CONNECTED VEHICLE PILOT
Deployment Program

Tampa (THEA) CV Pilot Deployment Results and Transition Plan

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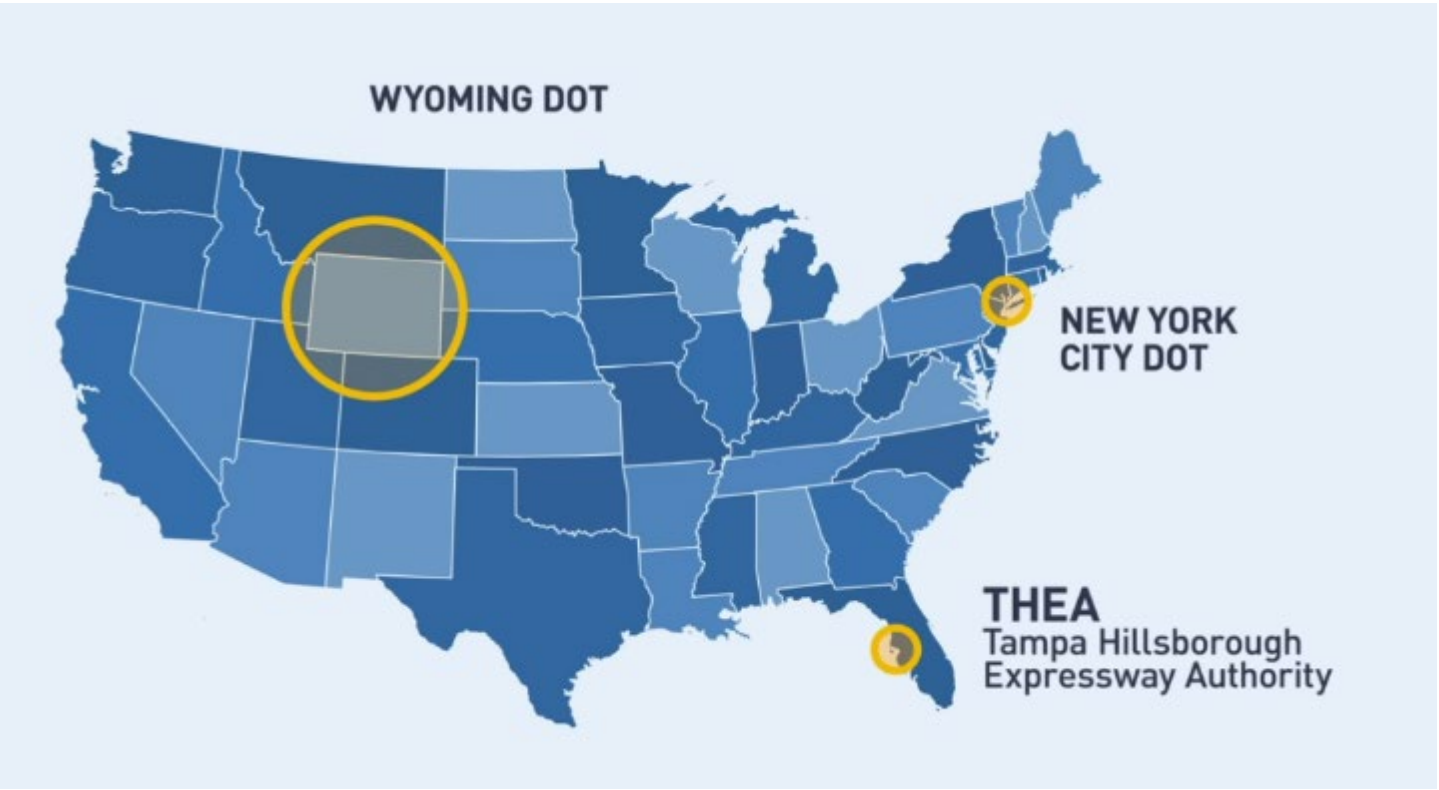
Webinar Agenda

- Purpose of this Webinar
  - Share the deployment performance results from THEA Connected Vehicle Pilot
  - Outline the plan to migrate the current pilot to Connected Vehicle Real-World Test Site (CVRTS).
- Webinar Content
  - Connected Vehicle Pilot Deployment Program Overview
  - THEA Pilot Deployment Performance Results and Transition Plan
  - Stakeholder 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.

CV Pilot Deployment Program Goals

The Three Pilot Sites



THEA CV Pilot Deployment Overview

Steve Novosad

DEPLOYMENT LOCATION

- Located in the core of Tampa Central Business District
- Project managed by the Tampa-Hillsborough Expressway Authority (THEA)
  - Owns / operates Selmon Expressway
  - Owns Meridian Ave traffic signals
- West: Residential community of Brandon
- East: MacDill Air Force Base

THEA CV Pilot Goals

- **Enhance mobility**
  - Travel time
  - Travel time reliability
  - Delay
- **Increase safety**
  - Crashes
  - Conflicts
- **Help sustain environment**
  - Tailpipe emissions

DEPLOYMENT AREA

Original Use Cases and Apps

- Use Case 1 – Morning Backups
  - Forward Collision Warning (FCW)
  - Emergency Electronic Brake Light (EEBL) Warning
  - Curve Speed Warning (CSW)
  - Intelligent Traffic Signal System (I-SIG)
- Use Case 2 – Wrong Way Entry
  - Red Light Violation Warning (RLVW)
  - I-SIG
  - Intersection Movement Assist (IMA)

Original Use Cases and Apps

- Use Case 3 – Pedestrian Safety
  - Mobile Accessible Pedestrian Signal System (PED-SIG)
  - Pedestrian in a Crosswalk Vehicle Warning (PED-X)
  - FCW
  - IMA
- Use Case 4 – Transit Priority
  - Transit Signal Priority (TSP)
  - I-SIG
  - IMA

Original Use Cases and Apps

- Use Case 5 – Streetcar Conflicts
  - Vehicle Turning Right in Front of Transit Vehicle (VTRFTV)
  - I-SIG
  - PED-SIG
  - PED-X
- Use Case 6 – Traffic Progression
  - Probe Data Enabled Traffic Monitoring (PDETM)
  - I-SIG
  - IMA

Changes to Apps by Use Case

- Use Case 1 – Morning Backups
  - Replace Curve Speed Warning (CSW) with End of Ramp Deceleration Warning (ERDW)
  - Replace I-SIG with queue length calculation algorithm
- Use Case 2 – Wrong Way Entry
  - Replaced RLVW with Wrong Way Entry (WWE) app

Changes to Apps by Use Case

- Use Case 3 – Pedestrian Safety
  - Replaced PED-SIG and PED-X with Pedestrian Collision Warning (PCW)
- Use Case 4 – Transit Priority
  - Replaced I-SIG with NTCIP 1202 v2 communication to the signal controller
  - Proposed to add Pedestrian Transit Movement Warning(PTMW)
- Use Case 5 – Streetcar Conflicts
  - PED-SIG and PED-X proposed to be replaced with PTMW
- Use Case 6 – Traffic Progression
  - Replaced Probe Data Enabled Traffic Monitoring (PDETM) by internal analytics

Final Use Case Apps

- Use Case 1 – Morning Backups
  - FCW
  - EEBL
  - ERDW
- Use Case 2 – Wrong Way Entry
  - WWE
  - Note while IMA could occur in this Use Case area, it was not the focus of this Use Case

Final Use Case Apps

- Use Case 3 – Pedestrian Safety
  - PCW
  - Note: While FCW and IMA could occur in this Use Case area, it was not the focus of the Use Case.
- Use Case 4 – Transit Priority
  - TSP
  - IMA

Final Use Case Apps

- Use Case 5 – Streetcar Conflicts
  - VTRFTV
- Use Case 6 – Traffic Progression
  - I-SIG
  - IMA

THEA CV Pilot Deployment Performance Results

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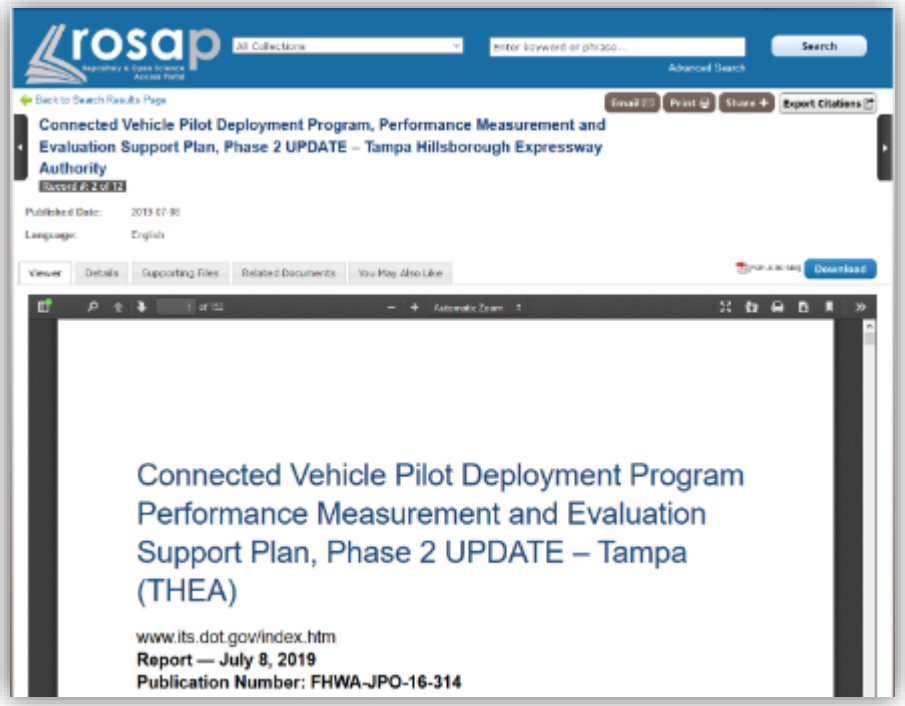
Performance Measurement & Evaluation Support

Main Goals

- Develop and implement Performance Measurement and Evaluation Support Plan (PMESP)
- Data Collection
- Data Sharing with USDOT and Independent Evaluators
- Develop CV Pilot Dashboard
- Final Impact Assessment



PERFORMANCE MEASURES

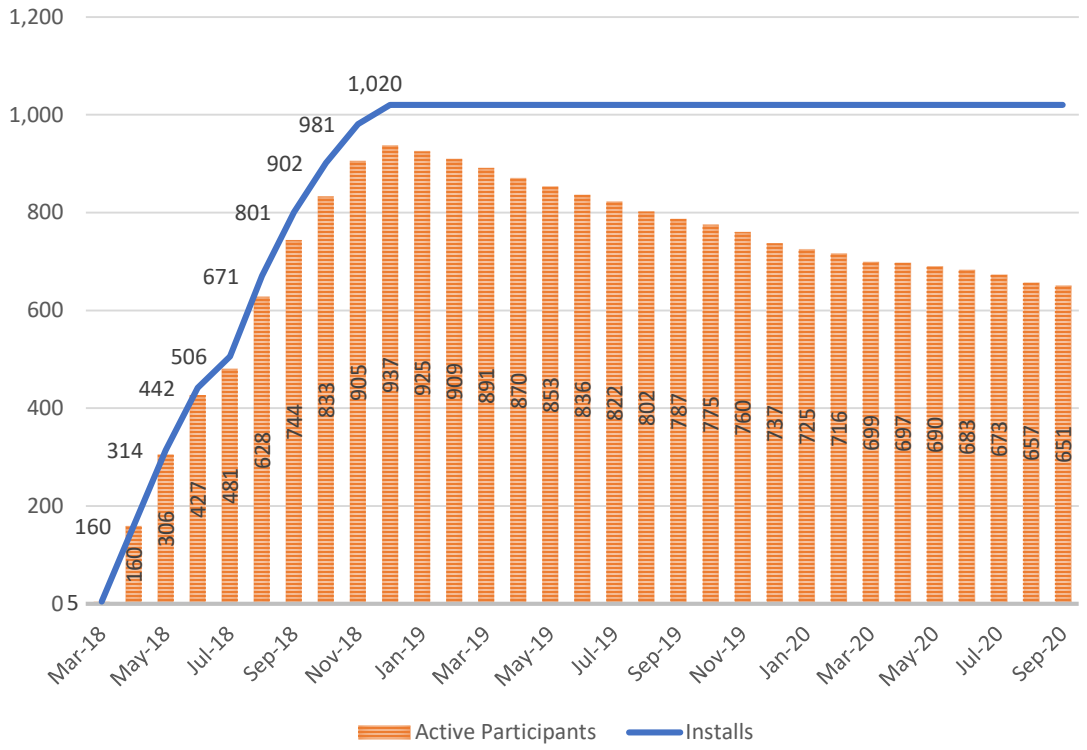
Pillars	Performance Measures	UC1 Morning Backups	UC2 Wrong-Way Entries	UC3 Pedestrian Safety	UC4 Transit Signal Priority	UC5 Streetcar Conflicts	UC6 Traffic Progression
Mobility	Travel time	P/A	P	P			P/A
	Travel time reliability	P/A		P			P/A
	Queue length	P/A		P			P
	Vehicle delay	P	P	P			P
	Percent (%) arrival on green	P			P		P
	Bus travel time				P		
	Bus route travel-time reliability				P		
	Percent (%) arrival on schedule				P		
	Excess time spent in idle	P/A			P		P
Safety	Crash comparison	P/A	P/A	P/A		P/A	P/A
	Types of crashes	P/A	P/A			P/A	P/A
	Severity of crashes	P/A	P/A	P/A		P/A	P/A
	Type of conflicts	P/A	P/A	P/A		P/A	P/A
	Severity of conflicts	P	P	P		P	P
	Approaching vehicle speed	P		P			P
	No. of alerts from apps	P/A	P/A	P/A		P/A	P/A
Environmental	Emissions reductions in idle	P	P	P	P		P
	Emissions reductions in running	P	P	P	P		P
Agency Efficiency	Mobility improvements through the mobility pillar analysis	P/A	P/A		P		P
	Safety improvements through the safety pillar analysis	P/A	P/A	P/A		P/A	P/A
	Customer satisfaction through opinion survey and/or CV app feedback	P/A	P/A	P/A	P	P/A	P/A

P = Planned, A = Actual

Experimental Design & Participant Recruitment

Participants exposed to HMI via experimental design:

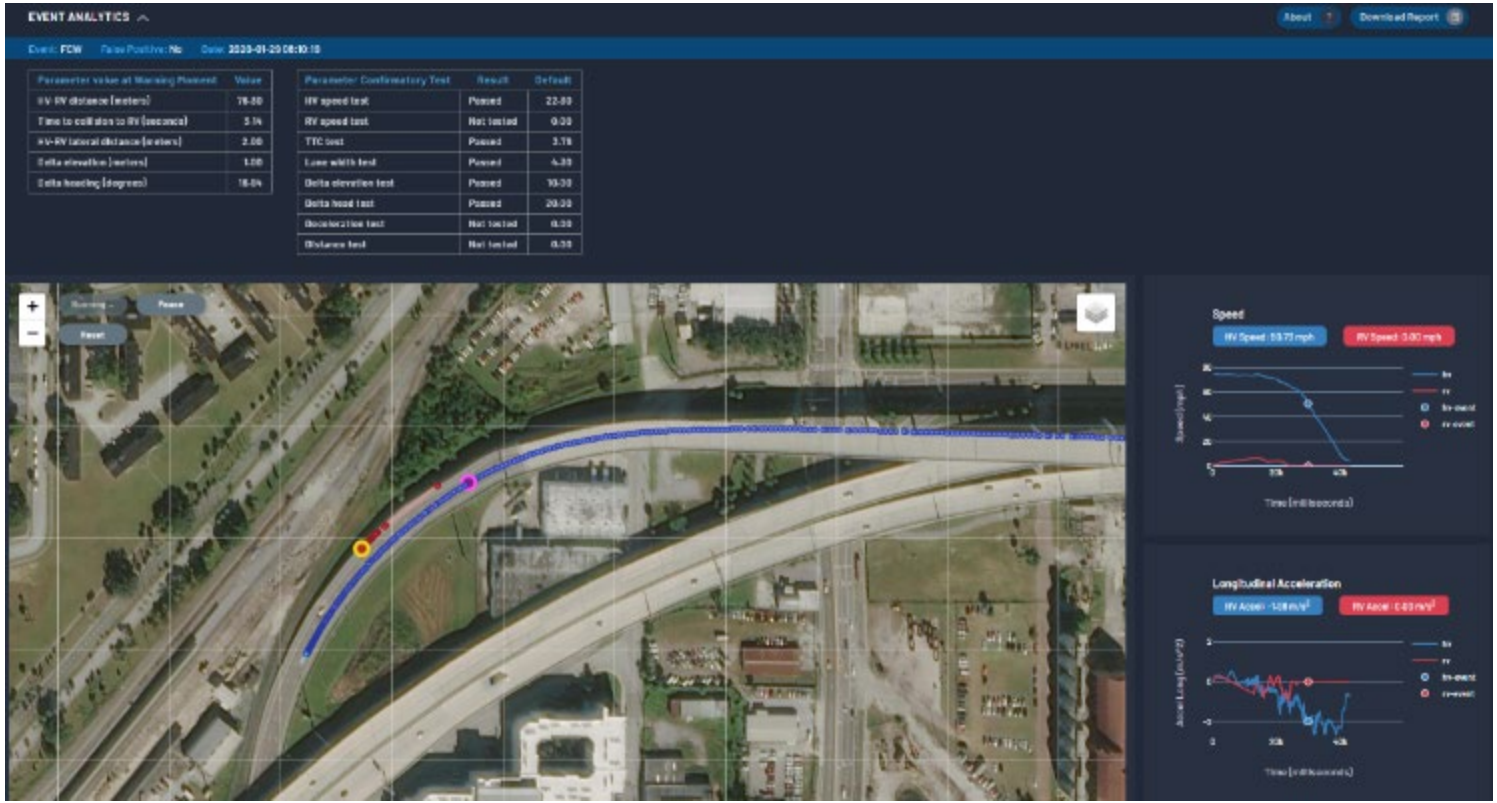
- Treatment (HMI on)
- Control (HMI off, stealth mode data collection)
- Group Assignment
  - ~ 2 to 1 match stratified by sex, age, income, education
  - 1,012 participants
  - Treatment = 621
  - Control = 391



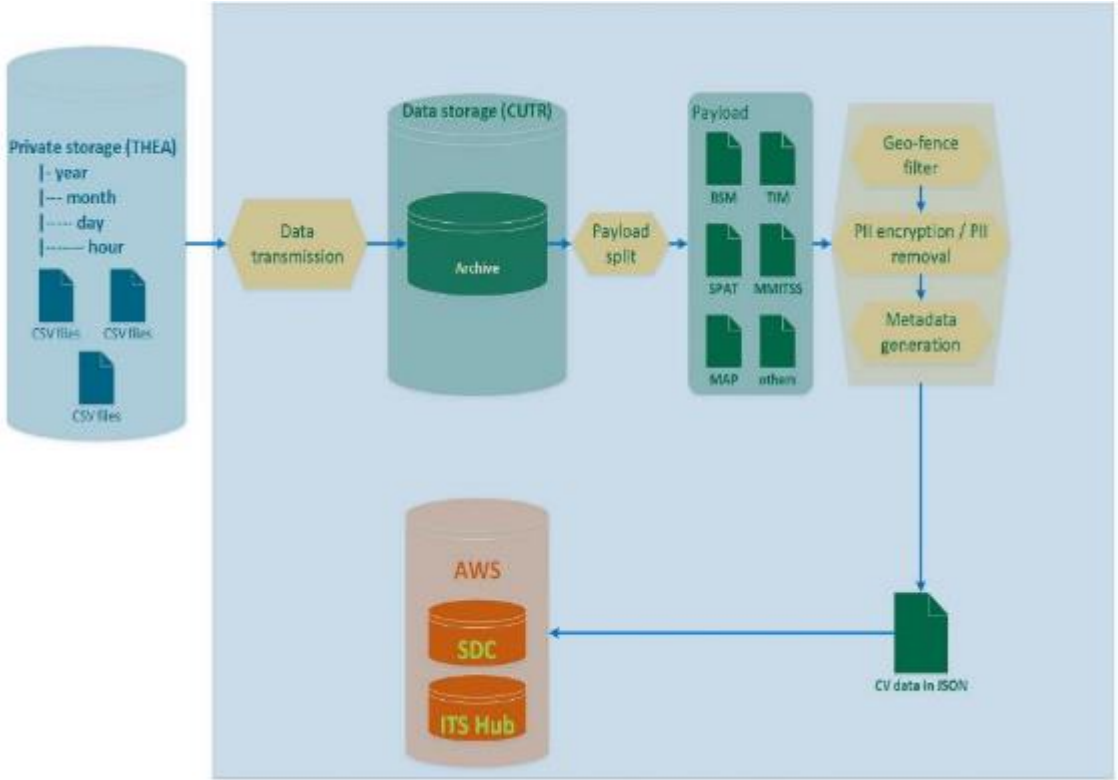
PERFORMANCE MEASUREMENT DASHBOARD

- 16+ Billion observations database
- Multiple stakeholders
- USDOT management
- USDOT analysts
- Independent evaluators
- Near-real time reporting
- Downloadable reports
- Custom queries
- V2V and V2I false positive assessment
- Overall impact evaluation

DATA ANALYTICS



DATA MANAGEMENT & SHARING



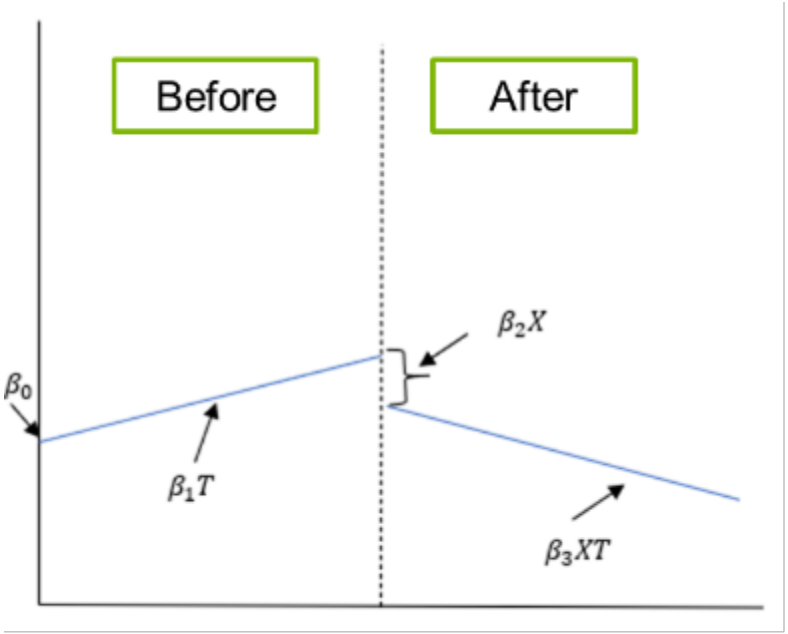
- CUTR Dedicated servers
- Database development (CV and non-CV Data)
- 24/7 Batch-uploading to USDOT Secure Data Commons (SDC) and ITS Public Data Hub
- Data parsing, repackaging, sanitization
- OBU vendor support to application development and testing

MOBILITY ANALYSIS - METHODOLOGY

- Regression modeling

  $Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_3 X_t T_t + \beta_4 Z_t + \epsilon_t$

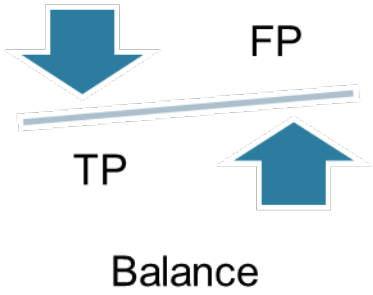
- Y_t is the outcome variable (mean travel time),
- X_t represents ERDW intervention (pre-intervention period is 0, otherwise 1),
- T_t is time measuring days over the analysis period,
- $X_t T_t$ is an interaction term,
- Z_t is a vector of controls for confounding factors (e.g., weather).



Visual Depiction of Interrupted Time-Series ERDW Assessment

Safety Analysis - Methodology

- Adopting Four Terms:
  - True Positive (TP) – An instance of a warning issued when there is a conflict
  - True Negative (TN) – An instance of NO warning issued when there is NOT a conflict (i.e., normal conditions)
  - False Positive (FP) – An instance of a warning issued when there is NOT a conflict
  - False Negative (FN) – An instance of a warning not issued when there is a conflict



SAFETY ANALYSIS - METHODOLOGY

Step 1
FP and TP Analysis

- OBU Data Logs to analyze warnings
- Identify the warning sequence and unique events
- 30-second before/after warning event profile assessment
- Identify FP and TP

Step 2
TN and FN Analysis

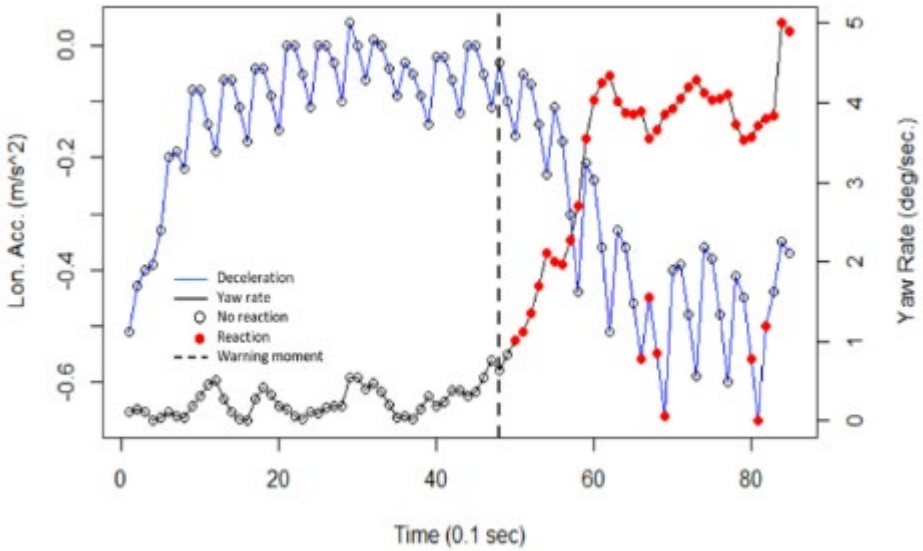
- RSU BSMs for HV-RV interaction count assessment
- Identify unique HV-RV interactions and potential conflicts
- 30-second before/after potential conflicts profile assessment
- Identify TN and FN

Step 3
True Conflict Analysis

- Use Step 1 and Step 2 output to estimate FP, FN, TP, and TN rates
- Identify factors affecting the analysis
- Identify and analyze reactions to warnings

DRIVER REACTION TO WARNINGS - Methodology

- Developed data-driven method to detect and identify reaction based on acceleration and yaw rate*
- Identification of reaction before and/or after the moment of warning



Example of Expected Driver Reaction to Warning

* Kamrani, M., S. Concas, and A. Kourtellis, *Systems and methods for detecting the location of debris and unexpected objects on roads*. US Patent App. 16/845,128, 2020. https://patents.google.com/patent/US20200327807A1/en

UC1: Morning Backups

Applications Deployed:

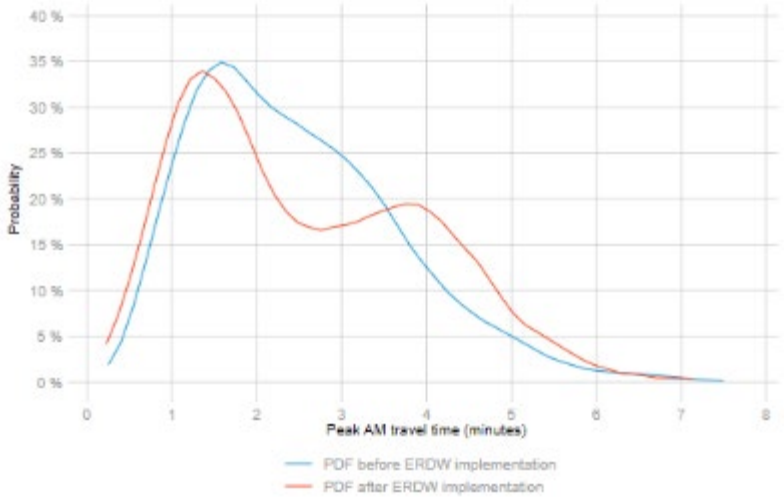
- End of Ramp Deceleration Warning (ERDW)
- Forward Collision Warning (FCW)
- Electronic Emergency Brake Light (EEBL)
- I-SIG (not successfully deployed)

Overall Analysis Period:

- 2/2019 - 3/2020*

** On March 20th, 2020, the REL was set to the eastbound direction 24/7, no westbound travel into Tampa*

UC1: Mobility Analysis



Before-After ERDW Deployment Travel Time Probability Density Functions

- Replication of RSU queue length estimation
- V2I app speed harmonization assessment
- Before/after interrupted time-series analysis

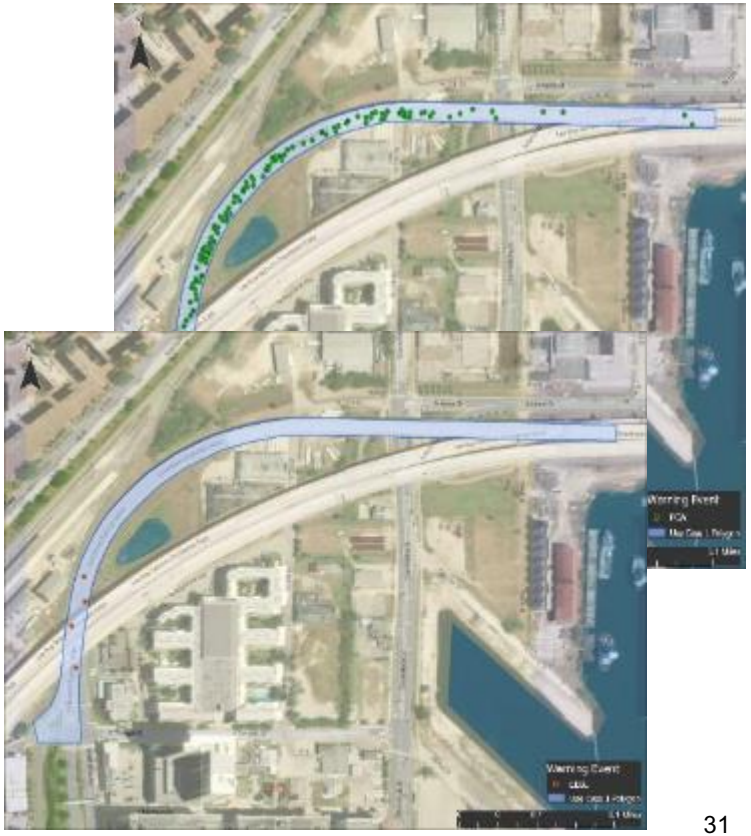
UC1: Mobility Analysis - Findings

- The ERDW contributed to:
- 2.1 percent reduction in mean travel times
- 1.8 percent reduction in idle time or time spent traveling at less than one mile per hour
- 1.8 percent reduction in queue length
- A travel time index reduction from 2.7 to 1.9

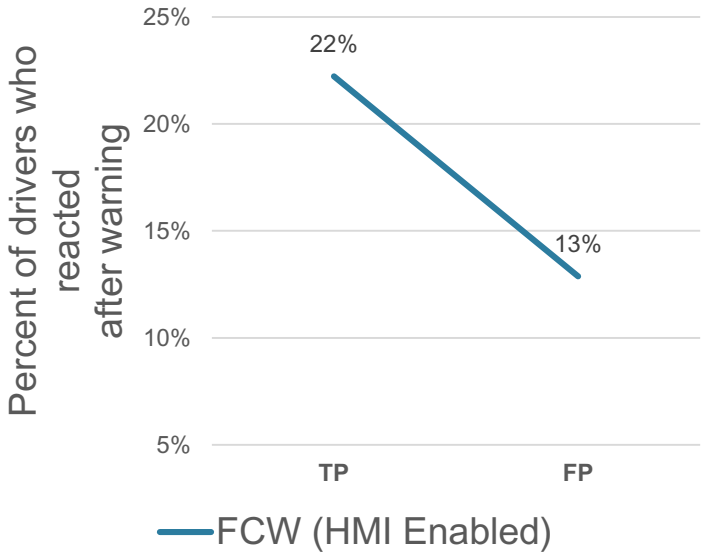
UC1: Safety Analysis Results

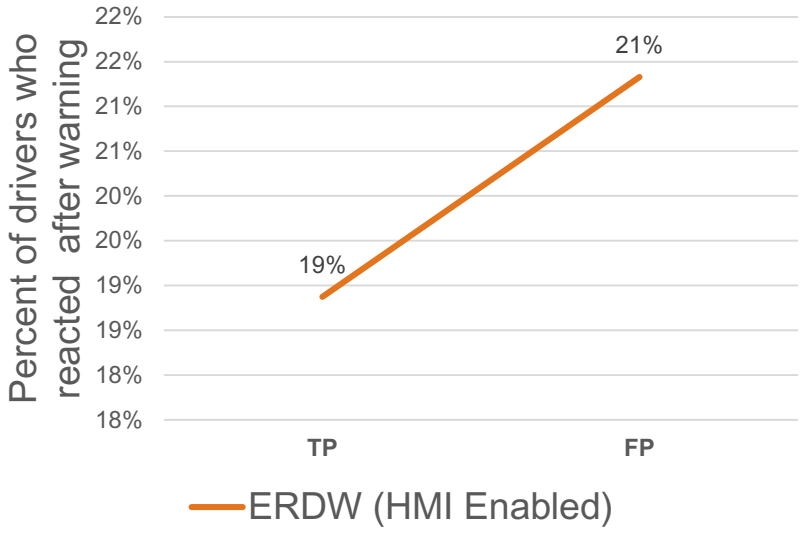
FCW and EEBL Movement Classifications and Rates

Warning	Description	Count	Rate
FCW	Number of warnings (TP + FP + Not tested)	150	--
	V2V interactions	12,450	--
	Conflicts	77	--
	True Positives (TP)	**9**	**11.7%**
	False Negatives (FN)	68	88.3%
	Non-conflicts	12,373	--
	True Negatives (TN)	12,241	98.9%
	False Positives (FP)	132	1.1%
EEBL	Number of warnings (TP + FP)	4	--
	V2V interactions	4,955	--
	Conflicts	43	--
	True Positives (TP)	**1**	**2.3%**
	False Negatives (FP)	42	97.7%
	Non-conflicts	4,912	--
	True Negatives (TN)	4,909	99.9%
	False Positives (FP)	3	0.1%



UC1: Driver Reaction to FCW and ERDW





UC1: Lessons Learned

Mobility

- Changes in lane queue calculation method resulted in evaluation period of less than 2 months
- Need to be prepared to implement changes at a fast pace to deploy solution in a timely manner
- ERDW can be tuned to deliver less FPs according to vehicle speed

Safety

- Curvature of REL resulted in high number of FPs for FCW and EEBL due to inability to correctly determine RV lane ahead of HV
- Issues with GPS shift due to urban infrastructure (overpasses/high buildings)

UC2: Wrong Way Entry

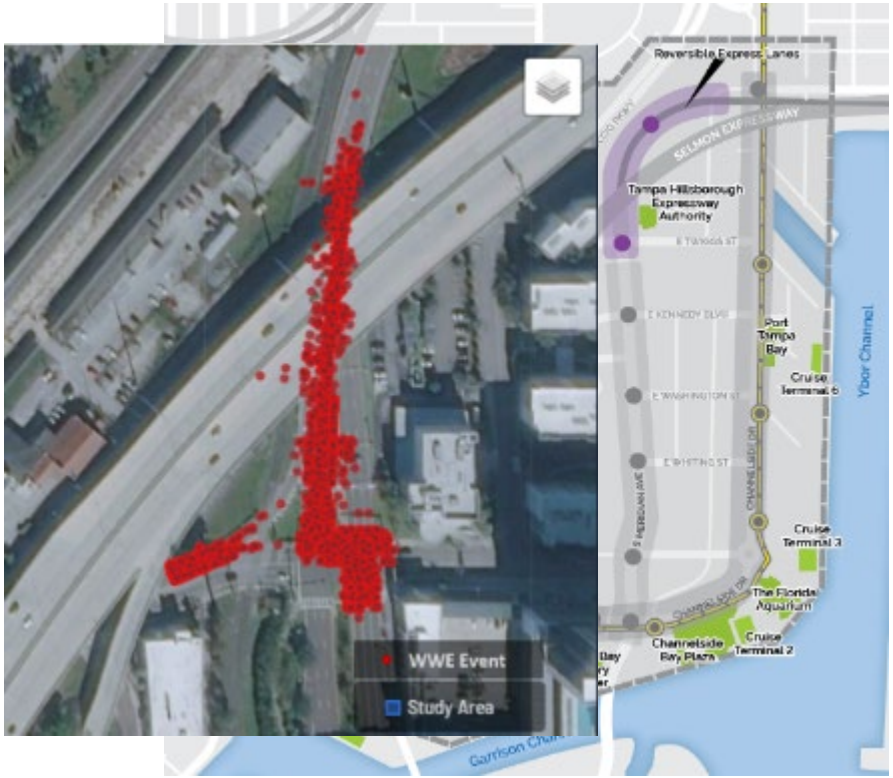
Application Deployed:

- Wrong Way Entry (WWE)
- At the entrance to the Reversible Express Lanes (REL) of the Selmon Expressway

Analysis Period:

- 3/2019 - 3/2020

REL Operation	Total WWE Warnings	Unique WWE Events
REL Westbound AM (6:00 to 9:59)	906	687
REL Eastbound PM (3:00 to 11:59)	5,070	4,137
Total	5,976	4,824

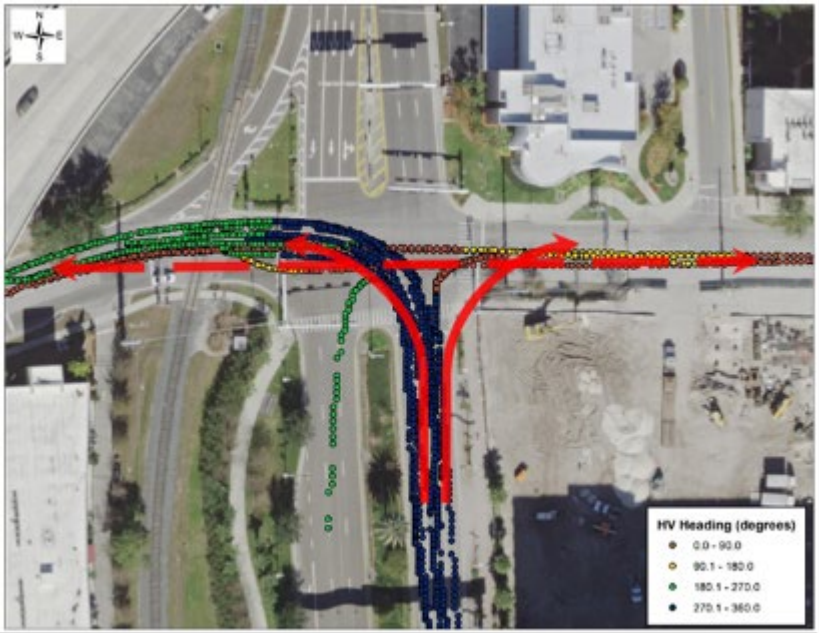


UC2: AM Operation (6:00 AM – 9:59 AM)

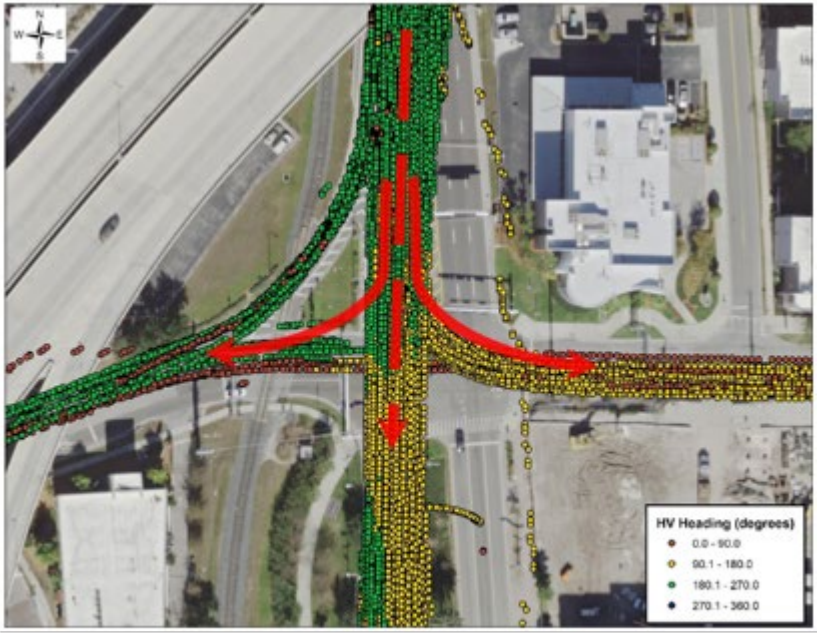
- REL in westbound direction
- Multiple WWE for a unique turning movement (event)
  - Do not enter
  - Wrong way
  - No travel

Description	WWE	Unique WWE events
REL to Twiggs Westbound	882	665
Other	24	22
Total	906	687

UC2: AM WWE Events Turning Movements



REL Westbound to Twiggs St



All Other Directions

UC2: Observed False Positives - AM

Zero vehicle heading (traveling south)

MAP Allowed Lanes and WWE Events

UC2: PM Operation (1:00 PM – 11:59 PM)

- REL is in Eastbound Direction
- Some participants expected to enter the wrong way (as a shortcut)

Movement	WWE Warnings	Unique WWE Events
W. Twiggs St. to REL Eastbound	2,033	1,310
E. Twiggs to REL Eastbound	145	139
N. Meridian Ave to REL Eastbound	2,434	2,279
Other*	458	409
Total	5,070	4,137

**Includes: Meridian to E. Twiggs, Meridian to W. Twiggs, E. Twiggs to Meridian, W. Twiggs to Meridian, E. Twiggs to W. Twiggs, W. Twiggs to E. Twiggs movements could not be assigned.*

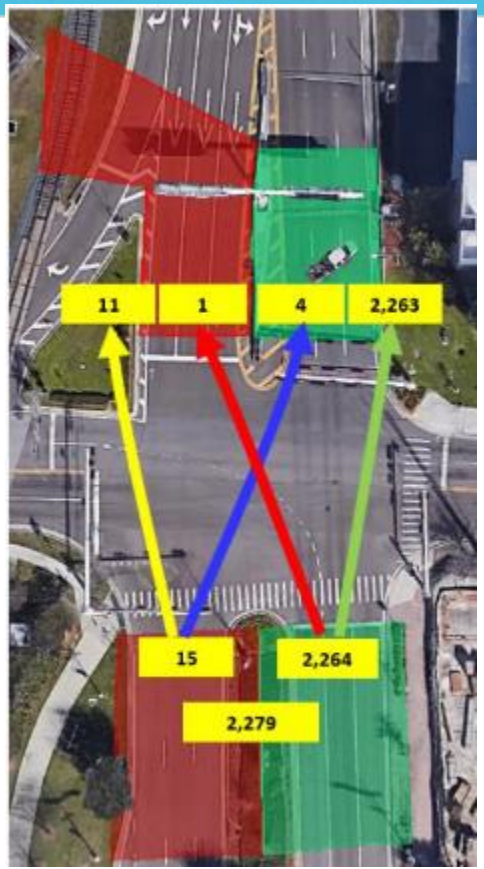
UC2: PM Movement Analysis – Twiggs St. to REL EB

Movement Type	Arrow Color	Comment
Allowed – WWE Not Expected	Green	
Allowed – WWE Not Expected	Blue	
Not Allowed – WWE Expected	Yellow	GPS Signal Drift; potential False Positive
Not Allowed – WWE Expected	Red	Potential True Positive; 18 observed

Unique WWE events
(with one or more WWE warnings)

UC2: Meridian Ave. to REL Eastbound

Movement Type	Arrow Color	Comment
Allowed – WWE Not Expected	Green	
Allowed – WWE Not Expected	Blue	GPS Signal Drift
Not Allowed – WWE Expected	Yellow	GPS Signal Drift
Not Allowed – WWE Expected	Red	Potential True Positive; 1 observed



UC2: Lessons Learned

- WWE application warnings needs fine tuning
  - Estimating the trajectory of the vehicle correctly is a challenge
  - Issues FP “Do not Enter” warnings
  - Suggest revising “Do not Enter”
- Impact of pre-warning in preventing WWE is unknown
- Loss of vehicle heading while stopped causes application to wrongly issue FP warnings – All AM events
- GPS signal drift leads to FP warnings mistakenly taken as entering in the wrong side of the road

UC3: Pedestrian Safety

- Deployed Pedestrian Collision Warning (PCW)

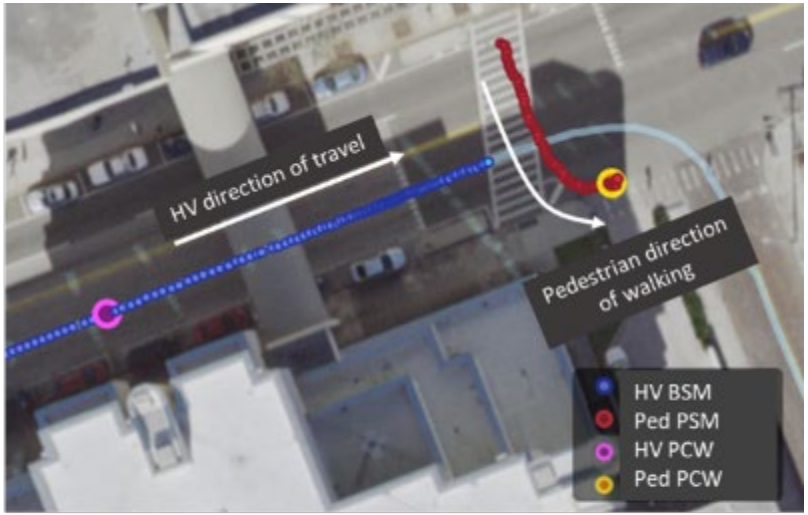
Analysis Periods:

- 3/2019 – 10/2019: pedestrian system utilizing LiDAR sensors
- 6/2020 – 8/2020: pedestrian system utilizing thermal camera sensors. Only test veh data analyzed.

Description	Count	Share
PCW (TP + FP + Not tested)	87	--
Not tested	8	9.2%
False Positives	63	72.4%
True Positives	16	18.4%

UC3: Observed PCW False Positives

Warnings issued when pedestrians are standing on sidewalk



Warnings issued when pedestrians have completed their crossing

UC3: Lessons Learned

- Application needs fine tuning to confirm warning is issued when pedestrians in the crosswalk, not sidewalk
- Have a plan B in case of equipment failure requiring a change of deployment technology
- Note: Data collection ongoing as part of Phase 4

UC4: Transit Signal Priority

- Three fixed routes selected for deployment
- TSP not successfully deployed in the evaluation period
- No evaluation feasible
- Continued improvements expected during Phase 4

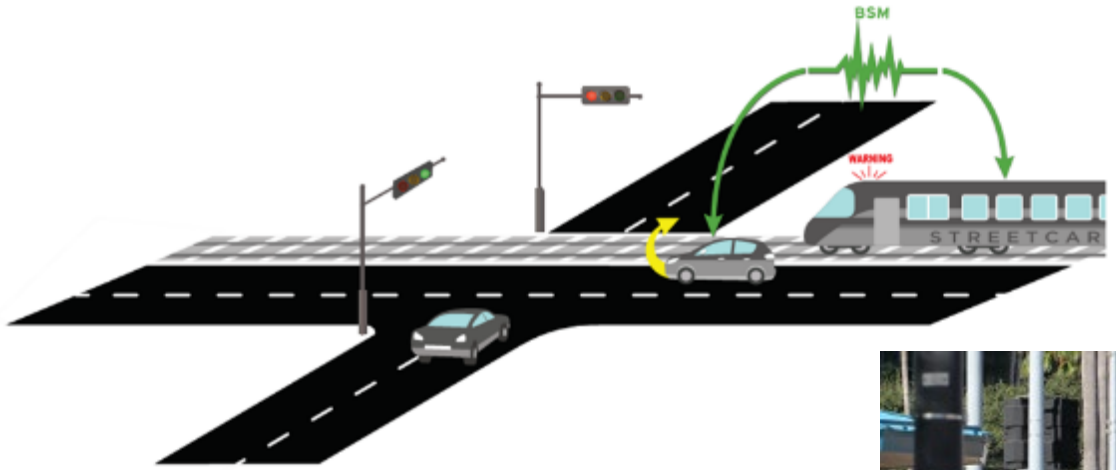
UC5: Streetcar Conflicts

- Deployed Vehicle Turning in Front of Transit Vehicle (VTRFTV)

Analysis period: 3/2019 – 8/2020

Description	Count	Rate
VTRFTV Unique Events (TP + FP)	34	--
V2V Interactions	7,167	--
Conflicts	64	--
True Positives (TP)	4	6.2%
False Negatives (FN)	60	93.8%
Non-conflicts	7,103	--
True Negatives (TN)	7,073	99.6%
False Positives (FP)	30	0.4%

UC5: VTRFTV Operation



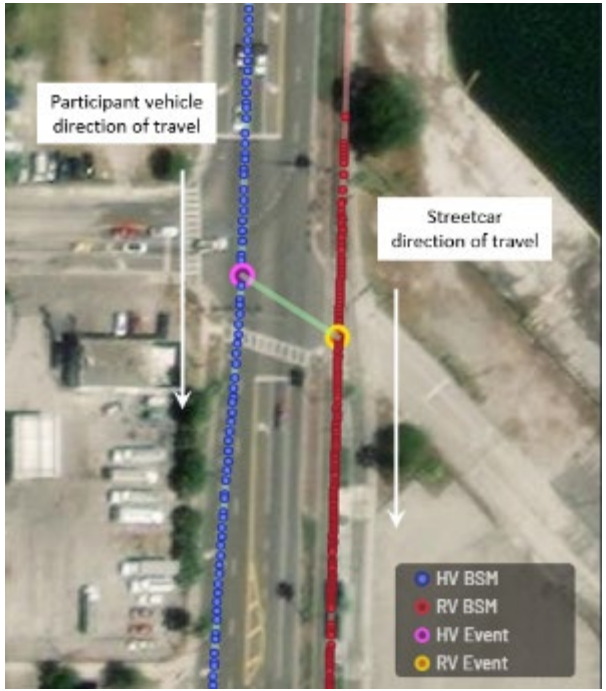
Source: System Architecture Document, Publication FHWA-JPO-17-459

- Application receives BSMs from surrounding vehicles
- Application determined collision trajectory
- Application issues warning to vehicle and transit vehicle

Source: THEA

UC5: Observed VTRFTV False Positives

Vehicle and streetcar traveling in opposite direction



Vehicle and streetcar traveling in same direction but not in adjacent lanes

Vehicle and streetcar traveling at different elevations

UC5: Lessons Learned

- VTRFTV application needs fine tuning to correctly determine the trajectory of the vehicle in relation to the streetcar
- Parameters need fine tuning for elevation difference

Description	Count	Rate (%)
VTRFTV Unique Events (TP + FP)	34	--
V2V Interactions	7,167	--
Conflicts	64	--
True Positives (TP)	4	6.2
False Negatives (FN)	60	93.8
Non-conflicts	7,103	--
True Negatives (TN)	7,073	99.6
False Positives (FP)	30	0.4

UC6: Traffic Progression

Applications Deployed:

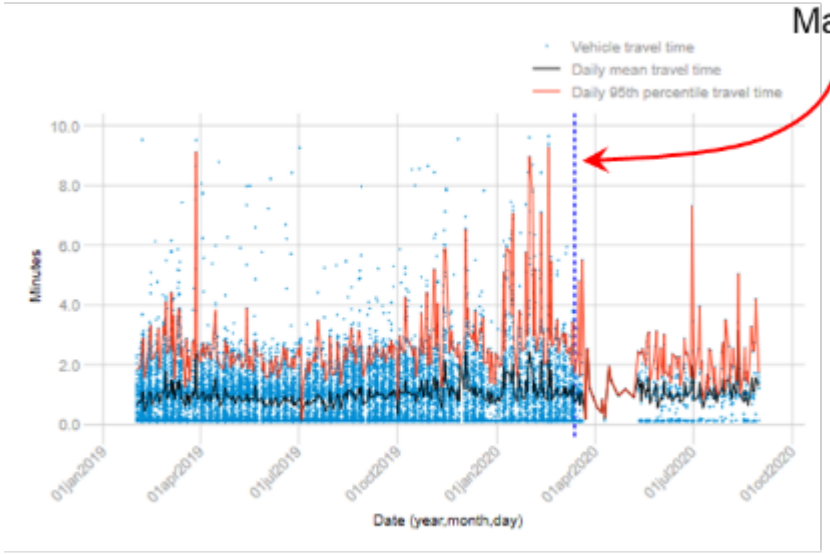
- Forward Collision Warning (FCW)
- Electronic Emergency Brake Light (EEBL)
- Intersection Movement Assist (IMA)
- I-SIG (not successfully deployed to participants)

Analysis Period: 5/2018 - 8/2020

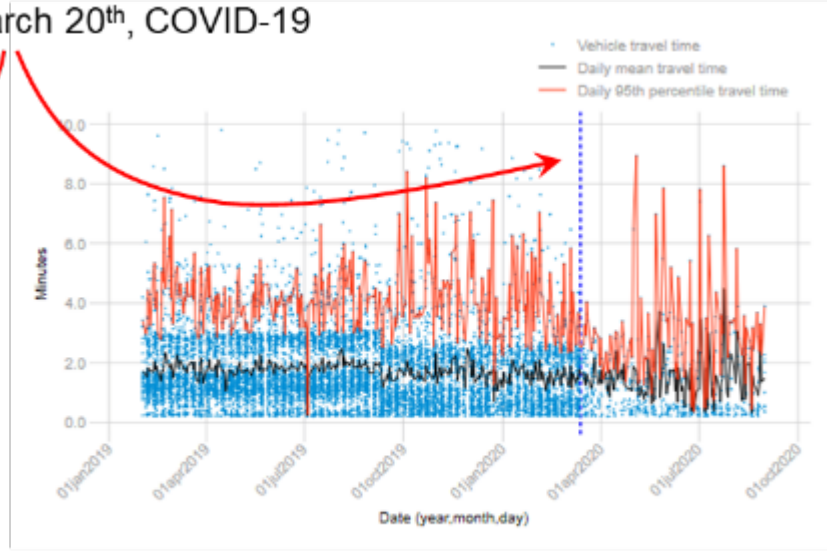
- AM period: 6 – 10am
- PM period: 3 – 7pm

UC6: Mobility Analysis

- Mobility impacts could not be assessed due to unsuccessful deployment of I-SIG
- Baseline data collection useful to conduct COVID impact analysis



Travel Time 10 Min Interval – AM Peak



Travel Time 10 Min Interval – PM Peak

UC6: Safety Analysis – FCW

	AM Period		PM Period	
Description	Count	Rate	Count	Rate
Time spent in area (hours)	282	--	278	--
FCW (TP + FP)	38	--	17	--
V2V interactions	3,237	--	1,656	--
Conflicts	85	--	61	--
True Positives	**14**	**16.5%**	**8**	**13.1%**
False Negatives	71	83.5%	53	86.9%
Non-conflicts	3,152	--	1,595	--
True Negatives	3,128	99.2%	1,586	99.4%
False Positives	24	0.8%	9	0.6%

UC6: Safety Analysis – EEBL

	AM Period		PM Period	
Description	Count	Rate	Count	Rate
Time spent in area (hours)	282	--	278	--
EEBL (TP + FP)	6	--	3	--
V2V interactions	2,517	--	299	--
Conflicts	18	--	4	--
True Positives	3	16.7%	1	25.0%
False Negatives	15	83.3%	3	75.0%
Non-conflicts	2,499	--	295	--
True Negatives	2,496	99.9%	293	99.3%
False Positives	3	0.1%	2	0.7%

UC6: Safety Analysis – IMA

	AM Period		PM Period	
Description	Count	Rate	Count	Rate
Time Spent in Area (Hours)	282	--	278	--
Number of Vehicles	450	--	452	--
IMA (TP + FP + Not tested)	16	--	15	--
V2V Interactions	8,490	--	4,023	--
Conflicts	1	--	5	--
True Positives	**0**	**0.0**	**0**	**0.0**
False Negatives	1	100.0%	5	100.0%
Non-conflicts	8,489	--	4,018	--
True Negatives	8,473	99.8%	4,006	99.7%
False Positives	16	0.2%	12	0.3%

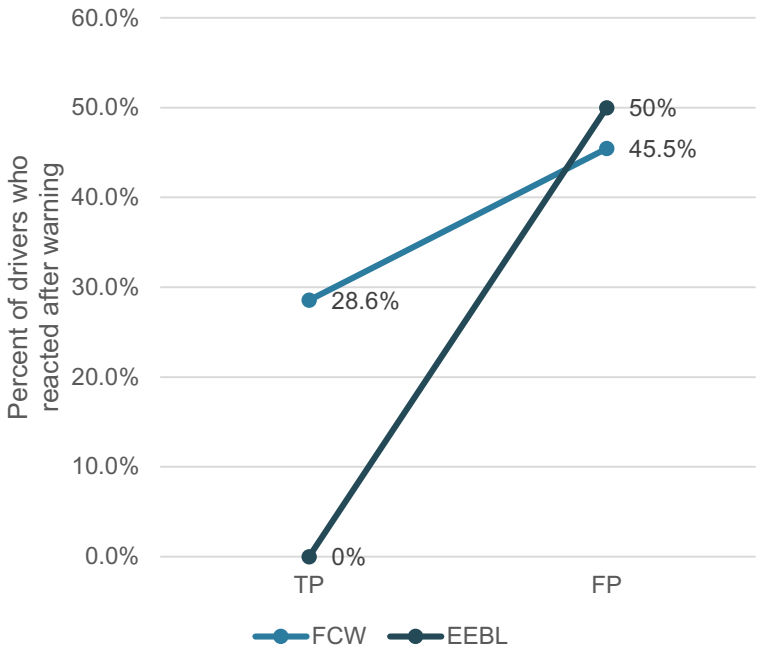
UC6: Observed IMA False Positives

Incorrect Veh Orientation

Large distance between HV-RV

No intersection between HV-RV

UC6: Reaction to Warnings



- No visible True Positives for EEBL
- Drivers might react to traffic conditions instead of issued warning(s)

Drivers reacting to FCW and EEBL with HMI enabled

SUMMARY OF FINDINGS (1)

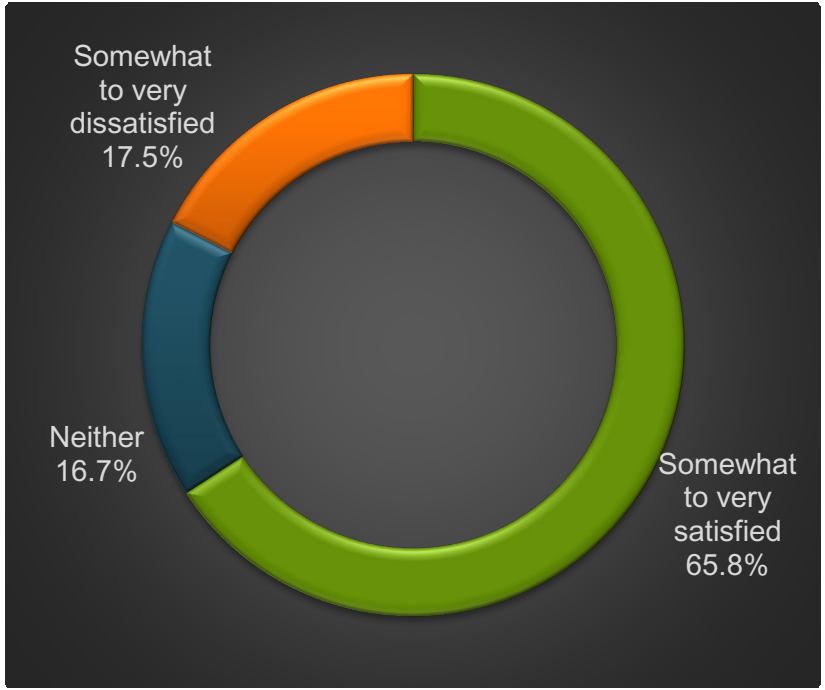
CV Technology

- The broadcasting of speed advisories via the ERDW application contributed to mobility improvements compared with the baseline conditions.
- The safety evaluation uncovered heterogeneity in how the V2V and V2I applications contributed towards improved safety based on the use case being evaluated
  - In UC6 the three applications issued 26 warnings which could have a significant effect in reducing crashes for the corridor
- Lessons learned consider application-specific issues that can be resolved by improving the currently deployed OBU firmware with further research and development

Summary of Findings (2)

Participants Feedback

- About two thirds of the participants were satisfied with the study's participation
- Perceived benefits
  - Safety (66%)
  - Reduced congestion (56%)
  - Less stressful commute (54%)
- Before entering the study, about 46 percent expressed concerns about the impact of CV technology on their privacy. These concerns decreased to 29 percent towards the end of the study.



Overall Participant Satisfaction with the Study

Summary of Findings (3)

CV Application Development

- Fine tuning of V2V and V2I application parameters needs to be fast and effective to quickly resolve issues
- Urban environment (tall buildings, overpasses) creates GPS accuracy challenges
- Some applications were not as mature as initially thought (TSP and I-SIG)

Connected Vehicle Real-World Test Site (CVRTS)

Steve Novosad
THEA CV Pilot System Engineering Lead, HNTB

THEA CV Pilot Phase 4

- Integration of Original Equipment Manufacturers (OEMs)
- Support United States Department of Transportation (USDOT) spectrum interference testing
- Implement Spectrum Interference Testing System (SPITS)

Integration of OEMs

- Partnered with Honda, Hyundai, and Toyota
- Implementing 6 CV Pilot Apps
  - FCW
  - EEBL
  - ERDW
  - PCW
  - WWE
  - IMA
- Developing 1 New App
  - RLVW

Integration of OEMs

- Denso chosen by OEMs as OBU provider
- Goal to Install in OEM customer's vehicles
  - Honda – 75
  - Hyundai – 75
  - Toyota – 50
- Existing Participants receive upgraded OBU
  - 400
- Data
  - Continue to acquire and provide to USDOT
  - Will contain OEM "Sniffed" BSMs at a minimum

SUPPORT USDOT SPECTRUM INTERFERENCE TESTING

- Provide access to USDOT test teams in the CV Pilot area
- Support testing of the USDOT test teams
- Provide access to Spectrum Interference Test System (SPITS)

Spectrum Interference Test System (SPITS)

- Capability to broadcast
  - Dedicated Short Range Communications (DSRC)
  - Cellular Vehicle to Everything (C-V2X)
  - Unlicensed Wifi
- Created a test plan for device testing
- Coordinating test plans with USDOT Spectrum team
- Will be available to device manufacturers and other entities for testing

DEPLOYMENT LOCATION

SPITS Location

THEA Perspective on CV Pilot Deployment

Bob Frey
Director of Planning and Innovation, THEA

Q&A


NYCDOT


Tampa (THEA)


WYDOT


USDOT

STAY CONNECTED

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Visit CV Pilot and Pilot Site Websites for more Information:

- CV Pilots Program: http://www.its.dot.gov/pilots
- NYCDOT Pilot: https://www.cvp.nyc/
- Tampa (THEA): https://www.tampacvpilot.com/
- Wyoming DOT: https://wydotcvp.wyoroad.info/