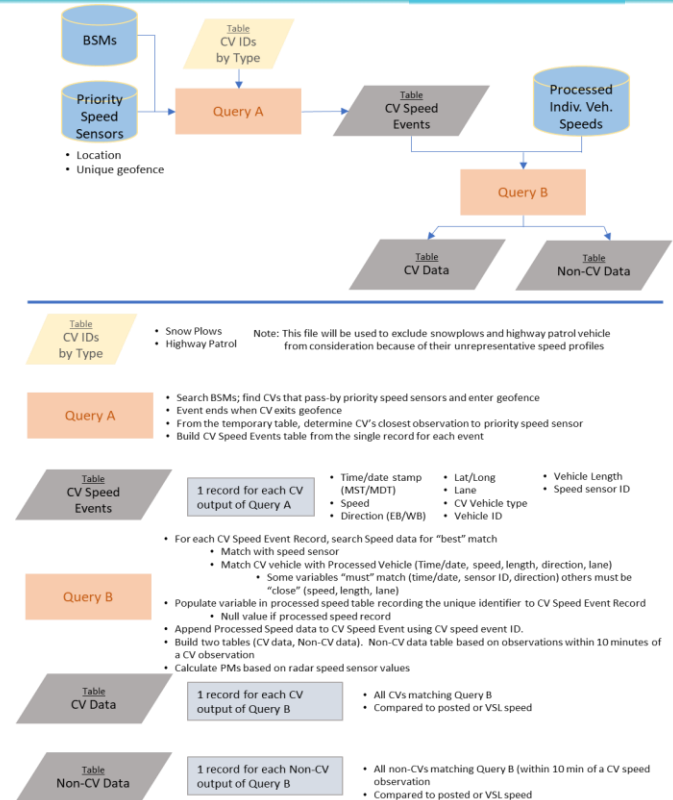
Summary of Performance Findings

Nayel Urena Serulle, ICF

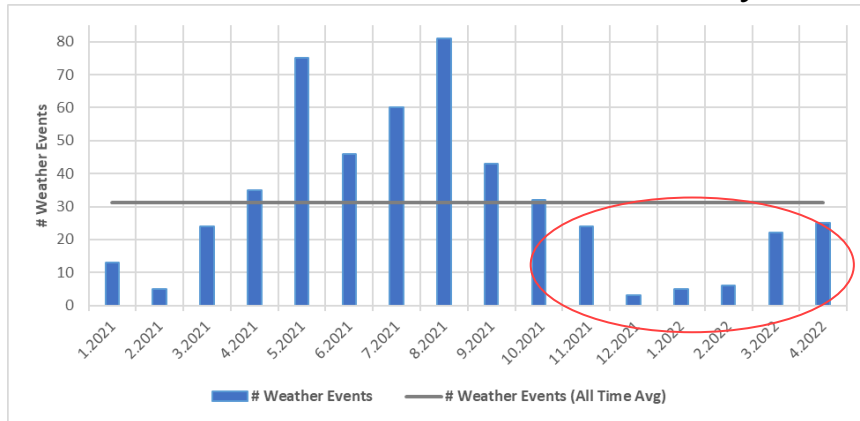Rhonda Young, Gonzaga University

Setting the Stage

- **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
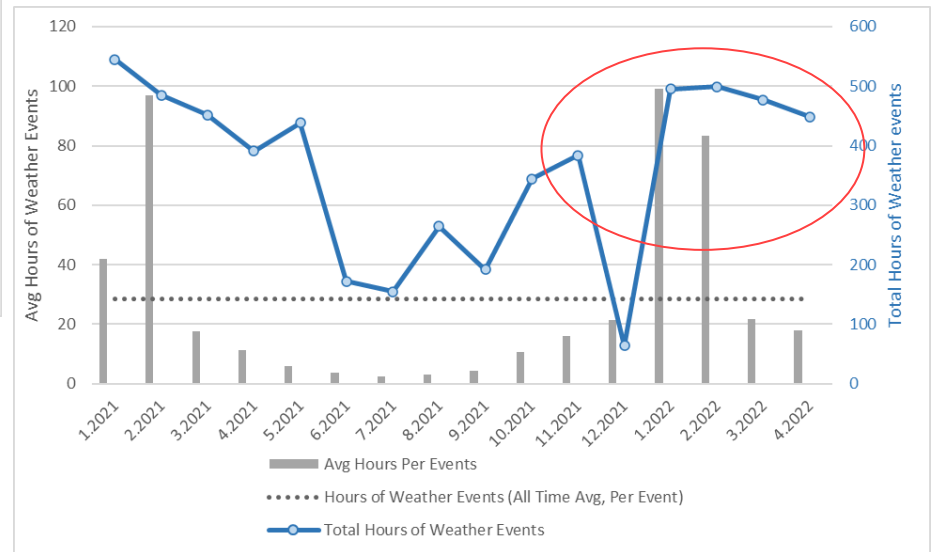   - (4) CV hours of operation

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- 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.

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- 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

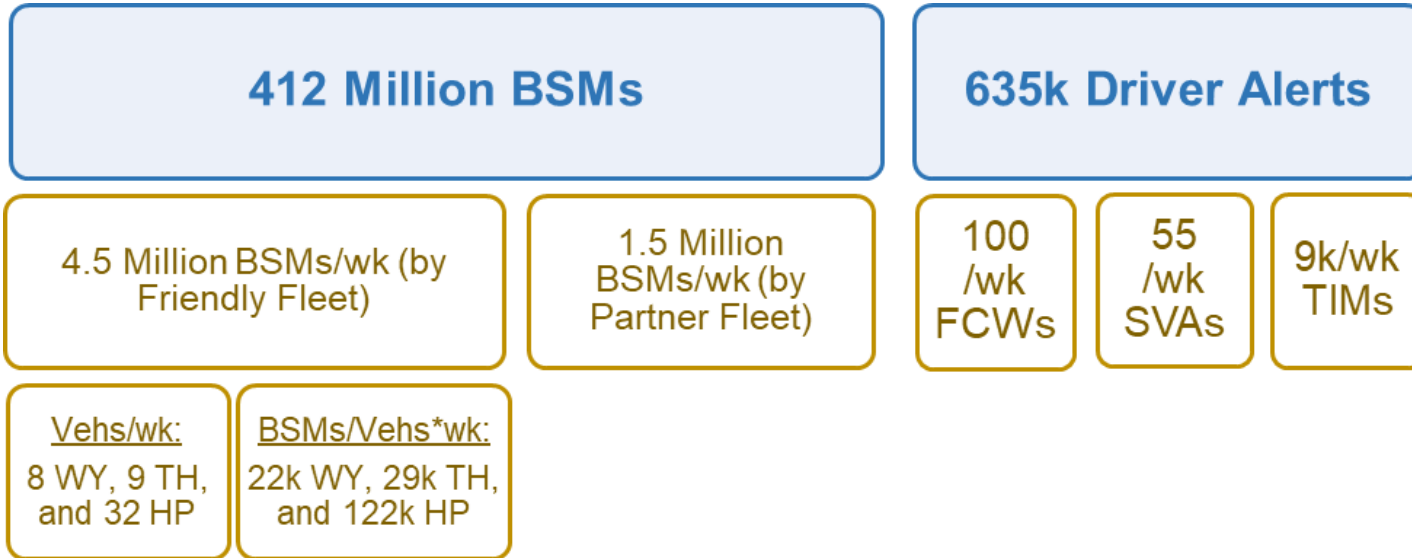**U.S. Department of Transportation**
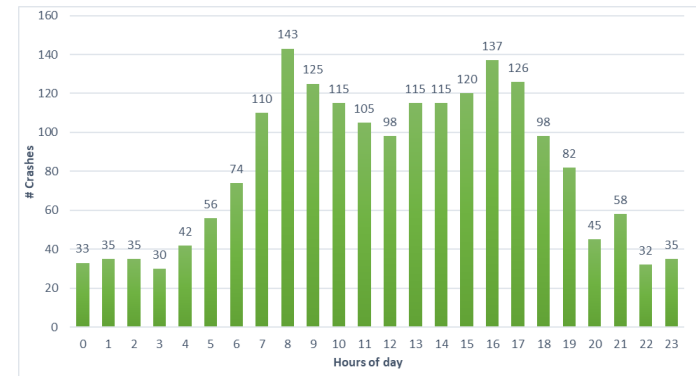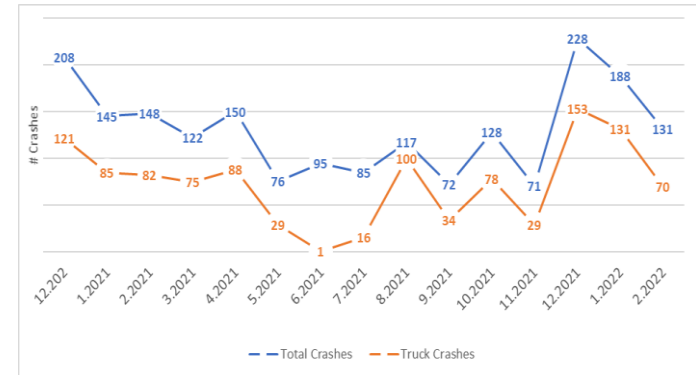
CV System Operations

- 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 ID_s. 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.

412 Million BSMs

635k Driver Alerts

4.5 Million BSMs/wk (by Friendly Fleet)

1.5 Million BSMs/wk (by Partner Fleet)

100 /wk FCWs

55 /wk SVAs

9k/wk TIMs

Vehs/wk:
8 WY, 9 TH, and 32 HP

BSMs/Vehs*wk:
22k WY, 29k TH, and 122k HP

* Between January 1, 2021, and April 30, 2022, within the I-80 corridor

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CV System Operations – Outliers

Month	FCW Outliers	SVA Outliers
Year 2021		
January	Jan' 23-24: 3,084	Jan' 6-7: 113,983 Jan' 23-24: 6,159 Jan' 30: 579
February	Feb' 11: 955	Feb' 5: 511
March	No outliers detected.	Mar' 16: 11,158
August	Aug' 10: 3,604	No outliers detected.
November	Nov' 20: 3,344	Nov' 20: 1,430
December	Dec' 9: 793 Dec' 13-14: 3,941 Dec' 27: 4,557 Dec' 30-31: 6,549	Dec' 10-11: 4,889 Dec' 27: 1,328
Year 2022		
January	Jan' 11: 13,075	No outliers detected.
February	Feb' 16: 8,367	Feb' 16: 896
March	Mar' 7: 9,940 Mar' 15: 18,444	Mar' 10: 10,655 Mar' 15: 48,592
April	Apr' 1: 13,815 Apr' 6-7: 65,566 Apr' 11: 1,463 Apr' 20: 449	Apr' 1: 501 Apr' 4; 30,611 Apr' 7-8: 152,324 Apr' 18; 476 Apr' 20: 64,990

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.**

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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.
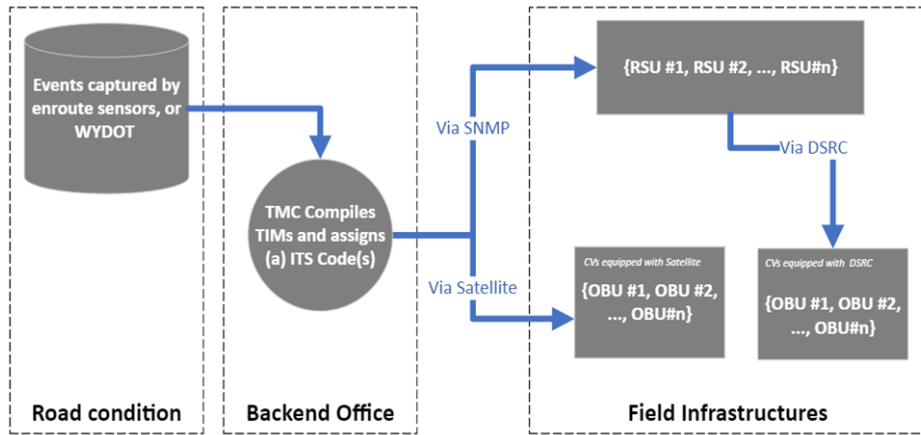 - **Reduced** the refresh time of road condition reports.

Baseline	Target	Post Deployment
4.3 reports	+30%	16.88 **(+293%)**
5 sections	+25%	6.4 **(+29%)**
3.9 hours	-25%	3.2 **(-13.5%)**

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Information Dissemination

- One TIM package logs the transmission of a single TIM as it is disseminated across different RUSs and/or OBUs.

TIMs Generation and Flow

Timeframe	No. TIM Packages	No. TIM Records
01.2021	1,860	36,784
02.2021	9,956	48,053
03.2021	6,236	68,520
04.2021	4,835	32,064
05.2021	3,524	45,436
06.2021	1,443	25,656
07.2021	1,405	36,111
08.2021	2,173	52,981
09.2021	936	39,135
10.2021	5,152	38,777
11.2021	2,995	38,957
12.2021	13,239	40,117
01.2022	10,989	46,134
02.2022	9,121	23,312
03.2022	6,754	16,861
04.2022	5,791	35,602

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.

Timeframe	No. TIM Packages	% TIMs received by at least one OBU via Satellite	% TIMs received by at least one OBU via Satellite or RSU
01.2021	1,860	91.8%	92.0%
02.2021	9,956	92.8%	93.0%
03.2021	6,236	89.2%	89.3%
04.2021	4,835	90.6%	91.0%
05.2021	3,524	86.0%	86.2%
06.2021	1,443	87.6%	87.7%
07.2021	1,405	81.5%	81.5%
08.2021	2,173	85.7%	85.7%
09.2021	936	81.4%	81.5%
10.2021	5,152	92.0%	92.0%
11.2021	2,995	94.4%	94.4%
12.2021	13,239	91.3%	91.5%
01.2022	10,989	93.1%	93.3%
02.2022	9,121	93.7%	94.1%
03.2022	6,754	82.3%	82.43%
04.2022	5,791	91.0%	91.0%

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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.

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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.

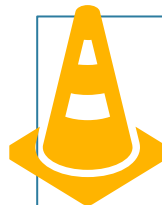 □ This PM requires self notification by the CV fleets managers (Friendly and Partner).

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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

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Reactions seem to be in line with expectations

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

Event	Speed (MPH)	Driver Action
1	21.74	**Vehicle Stopped**
2	77.40	No Action
3	69.88	No Action
4	13.96	**Vehicle Stopped**
5	54.27	**Vehicle Reduced Speed**
6	77.31	**Vehicle Reduced Speed**
7	77.67	No Action
8	75.70	No Action
9	33.33	**Vehicle Reduced Speed**
10	78.69	**Vehicle Reduced Speed**

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

Event	# of Alerts	Driver Action
1	8	**Vehicle Exited**
2	6	No Action
3	2	No Action
4	6	**Reduced Speed**
5	1	**Reduced Speed**
6	6	**Reduced Speed**
7	1	**Reduced Speed**
8	2	**Reduced Speed**
9	2	**Reduced Speed**
10	1	No Action
11	6	**Reduced Speed**
12	1	**Reduced Speed**
13	3	No Action
14	3	No Action
15	1	No Action
16	4	No Action

Winter storm alerts during the month of Feb 2, 2022

Event	# of Alerts	Alert Types	Driver Action
1	5	Icy Patches (2), Snow, Blowing Snow, Ice	**Vehicle Reduced Speed**
2	2	Snow (2)	**Vehicle Reduced Speed**
3	1	Snow	No Action
4	1	Icy Patches	No Action

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Human Machine Interface Development, and Assessment
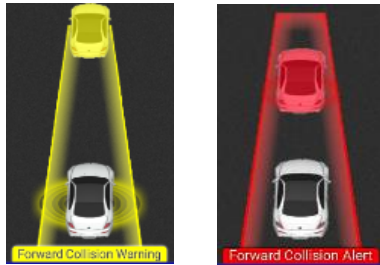# Simulation Analysis of Driver Behavior to CV Applications

Mohamed M. Ahmed, University of Wyoming

ADAS Human Machine Interface

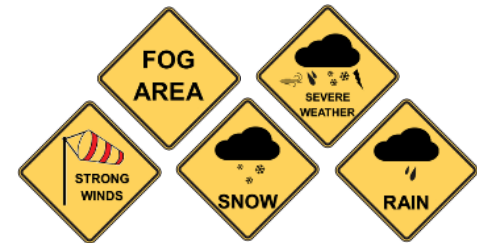Forward Collision Warning (FCW) – *V2V*

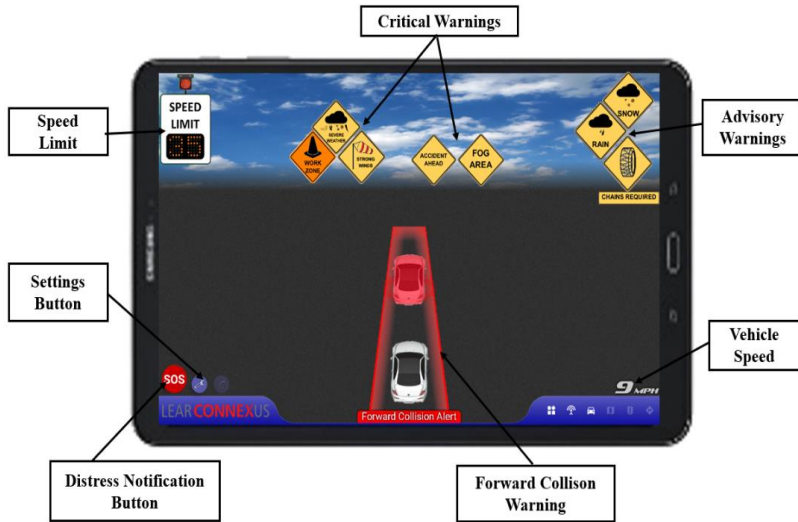Situational Awareness (SA) – *I2V*

Distress Notification (DN) – *V2I & V2V*

Work Zones Warning (WZW) – *I2V*

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.**

CV HMI Equipped on the Truck Driving Simulator

Simple 5-stage iterative training design model [6].

Content → Prototype → Test → Next Cycle → Hand-off Training

Content:
- Literature Review
- Focus group
- One-to-ones
- Task analysis
- Testing

Prototype:
- Training Manual
- Simulator Scenarios

Test:
- Focus group
- Pilot test
- Train-the-trainers
- Observe training

https://www.youtube.com/watch?v=JLaS-s1OvCI&feature=youtu.be

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Emphasis on Training

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

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Emphasis on Training

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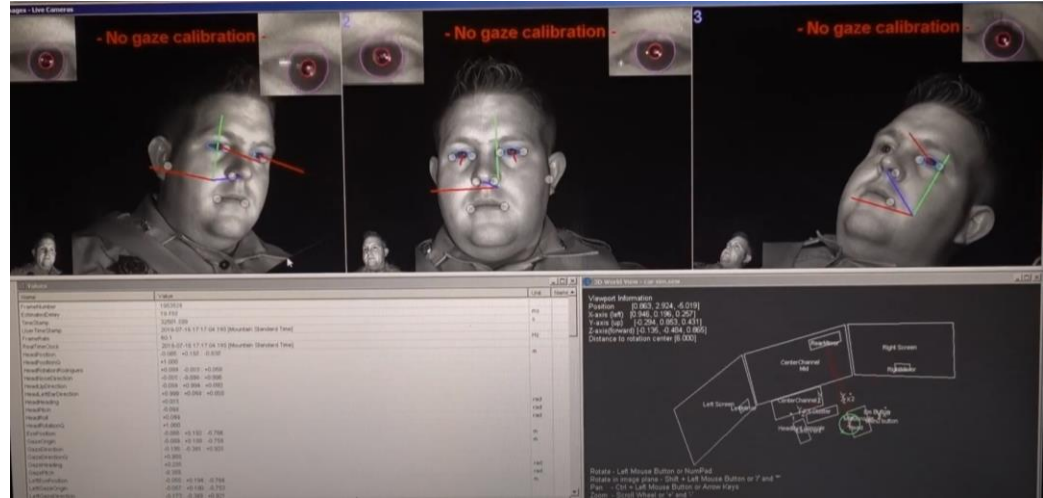
Eye Tracking/ Data Visualization

Omar Raddaoui, and Mohamed Ahmed, Evaluating the Effects of Connected Vehicle Weather and Work Zone Warnings on Truck Drivers' Workload and Distraction Using Eye Glance Behavior, Journal of **Transportation Research Record,** https://doi.org/10.1177/0361198120910743, 2020.
Best Paper Award: Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, Truck and Bus Safety (ACS60) Deborah Freund Paper Award, 2021.

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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

SMART EYE®
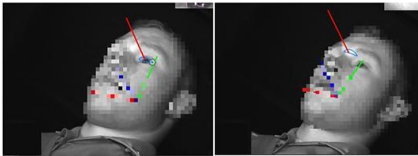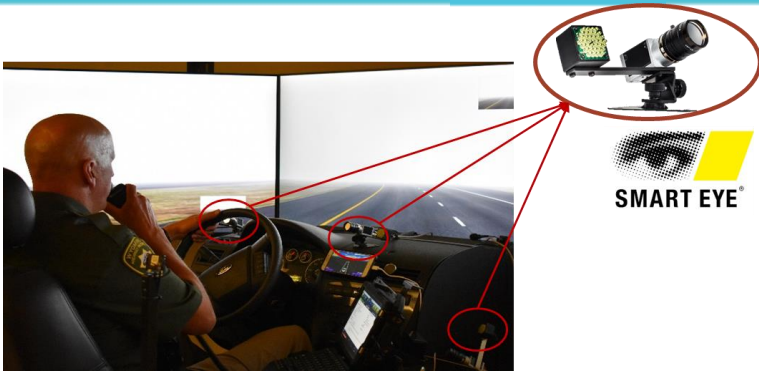
Calibration Loss
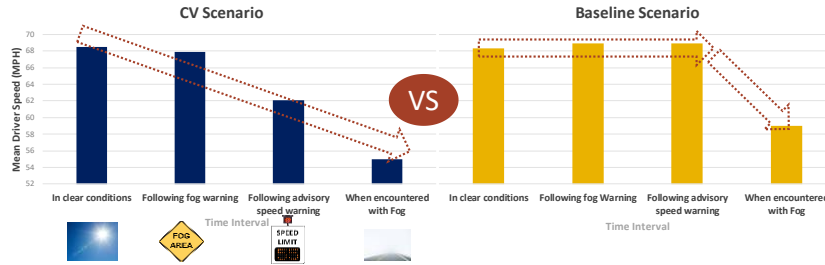
3D World Model

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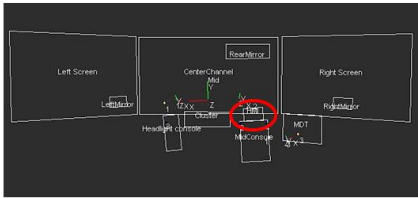
Simulation Analysis
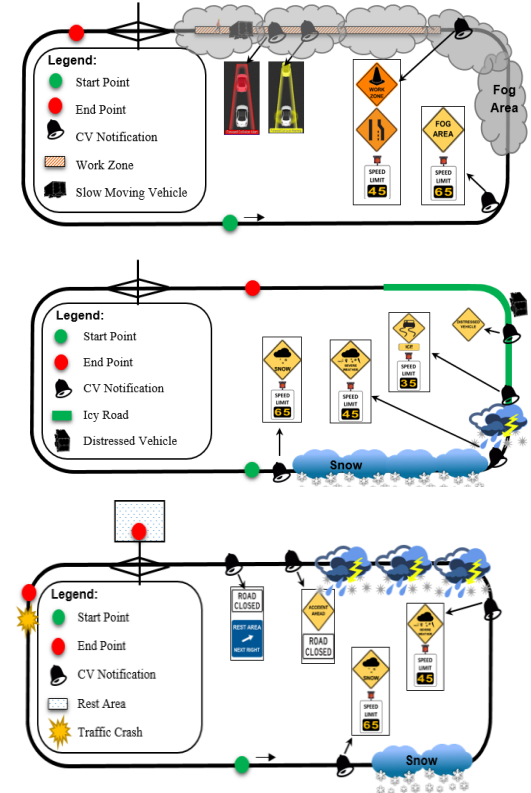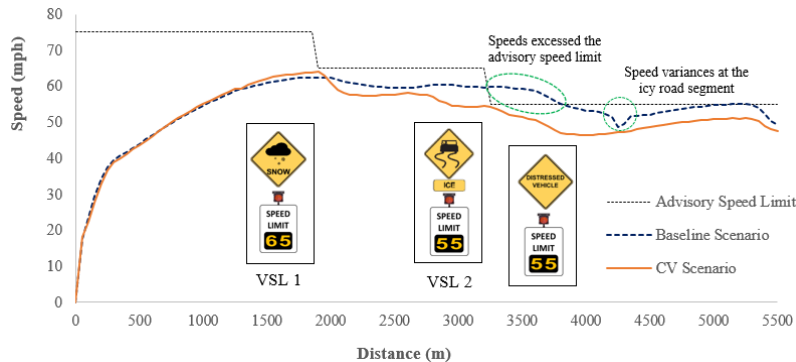
Microsimulation Modeling

✓ SHRP2 and Driving Simulator Data to calibrate and validate;

Cumulative Effect of Weather Warnings

Gradual Reduction in Speed
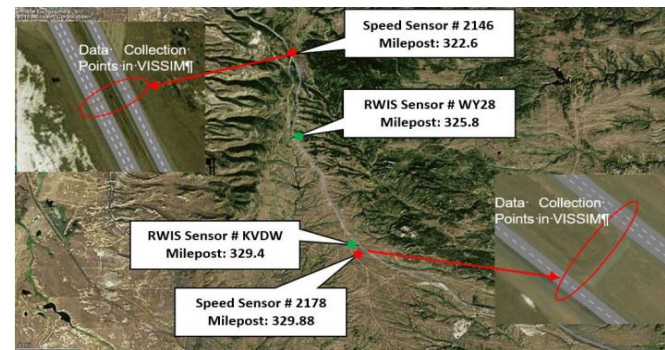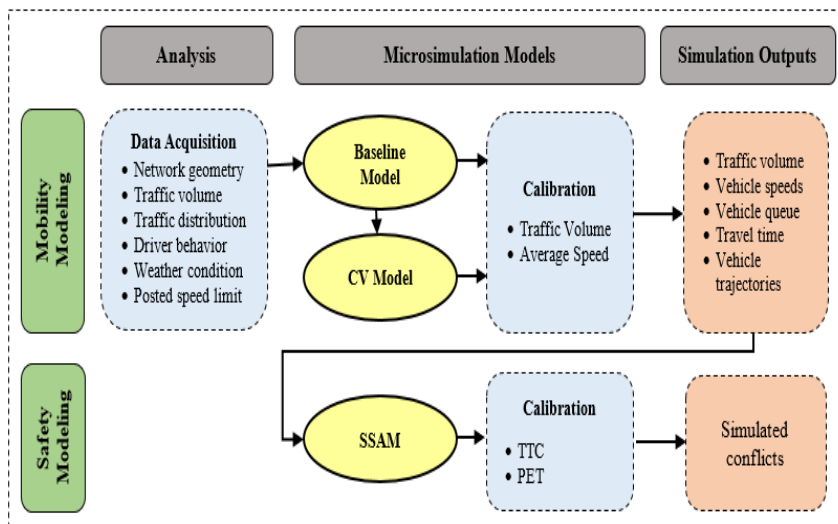
Abrupt Reduction in Speed

Simulation Analysis

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.

Documentation – Journal Publications

- 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.

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Lessons Learned

Tony English, Neaera Consulting

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SCMS Integration

OBU Failing at Scale

Radio Integration

Network Security

Log File Size

DSRC Shadow and
Heavy Freight Vehicles

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.

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 re-startable. Consider time needed for cert top off and CRL/MB reports.

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

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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

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, **<u>it is an entire ecosystem</u>**.

- 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.

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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

Ongoing Risks

- 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.

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Q&A

STAY CONNECTED

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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/

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