U.S. 33 Smart Mobility Corridor Program
Final Report

Prepared for:
Northwest 33 Innovation Corridor Council of Governments

Prepared by:
Michael Baker International, Inc. and DriveOhio

Table of Contents

Chapter 1. Project Summary

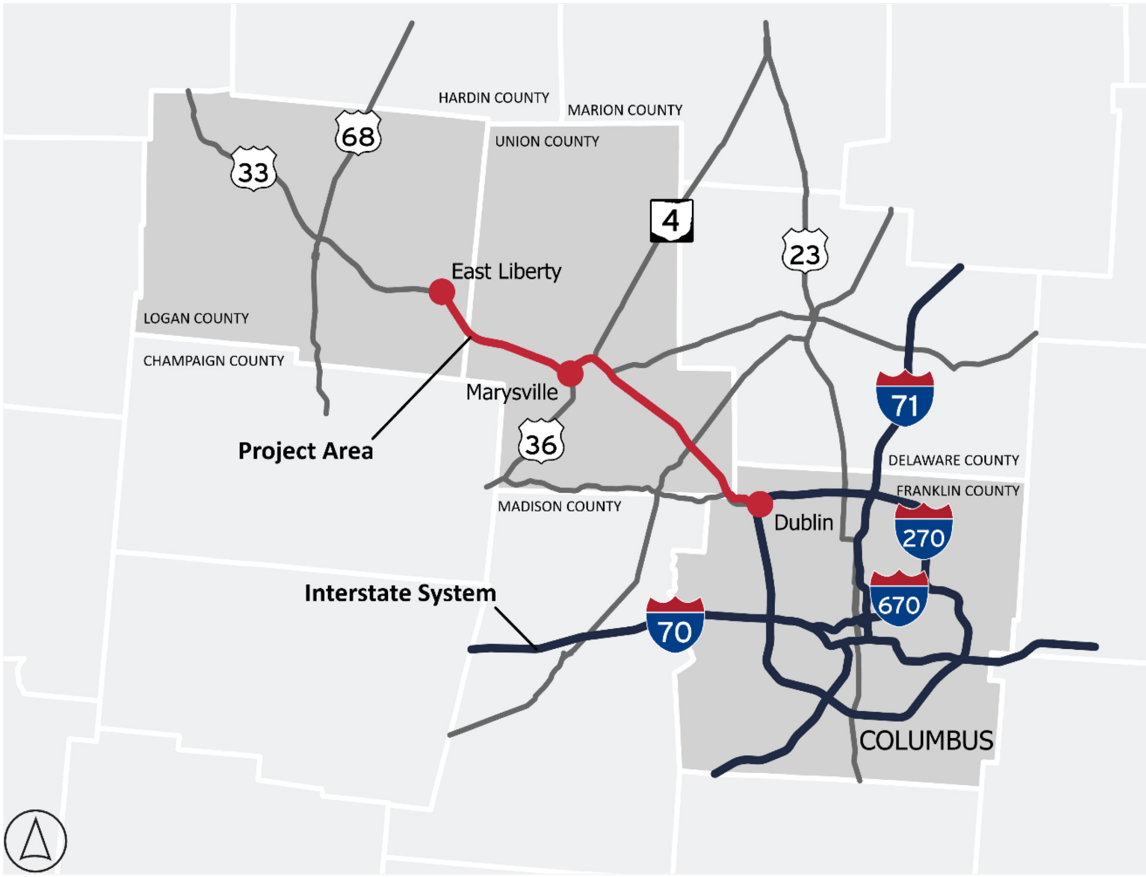
In 2016, the U.S. Department of Transportation (USDOT) awarded an Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program grant to the Northwest 33 Innovation Corridor Council of Governments (COG) for the U.S. 33 Smart Mobility Corridor (33 SMC) project. With grant funding and matching funds provided by local and state governments, connected vehicle (CV) technology was deployed throughout the corridor, spanning various community types and land uses over 33 miles, to fully develop a transportation technology test corridor, while also improving safety and congestion on U.S. 33 and advancing the use of transportation technology in the state of Ohio. This corridor was chosen for this project due to its unique characteristics. U.S. 33 between Dublin and East Liberty is 4-lane, grade-separated highway. It is used as the main route between the Columbus region and points northwest and, because of this, it is used as a major route for commuters for a variety of industries. The route is heavily congested at the eastern end toward Dublin during rush-hour while relatively less congested as one travels west through Marysville toward Bellefontaine. The corridor offers these traffic characteristics within an urbanized, suburban, and rural setting. These compounding characteristics made the U.S. 33 Corridor a prime candidate for this project and use as a testbed for future technologies. The project was led by the COG, with support from the Ohio Department of Transportation and DriveOhio.

The 33 SMC project was one of the first deployments of CV technologies in the State of Ohio. Connected vehicle technology is a broad term encompassing vehicle applications, roadside infrastructure, on-board units, and associated systems utilizing vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The 33 SMC focused on demonstrating CV technologies and V2I applications to advance the following goals:

1. Enhance safety with the deployment of V2I safety applications along the corridor and at municipal signalized intersections.
2. Reduce congestion with intersection roadside units and V2I applications.
3. Accelerate the deployment of smart mobility technologies by providing a test bed for automated and connected vehicles, unmanned aerial systems, and other intelligent transportation technologies.

As illustrated in **Figure 1**, the project encompassed 33 miles of US-33 from the City of Dublin through the City of Marysville to East Liberty, Logan County at OH-347.

Figure 1. A map of the US 33 Smart Mobility Corridor project.



Just outside the 33 SMC, the City of Columbus developed a cutting-edge, region-wide connected and autonomous (CAV) transportation network after receiving a federal grant through its successful bid for the Smart City challenge. Various multi-modal programs were developed under the Smart City Challenge, including CV applications, and dedicated short range communications (DSRC). The 33 SMC was intended to bolster this region's commitment to smart transportation and provide a unique opportunity to coordinate adjacent CV deployments while fostering interoperability.

Project Scope

The 33 SMC project was originally scoped to include the following:

1. Installation of 87 DSRC roadside equipment along US33 within multiple jurisdictions.
2. Dynamic traffic signal phase, timing, and preemption through the cities of Dublin and Marysville.
3. Pedestrian in Crosswalk Warning systems at high-traffic locations.
4. Installation of onboard units on a diverse set of fleet vehicles (600 – 1,200 total) with multiple jurisdictions and vehicle types.
5. Deployment of connected vehicle safety and mobility applications to enhance end of queue safety and reduce congestion. The V2I applications deployed include:
    a. Queue Warning
    b. Speed Harmonization

6. Dynamic ride sharing at select major employers to encourage carpooling and increase access for carless households.
7. Roadside video equipment and sensors to allow for autonomous vehicle tracking and open road testing.
8. Connecting the Dublin Metro and Honda Data Centers with fiber communications for ongoing system monitoring and program evaluation.

Work on the project spanned from 2018 through 2023. During this time, several modifications to the project scope were made in response to schedule and cost impacts affected by external factors. The COVID-19 pandemic, the determination of the total funding required to provide power to the Roadside Units (RSUs) along the corridor, and the Federal Communication Commission's (FCC's) Final Rule and Order pertaining to the 5.9GHz spectrum most notably reshaped the direction of the project.

The pandemic altered travel patterns significantly, reducing traffic along the corridor from spring of 2020 through 2021. The pandemic also had an impact on the availability of equipment, as many suppliers were forced to halt operations due to limited staffing. This supply shortage affected the ability to purchase various components for the on-board unit installations and thus caused schedule delays.

The desire to fully-develop the entire corridor as a testing corridor, with complete coverage, required power for each RSU. Early on it was thought that power would be readily available, due to the nature of the corridor. As the project progressed, it was learned that power was going to be another challenge that would be uniquely resolved by the project.

The FCC Final Rule and Order pertaining to the 5.9GHz spectrum, made in late 2020, reduced the available spectrum for CV safety applications. During rulemaking, the FCC froze license requests for use of the 5.9GHz spectrum. After attempting to obtain experimental licenses for use of the spectrum, the project team pivoted to use a single channel (Channel 180) for all deployment communications. This process created significant schedule delays and significantly impacted the viability of the envisioned project.

These factors necessitated a reduction in the expected simultaneous penetration of vehicles equipped with onboard units along the corridor. Accordingly, the expected project performance measures were modified to assess CV performance in a smaller sample of vehicles. The following are the primary scope modifications seen with the project deployment.

Modified Scope Components:

Fewer DSRC roadside units along U.S. 33.

The number of roadside DSRC units was refined based on the anticipated coverage required for the applications that were being deployed. It was determined that 63 units along the corridor would provide adequate coverage (initially proposed 87 units). Note, the Cities of Marysville and Dublin added 6 and 10 units, respectively, outside of the grant for a total of 33 and 20 DSRC units, bolstering the state of CV infrastructure in the 33 SMC area.

Fewer vehicles equipped with onboard units.

The project deployed connected vehicle technology in a mixed fleet of 200 vehicles from the City of Marysville, City of Dublin, and Union County. Additionally, Honda outfitted 200 employee vehicles with DSRC-based OBUs in conjunction with the grant project in addition to 57 C-V2X OBUs. Focus from this project was not given to the additional 57 C-V2X OBUs, as the project installed infrastructure was not able to communicate with them and they were not interoperable with the other OBU deployments within the project region. The initial 33 SMC scope intended to equip up to 1,200 vehicles. However, this proved to be cost prohibitive. The project team worked to secure spare OBUs from complementary deployments, including the Smart Columbus program and USDOT New York City Connected Vehicle Pilot project, but repurposing those units would require additional funding to cover reconfiguration costs.

Curve Speed Warning and Reduced Speed Zone Warning/Lane Closure Warning applications were advanced.

The grant application and the scope of work described two traffic flow applications that were anticipated to be advanced through the grant: Queue Warning and Speed Harmonization. Through stakeholder engagement and development of the systems engineering analysis, it was determined that five applications would address the needs of the corridor and are able to be deployed: Lane Closure Warning (LNCLW), Reduced Speed Zone Warning (RSZW), Curve Speed Warning (CSW), Pedestrian Conflict Warning (PCW), and Red-Light Violation Warning (RLVW); these applications were advanced instead.

Removed Dynamic Ridesharing application testing.

The grant application contemplated testing a ridesharing application (D-RIDE) in partnership with private entities along the corridor. This deployment was not pursued due to high costs.

Roadside video equipment was installed outside of the grant.

During the development of the Concept of Operations, it was decided that roadside video equipment and sensors did not support the primary use cases associated with the grant project. However, twenty-four cameras have been installed along US-33 using funding separate from the grant. The cameras support operational uses like traffic counts and wrong way driving alerts.

A summary of the proposed and modified scope is demonstrated in **Table 1**.

Table 1: Proposed Scope of Work compared to the Modified Scope of Work

Scope as Proposed	**Scope as Modified**
87 DSRC-equipped Roadside Units (RSUs) utilizing the full 5.9 GHz DSRC spectrum. 27 RSUs will be added in Marysville. 10 RSUs will be added in Dublin. The total number of RSUs installed will be 124.	63 RSUs installed and use of the DSRC spectrum was limited to Chanel 180 only. 27 RSUs were added in Marysville. 10 RSUs were added in Dublin. The total number of RSUs installed under the grant project was 100.
Dynamic traffic signal phase, timing, and preemption through the cities of Dublin and Marysville	Signal pre-emption was not implemented.

Scope as Proposed	Scope as Modified
Pedestrian in Crosswalk Warning systems at high-traffic locations	No change.
Installation of onboard units on a diverse set of fleet vehicles (600 to 1,200 total) with multiple jurisdiction and vehicle types.	200 OBUs installed on multiple vehicle types from the cities of Marysville and Dublin, and Union County. While Honda was included in the original scoped quantity of OBUs, their 200 DSRC and 57 C-V2X OBUs are not reflected here, due to Honda not utilizing any grant funding.
Deployment of connected vehicle safety and mobility applications to enhance end of queue safety and reduce congestion. V2I applications deployed: - Queue Warning - Speed Harmonization	Queue Warning and Speed Harmonization applications were not deployed. However, the following applications were deployed: a. Lane Closure Warning (LNCLW) b. Curve Speed Warning (CSW) c. Reduced Speed Zone Warning (RSZW) Pedestrian Conflict Warning (PCW) Red-Light Violation Warning (RLVW)
Dynamic Ride Sharing at select major employers to encourage carpooling and increase access for carless households.	Dynamic Ride Sharing was not deployed.
Roadside video equipment and sensors to allow for autonomous vehicle tracking and open road testing.	Roadside video and sensors were not installed as part of the project. However, the project infrastructure supported installation of 24 video camera units.
Connecting the Dublin Metro and Honda Data Centers with fiber communications for ongoing system monitoring and program evaluation.	No change.

Project Timeline

The following list provides an abbreviated project schedule:

- October 2016: USDOT-FHWA awards ATCMTD Grant
- May 2017: Grant Cooperative Agreement executed between FHWA, the City of Marysville and ODOT
- January 2018: The 33-SMC Program Manager is issued Notice to Proceed
- March 2018: Systems Engineering Analysis begins (through Jun. 2019)
- January 2019: RSU Procurement and Installation (through Jun. 2022)
- November 2018: Civil, ITS, and Power Design and Construction (through Sept. 2020)
- January 2020: OBU Procurement and Installation (though July 2022)
- May 2022: Operational Test Period begins (Post Deployment Data Collection begins)
- May 2023: Operational Test Period complete and Evaluation begins (Post Deployment Data Collection ends)

Chapter 2. Performance Metrics, Evaluation Methods, and Data Sources

In alignment with Section 6004 of the Fixing America's Surface Transportation (FAST) Act, the 33 SMC project goals were to improve safety, improve mobility/reduce congestion, and accelerate deployment of technology. These goals were maintained throughout the project, but metrics and evaluation methods were changed due to scope and project modifications.

Performance measures, evaluation, and data sourcing for each goal are discussed in this section of the report. The project evaluation period was for the one-year operational test period starting on May 1, 2022, which represents the point that all devices were installed and operational, to May 1, 2023.

A summary of performance measures is included at the end of Chapter 4 in **Table 15**.

Improving Safety

It is estimated that CV technology could address 80% of crash scenarios.[1] V2V and V2I applications help drivers increase situational awareness and decrease crashes by alerting drivers to hazardous situations. The CV safety applications that were deployed and evaluated as part of this project include:

1. Reduced Speed Zone Warning (RSZW)
2. Lane Closure Warning (LNCLW)
3. Curve Speed Warning (CSW)
4. Pedestrian Conflict Warning (PCW)
5. Red-Light Violation Warning (RLVW)

The goal of improving safety was measured by the number of safety related OBU application events recorded, representing near misses, and through feedback from an end-user experience survey.

OBU Application Events

The OBU application data was collected and analyzed. The application alert events captured represent situations in which an alert was generated based on application requirements. An application event occurs when an on-board application is triggered to warn the driver of a condition, such as a red-light violation warning or a warning that the vehicle is traveling too fast for the conditions of the curve ahead. The application events were obtained via over-the-air event downloads from the project OBUs. These events were captured daily, and the data was saved to an Amazon cloud storage solution. Each event was correlated to a unique OBU ID based on its serial number. During the evaluation period, 13,930 application events were recorded for the five CV safety applications across 189 unique OBUs. This included application alerts from a subset of 110 OBUs that were not part of the grant project. Without access to unique identifiers, such as serial numbers for non-project OBUs, there is no way to verify the source of the deployment of the other OBUs captured. The project did not capture any application events from approximately 61 OBUs (43%) of the project vehicles for reasons that are unknown. It may have been that these vehicles were not driven often enough to encounter situations that would have

[1] *National Highway Traffic Safety Administration,* "Fact Sheet: Improving Safety and Mobility Through Vehicle-to-Vehicle Communication Technology."

activated any application alerts. Additionally, the project related vehicles were public fleet vehicles driven by government employees and they may have been operating with increased safety awareness when driving in the areas of RSU deployment. The evaluation data did not include all the project OBUs since the devices provided by Danlaw were the only devices that provided the capability to obtain event logs through over-the-air downloads. The 60 dual-mode devices (DSRC and C-V2X) provided by Commsignia were not included in the event dataset. While initial validation of the applications was performed during testing by the consultant team, no additional validation of alerts was performed for the duration of vehicle deployment activities. Due to the utilization of public fleet vehicles, there were some city staff members with expertise in understanding of application alert thresholds that did notify if they felt something was not working as intended. These notifications were then communicated to the project team to investigate further. It was expected that the OBUs would be accurate in logging any alerts that were generated in the device event log. Those alerts were then examined, not for accuracy, but for awareness of V2X operational data transfer.

CV Technology User Survey

A user experience survey was sent to drivers of equipped public fleet vehicles to capture qualitative feedback of their perception and experience with the technology and use of the 5 applications that were installed. The survey attempted to capture qualitative data on the effectiveness of warnings, satisfaction with the technology, perception of impact, and attitudes about the technology, among other topics. The survey was administered virtually via Microsoft Forms and sent to project contacts for disbursement at the City of Dublin, City of Marysville, and Union County. The survey was initiated in late July 2023 and was open for approximately two weeks. Although surveys were provided to all potential drivers of the OBU-equipped vehicles, survey participation was not mandatory. Responses were given back to the project team on a voluntary basis. Thus, out of a total of 200 surveys sent to all OBU participants, seventy-five responses were collected for an approximate 37.5% response rate. Also, those that did respond had the option to leave the answer to a question blank or choose not to answer the question.

Survey results showed that respondents have an overall negative view of the use of technology and safety applications. This is not surprising given the many challenges the project had to overcome in the deployment phase. No formal training was provided to potential users of the technology. As a result, biases in the use of technology and level of expectation of what it does and what it does not do certainly influenced the responses of the survey.

Refer to **Appendix A** for the Survey Questions and responses.

Reducing Congestion/Improving Mobility

This goal from the original grant application was based on mobility-specific applications that were intended to be deployed. However, as the project Concept of Operations progressed, it was apparent that it was not feasible to deploy all originally envisioned applications, due to the funding challenges associated with desire to deploy infrastructure elements at scale so that the corridor would be able to support many additional applications in the long term. As such, the performance metrics for reducing congestion and improving mobility were modified to consider the impact of work zones or crashes that would provide secondary congestion. After consultation with DriveOhio, it was determined that data from Honda, who equipped 257 vehicles with CV technology (200 DSRC and 57 CV2X) and safety applications, could be used as a data source for evaluating this goal since the Honda vehicles would be interacting with the 33 SMC project infrastructure and project fleets. The V2X system and security is set up in a way that conforms to industry security standards including anonymity. Therefore, there is no way to distinguish between a Honda vehicle OBU and a project installed OBU on a government fleet vehicle. The project did not examine specific BSM-received data on a specific OBU and attempt to correlate that with application event alerts as V2V interactions were not a main component of the project.

Accelerated Deployment of V2I and Other Advanced Technologies

This project aimed to implement a robust network of CV infrastructure along the corridor that could serve future CV or other smart mobility testing and deployments. This goal was measured through RSU uptime percentages during the evaluation period, the number of OBUs using the system, the number of unique testers using the infrastructure, and the number of other deployments leveraging the technology infrastructure installed under the grant.

The RSU up-time percentages measured the reliability of the roadside, physical infrastructure. RSU uptime was monitored and recorded in real-time through a dashboard maintained by the project's RSU integrator. The dashboard was constructed with the intent to archive data for the entire reporting period. However, it was discovered that the archive nature of the Amazon Web Services data storage was only archiving the most recent 90 days. Archived data is limited to 90 days' worth of historical data due to the subscription options of the recording database, therefore the reported data for this report is only from 5/27/2023 to 8/25/2023. Refer to **Appendix B, Table 30** for this data.

The number of OBUs using the system relative to the OBUs deployed through this project indicates the number of third-party systems or deployments using this project's infrastructure. Object serial numbers were recorded within application event logs and are used to identify the number of users in the system. Serial numbers were cross referenced to those devices deployed through this project. Serial numbers not associated with this project are considered third party as well.

The number of other deployments leveraging the technology infrastructure was measured through qualitative data collected from discussions with project partners, and through formal interviews of stakeholders, including DriveOhio employees who are privy to conversations and activities regarding past, current, and planned projects that will benefit from this project's infrastructure. For example, the infrastructure and implementation of the head-end system and SCMS allowed for the region to support an OmniAir Plug-fest in which CV2X devices were both installed and tested by many manufacturers for interoperability. This demonstrates how the infrastructure supports the interoperability of new V2X technology. Bosch cameras were also installed to support more advanced pedestrian detection applications using Personal Safety Messages (PSMs) generated by the infrastructure. Bosch also developed more advanced camera analytics for detecting wrong-way driving and other objects while their products were deployed along the US-33 Corridor.

In addition to Bosch, several other developers have been active along the corridor. While these companies did not utilize grant funding and were not a part of the Smart Mobility Corridor project scope, the US-33 COG and DriveOhio have benefited from their involvement and advancement of safety-related technologies. These developers include Panasonic, Terrasound, and Denso (DERQ + NoTraffic).

Panasonic, based in Denver, Colorado, provided equipment such as a mm wave communications technology suite to link intersection infrastructure and vehicles. ODOT and City of Marysville personnel installed the equipment required to be installed on the infrastructure near intersections where the demonstration took place.

Terrasound, based in Dublin, Ohio, is developing infrastructure health monitoring technology utilizing fiberoptic strands. Their system is able to detect variations within the light spectrum that are related to vibrations generated from around the physical location of the fiberoptic cable. This technology can be applied to monitoring the health and status of fiberoptic systems in the ground by measuring vibrations of traffic activity near the cable. They continue to develop this technology to monitor the health and safety of the traveling public along the US-33 Corridor. This application of the technology has the potential to accurately detect traffic accidents, backups, and general traffic counts along the corridor.

Denso, DERQ, and NoTraffic partnered with the City of Dublin to improve safety around highly pedestrian traveled areas, including school zones. This project was successful in showcasing how different vendors solutions could be integrated into a V2X ecosystem. Dublin continued this work with DERQ, through a partnership with DriveOhio, with focus on the US-33 and SR-161 roundabout located just east of the US33 Smart Mobility Corridor. The partnership is exploring potential solutions to assist traffic in the navigation of the roundabout using CV technology and predictive-path sensor-fusion analytics.

Chapter 3. Evaluation Results

This chapter provides a comprehensive overview of the assessment and validation of the methodologies presented in Chapter 2. By presenting a thorough evaluation, this chapter offers valuable insights into the effectiveness, efficiency, and validity of the approaches undertaken.

Improving Safety

Grant-Related OBU Application Events

During the evaluation period, 15,974 total application notifications were recorded across 189 unique OBUs. However, 13,930 of the 15,974 application notifications were related to the project goals. The additional notifications were V2V application alerts. **Table 2** describes a breakdown of the 13,930 notifications by Application Type, Number of Notifications, and Percentage of Total Notifications.

Table 2: Notifications by Application

Application Type	# of Notifications	% of Total Notifications
Curve Speed Warning (CSW)	5,591	40%
Lane Closure Warning (LNCLW)	74	<1%
Reduced Speed Zone Warning (RSZW)	110	1%
Pedestrian Conflict Warning (PCW)	61	<1%
Red-Light Violation Warning (RLVW)	8,094	58%
TOTAL	13,930	100%

Red Light Violation Warning (RLVW) accounted for 58% of all events evaluated. Curve Speed Warning (CSW) accounted for 40%. **Figure 2** illustrates the number of applications recorded for each month of the evaluation period. It should be noted that in emergency service vehicles, red-light violation warning was deactivated when the light bar was activated, however, event logs are still being created. Therefore, there is a high likelihood that some of the events noted for RLVW are created during emergency events.

Figure 2: Application Notifications by Month for the Evaluation Period

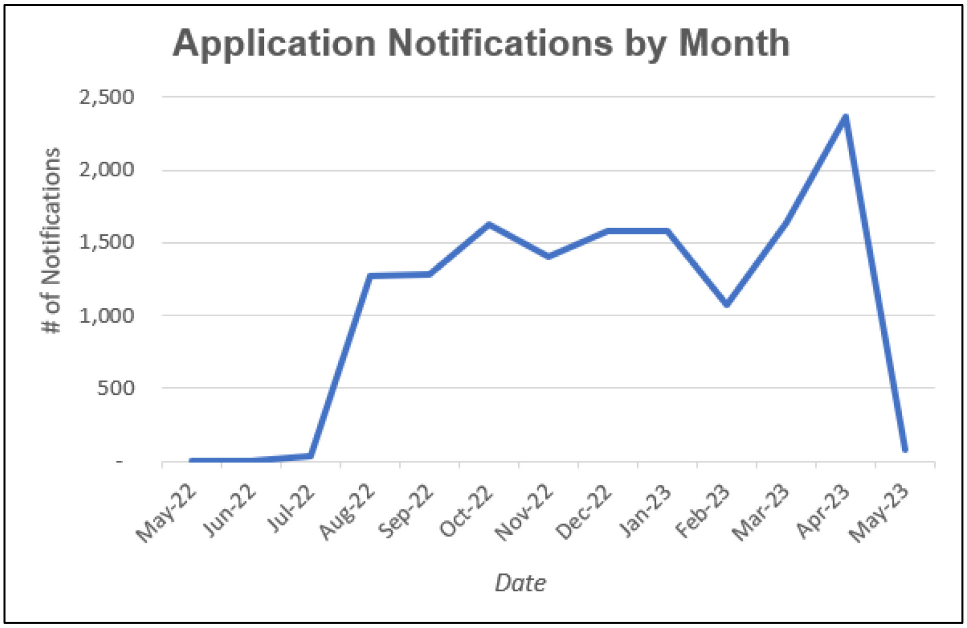


Table 3 describes the application events by month with the number of total events per a month and the total number of applications and percentage total of each event per an application.

Note: Full names for the applications are: CSPDCOMP=Curve Speed Compliance, LNCLSRW=Lane Closure Speed Reduction Warning, LNCLSRA=Lane Closure Speed Reduction Alert, PEDINX=Pedestrian in Crosswalk, RLVW=Red Light Violation Warning

Table 3: Applications of Events by Month

Application	Jul-2022	Aug-2022	Sep-2022	Oct-2022	Nov-2022	Dec-2022	Jan-2023	Feb-2023	Mar-2023	Apr-2023	May-2023	**Application Total**	**Percentage of total**
CSPDCOMP	18	604	531	619	653	708	733	401	630	679	15	**5591**	**40%**
LNCLSRW	-	20	-	-	-	-	-	40	14	-	-	**74**	**<1%**
LNCLSRA	-	21	-	-	6	-	-	39	29	15	-	**110**	**<1%**
PEDINX	-	5	-	-	-	-	-	42	13	1	-	**61**	**<1%**
RLVW	13	626	748	1012	744	872	847	552	948	1669	63	**8094**	**58%**
Monthly Totals	**31**	**1276**	**1279**	**1631**	**1403**	**1580**	**1580**	**1074**	**1634**	**2364**	**78**	**13930**	**100%**

The information provided in **Table 3** indicates an observed decrease in the data set during February 2023. This is attributed to an issue with RSU application certificates that had expired. Until the issue was corrected, there was no communication between the RSUs and OBUs, therefore no alerts were being created or issued to drivers. Application events during the period between May 2022 and July 2022 were also much less than the other months of operation. During this time, it was noted that there was an issue with the over-the-air data download function not working properly. Based on this, it can be surmised that the sheer number of event log files being generated on each OBU was exceeding the available memory available for storage on the OBUs and events were being overwritten in some cases. Once this issue was rectified by the OBU integrator, the event logs for a portion of this time period were lost. The ability for event logs to be downloaded is also predicated on the ability to have clear communication with an RSU for the time period required to complete the download. Some, but not all, of the RSUs within the project limits can handle over-the-air updates or downloads. This is because only a portion of the project RSUs are connected to an IPv6 network protocol backhaul. These include the RSUs deployed along US 33 and a handful of RSUs in the City of Marysville. None of the RSUs deployed at City of Dublin signals include IPv6 backhaul communications.

The spike in Application Events observed in April 2023, unfortunately, cannot be attributed to any specific cause. However, the project team speculates this may be attributed to the usual increased pedestrian and vehicular traffic during warmer weather.

Overall, there were several V2V application alerts that were generated on OBUs that fell outside of the Honda vehicle installations. There was no clear evidence of which vehicles interacted with the vehicles in which the alerts were generated. Those vehicles could have been Honda vehicles, Grant-related OBU vehicles, or Connected Marysville private citizen vehicles. In total, from August 2022 through February 2023, there were 18 Blind Spot Warnings, 1305 Emergency Vehicle Alert messages, and 8 Forward Collision Warnings.

Non-grant-Related OBU Application Events

Project partner, Honda, deployed 200 vehicles equipped with DSRC technology. The technology was deployed in Honda associates' commuting vehicles. These vehicles interacted with other connected vehicles in the corridor and the project infrastructure system. Based on data provided by Honda, V2V applications utilized included:

- EEBL (Emergency Electronic Brake Lamps)
- FCW (Forward Collision Warning)
- IMA (Intersection Movement Assist)
- BSW/LCW (Blind-spot Warning/Lane-change Warning)
- DNPW (Do Not Pass Warning)
- CLW (Control Loss Warning)
- RSZW (Reduced Speed Zone Warning)
- CSW (Curve Speed Warning)
- PDA (Pedestrian Detection Alert)
- LTA (Left Turn Assist)
- EVA (Emergency Vehicle Alert)
- LSM (Lane Slowing Message)

The most common inform message was an LSM (Lane Slowing Message). LSM accounts for almost 80 percent of all inform messages. This is followed by Blind Spot Warning at 751 messages during the study. For Imminent alerts the LTA (Left Turn Assist) was issued 85 times (36 percent of all imminent alerts) followed by FCW (Forward Collision Warning) and IMA (Intersection Movement Assist) with 36 and 37 alerts, respectively. There were zero inform and imminent DNPW (Do Not Pass Warnings) and CSW (Curve Speed Warning) recorded during the Honda study.

The data analysis provided by Honda reflects limited interaction with the infrastructure. Unfortunately, additional data analysis is not possible with this data set as this deployment occurred outside of the grant. Thus, validation of the data and the removal of "false positives" are not possible. However, it does show increased OBU operation and valuable V2V interactions. It is important to note that the vast amount of vehicle interaction and related safety alerts would not have occurred, if not for the grant project. For example, the Honda OBUs recorded 5,591 Curve Speed Compliance (CSPDCOMP), 74 Lane Closure Speed Reduction Warning (LNCLSRW), 110 Lane Closure Speed Reduction Alert (LNCSRA) and 61 Pedestrian in X-Walk (PEDINX) alerts. This Honda partnership and related activities are clear examples of how further research, development, and deployments are occurring in areas where active and open testing is promoted in environments where technology has been deployed to support those activities.

Table 4 provides a summary of the application data for the evaluation period according to Honda DanLaw OBU including counts and percentages per an application of the Honda-enabled V2V interactions.

Table 4: Application Data Summary for the Evaluation Period

Application and Abbreviation	**Count**	**Percentage**
Red Light Violation Warning - RLVW	8094	28%
Curve Speed Compliance - CSPDCOMP	5591	19%
Pedestrian - PEDPSM	5562	19%
Private Use PSID - SRA	3179	11%
Emergency Communications and Evacuation - EVAC	2616	9%
Speed Compliance/Work Zone - SPDCOMPWZ	1588	5%
Blind Spot Warning - BSW	731	3%
Emergency Electronic Brake Lamps - EEBL	447	2%
Oversize Vehicle Compliance - OVC	405	1%
Incident Warning - IW	201	1%
Forward Collision Warning - FCW	143	<1%

Application and Abbreviation	Count	Percentage
Intersection Movement Assist - IMA	114	<1%
Lane Closure Speed Reduction Alert - LNCLSRA	110	<1%
Speed Compliance - SPDCOMP	94	<1%
Lane Closure Speed Reduction Warning - LNCLSRA	74	<1%
Pedestrian in Crosswalk - PEDINX	61	<1%
Green Light Operations Speed Advisory - GLOSA	33	<1%
Personal Safety Message - PSM	1	<1%
Lane Closure Alert - LCA	-	<1%

CV Technology User Survey

The user experience survey was intended to measure the fleet vehicle operator's experience, understanding and perception of CV technology. The survey was administered to end users in the City of Marysville, the City of Dublin, and Union County. In Marysville and Dublin, the end users included employees from public works departments, engineering divisions, police, and fire departments, as well as school bus drivers. Union County included the sheriff's office and the senior citizen transit service (UCATS). The survey collected 75 responses across the three participating municipalities. The survey relied on voluntary responses. As a result, several responses to questions were left blank and the number of respondents to each question was not always consistent.

Results of the user survey indicate that most respondents stated that they experienced improved safety regarding an increase in driver's awareness, a decrease in near misses, and a decrease in crashes. Other feedback provided suggested a universal lack in training and understanding of the on-board technology, with many comments stating that they were not clear on the message's meaning or whether the technology was working or not working. Analysis showed that ratings for "ease of use of the technology" were correlated with "overall satisfaction with the CV technology." This indicates that respondents who found the technology easier to use also tended to be more satisfied.

Additional comments noted inconsistency and inaccuracy of alerts and a distracting system interface with lights and sounds. Although additional insights could have been gained with in-depth research, the project timeline and budget did not facilitate such research. Full survey questions and results can be found in **Appendix A**.

Table 5 illustrates that respondents to the survey were primarily comprised of employees from the City of Dublin (44%) and the City of Marysville (38%). Significantly fewer respondents were from Union County (18%).

Table 5: Responses by Public Agencies

Agency	Number	Percentage
Union County	13	18%
City of Dublin	34	44%
City of Marysville	28	38%
Total	**75**	**100%**

Table 6 provides information on the benefits of the connected vehicle system, as reported by respondents. A total of 41% of respondents experienced safety enhancements through fewer crashes (8%), increased driver awareness (28%), and fewer "near misses" (5%).

Additionally, 11% of respondents reported improved mobility due to the CV system's provision of accurate information about the driving environment.

It should be noted that 48% of the surveys did not provide a response to this question. This may be an indication that those taking the survey did not perceive any benefit to the technology at all.

Table 6: Benefits of Connected Vehicle Technology

Options	Responses	Percentage
Improved Safety: Fewer Crashes	6	8%
Improved Safety: Increased Driver Awareness	21	28%
Improved Safety: Fewer “near misses”	4	5%
Improved Mobility: Accurate Information on Driving Environment	8	11%
No Response	36	48%
Total	**75**	**100%**

When asked about the ease of learning and using the CV features in the vehicle, a combined 19% of participants found the CV features either somewhat easy to learn and use (11%) or extremely easy (8%). A sizeable number of respondents, 43%, had a neutral experience, suggesting an average level of difficulty in using the CV features. A combined 27% of respondents encountered challenges, with 6% indicating the features were somewhat difficult to use and 21% finding the features extremely difficult to use as referred to in **Table 7**.

Table 7: Ease of Learning and Using CV Features

Options	Responses	Percentage
Extremely Easy	6	8%
Somewhat Easy	8	11%
Neutral	32	43%
Somewhat Difficult	5	6%
Extremely Difficult	16	21%
No Response	8	11%
Total	**75**	**100%**

Questions 5 and 6 of the User Experience Survey asked about the technology's reliability to work as intended and about providing accurate, timely, or relevant information, respectively. Answers to the two questions seem to correlate with a large number of those surveyed having overall negative responses.

Concerning the reliability of the Connected Vehicle technology, respondents were asked if the technology worked as intended. Respondents indicated the technology as generally unreliable with a combined 59% of respondents indicating somewhat (16%) or extremely unreliable (43%). Only a small proportion of respondents indicated the technology being reliable with a combined 19% of responses indicating somewhat reliable (15%) or very reliable (4%). A noticeable proportion of respondents indicated a neutral position (21%). These responses are represented in **Table 8**.

Table 8: Technology Devices Working as Intended

Options	Responses	Percentage
Very Reliable	3	4%
Somewhat Reliable	11	15%
Neither Reliable or Unreliable	16	21%
Somewhat Unreliable	12	16%
Extremely Unreliable	32	43%
No Response	1	1%
Total	**75**	**100%**

Regarding perceptions of the CV technology's reliability in providing accurate, timely, and relevant information, a small percentage found it very reliable (5%) and about one-fifth (20%) considered it somewhat reliable. A similar portion had a neutral viewpoint (17%). A majority of respondents (55%) reported that the CV technology was unreliable, with 12% indicating it was somewhat unreliable and 43% indicating it was extremely unreliable as demonstrated in **Table 9**.

Table 9: Reliability of providing accurate, timely, or relevant information.

Options	Responses	Percentage
Very Reliable	4	5%
Somewhat Reliable	15	20%
Neither Reliable or Unreliable	13	17%
Somewhat Unreliable	9	12%
Extremely Unreliable	32	43%
No Response	2	3%
Total	**75**	**100%**

It is clear from the experience of those using the technology and the difficulty in using the features of the technology as well as the perception of its unreliability that the majority of respondents would prefer not to use the technology going forward. This is indicated with 66% of responses indicating they were somewhat unlikely (11%) or very unlikely (55%) to retain or recommend the demonstrated CV technology. Only a small set of respondents indicated positive responses of very likely (6%) or somewhat likely (1%). Also, a significant portion of those surveyed had a neutral position (23%) on the question. Results are references in **Table 10**.

Table 10: Retaining or Recommending the CV Technology

Options	Responses	Percentage
Very Likely	5	6%
Somewhat Likely	1	1%
Neutral	17	23%
Somewhat Unlikely	8	11%
Very Unlikely	41	55%
No Response	3	4%
Total	**75**	**100%**

Respondents were also asked about the effectiveness of the deployed applications. They were asked to rank the effectiveness of each application on a ‘1’ through ‘5’ scale with ‘1’ indicating “low effectiveness” and ‘5’ indicating “high effectiveness". These questions had a relatively high response rate with very few submitting a blank or no response to each application effectiveness question.

The full results of the survey are included in **Appendix A**. However, the average score of each application indicates relatively low effectiveness on the 1 through 5 scale. **Table 11** summarizes the average score of each application’s effectiveness as deployed.

Table 11: Average Rating of Application Effectiveness

Application	Average Score
Red Light Violation Warning	2.01
Reduced Speed Zone Warning/Lane Closure Warning	1.68
Curve Speed Warning	1.77
Pedestrian In Conflict Warning	2.08

Less than positive results were evident thought the rest of the survey. Respondents were asked about the application's impact on their attentiveness while driving. Again, using the same rating scale as the previous question of '1' through '5' with '1' indicating "No Change or Not Effective" and '5' indicating "Highly Effective".

As indicated in **Table 12**, a majority of the respondents (60%) indicated that the CV technology had no change or effect on their attentiveness to driving. Relatively low numbers of respondents indicated varying levels of effectiveness on their attentiveness while driving.

Table 12: Effectiveness of CV Technology on Driving Attentiveness

Options	Responses	Percentage
1 (No Change or Not Effective)	45	60%
2	10	13%
3	11	15%
4	4	5%
5 (Highly Effective)	4	5%
No Response	1	1%
AVERAGE:	**1.81**	**-**

Respondents rated the overall satisfaction with the Connected Vehicle technology with the same '1' through '5' scale. This time with '1' indicating low satisfaction and '5' indicating high satisfaction with various levels of satisfaction in between. As summarized in **Table 13**, the majority of the respondents (71%) expressed low or relatively low overall satisfaction with the Connected Vehicle technology. A sizeable proportion of respondents (16%) had a neutral level of satisfaction with the technology while only a small proportion (8%) had a combined positive satisfaction with the technology.

Table 13: Overall satisfaction with CV Technology

Options	Responses	Percentage
1	41	55%
2	12	16%
3	12	16%
4	3	4%
5	3	4%
No Response	4	5%
AVERAGE:	**1.80**	-

Accelerating Deployment of V2I and Other Advanced Technologies

RSU Uptime Percentages

RSU uptime was essential for monitoring the performance and reliability of the deployed RSUs, identifying potential issues, and ensuring the project's operational efficiency. OBUs that were installed along US33 were linked through Ohio Department of Transportation data network. This allowed for the continuous monitoring of the health and status of these OBUs. Network compatibility issues prevented the city managed OBUs from being monitored 100% of the time, creating consistency issues. The uptime percentages for the US33-installed OBUs range from 0% (indicating complete downtime) to 100% (continuous uptime). Sixty-five RSUs were monitored. The average uptime for all RSUs was 93%, while 72% of RSUs operated at 99% uptime or higher, indicating reliable and consistent operation. However, instances of lower uptimes, such as 26.73% and 57.04%, indicated potential issues or areas requiring improvement.

There are various reasons that could contribute to an RSUs being considered offline or not functioning. Some of those noted during the project operations and maintenance period include:

1. Power outages
2. RSUs losing connectivity to the network or down backhaul communication
3. Device failure
4. Device requiring a firmware upgrade

Appendix B, Table 30 includes a comprehensive overview of the various RSUs, their manufacturers, models, deployment sites, and the uptime percentages for each unit during the period from May 27, 2023 to August 25, 2023. Lack of historical and archived data of the RSUs prevents evaluation of RSU uptimes during the project evaluation period. The data management and subscription model archives 90 days' worth of data.

Number of OBUs Reporting in the System

OBUs were installed in 200 public fleet vehicles across three partner agencies. Again, Honda also deployed a number of vehicles equipped with DSRC and CV2X based OBU technologies. The DriveOhiofunded project of Connected Marysville also deployed DSRC-based OBU technology within the project environment. These Honda and Connected Marysville OBUs were not within the scope of this project but are noteworthy to mention. **Table 14** illustrates a breakdown of OBU equipped vehicles per partner agency, including Honda***.***

Table 14: Number of OBU-Equipped Vehicles by Partner Agency

Partner Agency	**Grant Equipped Vehicles (DSRC)**	**Honda Equipped Vehicles (DSRC)**	**Honda Equipped Vehicles (CV2X)**	**Connected Marysville Vehicles (DSRC)**	**Total**
City of Dublin	101	-	-	-	101
City of Marysville	83	-	-	-	83
Union County	16	-	-	-	16
Honda	-	200	-		200
Honda	-	-	57	-	57
DriveOhio	-	-	-	109	109
TOTAL	**200**	**200**	**57**	**109**	**566**

OBU application data was collected and recorded for all functioning OBUs using the project's technology. Throughout the entire project, 214 unique OBUs were recorded using the CV infrastructure. During the evaluation period (May 1, 2022, to May 1, 2023), 21 CV applications were recorded across the 207 OBUs. Of the 5 applications being evaluated, 189 unique OBUS were recorded. Of those OBUs, 79 corresponded to the project OBU equipped vehicles.

Through the project partnership with Honda, 257 Honda vehicles were equipped with CV technology and operated within the system. Additionally, 109 Connected Marysville equipped vehicles were also operating within the system. Within the corridor, across project fleet vehicles and project partner vehicles, 566 vehicles equipped with CV technology were theoretically using the corridor.

Number of Other Deployments Leveraging Technology Infrastructure

The investment in infrastructure installed as part of the grant project has provided significant return on fostering innovation and further testing in the corridor. The infrastructure that has been leveraged has ranges from fiber optics to the roadside units to the poles, cabinets and power that can support additional sensors and devices. The project's technology and infrastructure continue to be leveraged by past, current, and planned smart mobility projects, initiatives, and events. The following is a list of initiatives using the project's technology.

Connected Marysville

Connected Marysville is a research project being led by DriveOhio. The project is deploying and testing CV technology using Marysville private citizens for the purpose of using the 33 SMC RSU deployments to assess the effectiveness of the safety applications. The applications being evaluated include Red Light Violation Warning, Pedestrian Ahead, Curve Speed and Lane Closure Warning. At the time of this report, 109 private citizens have been recruited and their vehicles equipped with on-board units; the project goal is to equip 400 vehicles.

Wrong Way Driving Application Test

In June 2020, DriveOhio tested a wrong-way driving application at one of the US-33 eastbound exit ramps. The test used a combination of hardware to alert and perform the needed actions for a wrong way driving event. The testing was done using thermal imaging cameras with analytic triggers to identify and confirm a wrong-way driver. The system provided alerts to CVs by pushing a message to the nearest roadside unit. A series of lessons learned were developed and a permanent site for this application has been deployed. The second phase of this test has included Queue Warnings. The pilot program is utilizing the roadside units deployed under the 33SMC project.

Vulnerable Road User (VRU) Pilot Deployment

DriveOhio commissioned a vulnerable road user pilot at several intersections in the City of Marysville and the City of Dublin. This pilot deployed cameras and supporting VRU applications to evaluate the effectiveness of Personal Safety Messages. The project was deployed at three intersections in Marysville and one intersection in Dublin using the roadside infrastructure and equipment installed as part of the 33 SMC. The locations chosen were based on high pedestrian traffic volumes. The cameras utilize video analytic technology to generate streaming meta data that is communicated to edge processing units. The edge processors analyze this data and create/send related personal safety messages to an associated roadside unit for broadcast. There have been several industry-related tours and discussions related to these pilots.

Spot Weather Warning System

A Spot Weather Warning System was deployed by DriveOhio in the US 33 Corridor with the goal of monitoring visibility, weather-related pavement conditions and wind. The pilot has been successful and has received positive feedback from industry, due to usable and functional testing. The site was extensively tested during the OmniAir Consortium PlugFest in November 2021. It is also important to note that the original site configured with this equipment has had to be removed, due to road construction activities. The attributes of the corridor have allowed for the easy relocation of the equipment to another accommodating site.

Asset Protection System

An asset protection system project is currently being evaluated by ODOT along with the company TerraSound. The project involves utilizing the fiber optics that were installed as a companion to the project along the US-33 corridor to monitor, protect and secure infrastructure. The system installed can detect events such as stopped vehicles, equipment unloading, and earth digging, among others, by sensing fiber vibrations, or “listening” to the fiber. In the future, this technology will be evaluated for wrong-way driving, queue detection and accident detection use cases.

Uncrewed Aerial Systems Projects

Uncrewed Aircraft Systems (UAS) projects are utilizing the 33 SMC infrastructure for various initiatives. In collaborative efforts with ODOT Office of Research, an uncrewed traffic management research project is utilizing the 33 SMC infrastructure to deploy radar for the development of a low-altitude traffic management system. Communication device technology is being used for both air and ground vehicles to aid in traffic management efforts. Other UAS research and testing programs are using 33 SMC technology, including drone deployments and package delivery.

D.A.T.A. Automated Driving System (ADS) Grant Project

An ADS Grant was awarded to ODOT to advance automated vehicle testing and operations. The automated driving technology and on-road deployment for the project was conducted along the US-33 corridor. Although primarily concerned with automated vehicle operations, C-V2X technology is also being used to support truck platooning operations and testing. The 33 SMC is being leveraged as a proving ground for AV testing.

Connected Roundabout

The technology company DERQ is partnering with the City of Dublin and DriveOhio on a Dublin Connected Roundabout project to develop the ability to predict movement through a roundabout and coordinate traffic flow at surrounding signalized intersections.

Connected Intersection Project

DriveOhio is installing C-V2X roadside units at adjacent intersections (one in Columbus’ jurisdiction and one in Dublin’s) to validate technology readiness as it relates to the ITE CTI 4501 Connected Intersection Guidance document. This project tested emergency vehicle pre-emption using C-V2X technology and plans to work with industry to address any gaps in compliance with the Connected Intersection Guidance.

Honda Smart Intersection

Honda deployed what is coined as the World’s First Smart Intersection at the Marysville Intersection of 5th and Main Street. This deployment utilized infrastructure to provide tracking of all vehicles and pedestrians, connected or not, in the intersection and creating pseudo BSM and PSM messages that were broadcast to Honda equipped vehicles to highlight various safety applications. The applications supported by this smart intersection were Pedestrian Conflict Warning, Emergency Vehicle Warning, and Intersection Movement Assist. Honda has also used the infrastructure to test a technology they coined as “Safe SWARM”. This technology envisions vehicles communicating with each other regarding their operation and the things going on around them to support a more fluid movement of vehicles on the roadway network.

Events and Initiatives that are Leveraging the Technology

Many industry events and initiatives have leveraged the technology in the corridor because of the equipment, the security credential management system, and applications deployed within the project. These include:

- OmniAir Consortium ‘Plugfest’ in November 2021- This multiday event attracted over two dozen testers and equipment providers to evaluate the readiness for connected vehicles and infrastructure. This was the first time the event could be conducted on public roads and the largest set of V2I applications ever tested at the ‘Plugfest’.
- Connected Vehicle Pooled Fund Study (CV-PFS) in December 2020 – This event was hosted with CV-PFS members in the City of Dublin to showcase the High and Rock Crest Streets VRU deployment intersection. The CV PFS has also studied the US-33 RSU signal deployments within Marysville as part of a test site for its Connected Intersection Project. This project aimed to develop test procedures for determining the readiness level of a connected intersection deployment, as it relates to the CTI 4501 guidance document.
- Local and National Document Guidance - The 33 SMC has also aided in local and national document guidance. The Statewide Systems Engineering Analysis for Connected Vehicles that was developed by DriveOhio has used the 33 SMC to help craft statewide guidance and direction. Similarly, the City of Dublin and City of Marysville were selected as demonstration sites in the formation of CTI4501: Connected Intersection Implementation Guide’s initial release. Work has continued in further vetting technology compliance and operational gaps. The 33 SMC project was cited as a catalyst for this.
- CAMP Testing of RTCM – The US-33 SMC was selected by the Crash Avoidance Metrics Partners, LLC (CAMP) for the testing of RTCM. Ohio was selected to test the broadcast of RTCM Version 3.2.

Chapter 4. Lessons Learned, Recommendations, and Conclusions

This chapter summarizes insights learned through the 33 SMC project. Beyond the data and statistics, it investigates the experiential aspects, unveiling the lessons learned, challenges encountered, and insights acquired throughout the assessment process.

Lessons Learned

This section provides the key lessons that have emerged throughout the course of the project. By examining the strategies that worked well, as well as the areas that posed difficulties, this section aims to provide a holistic understanding of the project's evolution. These insights not only acknowledge the accomplishments achieved but also highlight opportunities for growth and improvement.

Real World Test Bed

Designating the Smart Mobility Corridor and making significant investments in technology along the corridor has signaled to the industry that Ohio is a desirable and viable place to test emerging transportation technology. Furthermore, local and state support for the project solidifies Ohio's commitment to advancing technologies that can benefit roadway safety and access. Since the 33 SMC infrastructure deployment, Ohio has successfully tested various technologies and attracted private entities to test technology along the corridor.

User Training

One of the significant lessons gathered from the project implementation relates to the crucial role of user training and equipment comprehension. User survey results indicate that the project's overall effectiveness was hindered by limited user training on the onboard alert system. Future technology deployments should ensure adequate end user training to empower users to navigate new equipment with confidence and ensure they harness its full potential.

Pedestrian Alerts

The PCW application was deployed at three midblock crossings with existing rectangular rapid flashing beacons. The project's implementation of pedestrian detection brought to light a crucial lesson regarding the effectiveness of Personal Safety Message (PSM) alerts. The PSM message set is intended to provide a pedestrian's presence, however without active sensors or analytic systems to determine the presence, heading and path of a vulnerable road user, the roadside integrator determined the best path for the roadside message was to assume a location in the middle of each lane of the crosswalk each time the pedestrian crossing beacon was pressed. The unintended fallacy was that it inadvertently misled drivers, especially when a pedestrian pushed the pedestrian button and then decided not to cross. This led to a perception that the alert system was flawed, as drivers failed to observe a pedestrian in the crosswalk in this scenario. Future efforts should consider installing additional sensors that detect pedestrian activity, rather than sole reliance on the activation of a push button.

Ongoing Costs

During the initial course of the project, the focus was primarily on the upfront expenditures, often overlooking the continuous or ongoing costs that emerged during the operational phase. This oversight resulted in unforeseen financial strains and a skewed perspective on the project's long-term viability. Data management costs, including storage and maintenance, roadside unit management software subscription fees for keeping the systems up to date, and the necessary on-going subscription costs for the SCMS (Security Credential Management System) for maintaining secure communication, all contribute to the project's overall expenses. Failing to account for these expenses lead to agreement for ODOT to assume these costs, since the Council of Governments did not have these costs budgeted. If these ongoing costs had not been accommodated by ODOT, the project's ability to maintain its operational effectiveness and deliver the intended outcomes would suffer.

Road Safety Message (RSM)

The system requirements were developed by the program management consultant for the purpose of development procurement documents to hire a roadside unit integrator and on-board unit integrator. The requirements that were specified for the Curve Speed Warning and Reduced Speed/Lane Closure Warning assumed that Road Safety Message (RSM), SAE J2945/4, would be available and published by SAE International sometime during the project. The use of RSM was proposed due to the advance map capabilities that included lane-level information and road geometries. When moving into the detailed systems engineering and project development phase, the J2945/4 standard was not yet published.

As a result, all parties agreed to make a modification to the system requirements to use a Traveler Information Message (TIM) message set instead for these two applications. While the TIM message set is a viable alternative, its lack of the sophisticated map capabilities of RSM ultimately led to some issues with the OBUs' interpretation of the messages. There were many instances where unintended vehicles were alerting drivers of messages due to failed assessment on the trajectory of vehicle. This was especially true of the CSW application since it was used exclusively on tight loop ramps that have various headings depending on the location within the curve. This issue created inconsistencies in the application of messages.

Continuous RSU Coverage

The project owners desired to have complete RSU coverage along 35 miles of US 33, much of which is rural. This desire stemmed largely from the desire to have a true test corridor that took advantage of the various environmental and roadway geometric designs present. These attributes provide the opportunities to develop and deploy varying types of applications to solve the many transportation issues present today and into the future. To support full coverage and the associated spacing of RSUs, sourcing and providing power at all RSU sites was extremely challenging. ODOT also desired to have enough power available at each site so that additional equipment could be added to support additional applications in the future. As such, the spacing of the poles made it difficult to meet the desired power requirements, given limited sources of power and the large amount of voltage drop between sites to run nominal 120/240 power for the RSUs. Multiple iterations of power designs were developed, and extensive coordination was required with the three local power companies before a power design was selected.

Application Consistency

The consistency of how applications are interpreted to function across industry and infrastructure owners and operators can be problematic. The functionality can be and has been interpreted differently by the OBU vendors. Without national guidance specific to application standardization, there likely will not be consensus on how applications should function and interpret the SAE J2945 standard. In addition, the interpretation of applications such as curve speed warning and how it correlates to the Manual of Uniform Traffic Control Devices is not consistent. This lesson learned has caused DriveOhio to lead national activities to try to develop standard operating specifications for applications, starting with the applications deployed as part of the grant project.

Network Architecture

Network architecture that is based on an IPv4 standard does not sufficiently provide the medium to conduct over-the-air-updates for OBU firmware or certificate top offs for the SCMS system. Due to multiple networks, some IPv4 and some IPv6, the project was able to navigate this issue however conversion of existing networks to support IPv6 is not simple and not without significant cost.

Rapid Changes in Technology

Another lesson learned is that technology changes very rapidly and because of what has happened with DSRC in relation to the FCC, DriveOhio will be upgrading US 33 devices in phases. This will enable the project to keep up with technology by installing a percentage of devices with the latest technology each year, while retaining older technology until it has been deemed to be obsolete or replaced by newer more functional devices. By operating in this manner, it is envisioned that the CV technology will never have to be replaced entirely at a holistic level at any one time period.

Recommendations

Multi-Organizational Structure

This project had four distinct entities at the table – the grant awardees: City of Dublin, City of Marysville, and Union County, and the infrastructure owner and operator, ODOT. A small group of key individuals (Executive Committee) was identified to represent each entity and were empowered to make decisions for their entity or responsible for getting decisions from their entity after consultation. This structure allowed project partners to achieve consensus on project objectives and develop a decision-making framework.

Use Cases

It was advantageous to develop and define clear use cases at the onset of the project. Use cases should be holistically evaluated by considering viability, benefit-cost, technology applications and measurement and evaluation criteria. Use case development should be a collaborative effort with applicable stakeholders to better recognize and address specific needs and challenges to best maximize the benefit and operation. Grantees or project developers should not deploy technology for the sake of technology.

Performance Measures

At this point, the impact of CV technology on general travel is difficult to measure due to limited CV penetration. CV performance measures may need to consider how equipped vehicles behave under various circumstances, to prove benefits with the CV technology. To collect such data, projects should establish metrics early on to feasibly execute data collection and analysis.

Sustainability of the Technology

Future proofing of the technology used in this grant has been a very significant issue. While care has been taken to future proof networks, power needs, and equipment processing power, the sunsetting of DSRC was never predicted at the time of the project development. There likely needs to be more certainty for both infrastructure owners and operators and original equipment vehicle manufacturers moving forward so that there is a willingness to invest in both the infrastructure as well as within the vehicles, without mandates. For the project, a portion of the OBU deployment was changed to dual-mode units (both DSRC and C-V2X technology) in the hopes of providing some sustainable utility of the deployment. The COG is now investigating opportunities to convert the infrastructure from DSRC to C-V2X and DriveOhio has prepared a US-33 C-V2X transition plan to develop a roadmap for converting the corridor.

Conclusions

This project has had considerable impact on the region and Ohio as a whole. It has initiated many conversations between industry, government, and academic institutions and has elevated Ohio to be at the forefront of many conversations and activities, both at the regional and national levels. The relationships that have developed as a byproduct of this project are invaluable. The ability to convene a large group of transportation technology stakeholders to discuss a certain topic is astronomical in terms of providing value to the industry.

While the data from the project is valuable, from the lessons learned and the experiences from both the deployer and user perspectives, the real value comes from the interactions and experiences in testing new technologies. The knowledge gained from a state and local government perspective is vast when working alongside industry professionals. This project has brought activities to the region including deployments of new technology, testing against standards, and development of new standards.

From the end-user perspective, overall satisfaction rates are correlated with ease of learning. Those who found technology easy to learn reported higher than average satisfaction rates. Respondents who found technology difficult to learn reported lower than average satisfaction rates. This correlation suggests one of the factors for public acceptance and adoption will be driven by understanding and training in how this technology works, including what it does and what it does not do. Other factors contributing to public acceptance include warning accuracy and improved human-machine interface.

The approach to evaluating benefits deviated from the conventional monetization approach. Instead of attempting to assign monetary values to the benefits, the assessment of the project combined both quantitative and qualitative considerations. The quantitative assessment involved measuring specific performance metrics such as OBU application events and RSU uptimes. The general knowledge gained from working with multiple CV equipment manufacturers and their implementations of the CV applications has been a driving force to standardize the application messages to a level that is simple and effective for an IOO to support. Understanding the challenges equipment manufacturers face in the interpretation of ambiguous standards requirements has had a significant impact in the directional focus of the state. Without the 33 SMC project, none of those lessons would have been learned and Ohio could not have supported efforts to further develop this life-saving technology. The qualitative evaluation consisted of gathering feedback from stakeholders. Their perceptions and experiences provided qualitative insights into the project's impact on convenience, user satisfaction, and improved safety. These benefits cannot be quantified in a way that would lead to the development of a true benefit-cost analysis. As the technology progresses and the 33 SMC corridor continues to update its technology, the information gleaned from stakeholders will be key in providing feedback to industry related to market needs.

In general, the conclusions from the project evaluation are that the project corridor and deployment has provided a heightened awareness of the potential for the technology to save lives and provide safer travel when and if there is ever full-scale deployment of V2X technology in vehicles. However, it should also be noted that without full scale deployment or mandates to auto manufacturers to include the technology in vehicles, there will continue to be limited added value for the infrastructure owners and operators to deploy the technology at traffic signals and along freeway corridors. It is not realistic to expect that vehicles will continue to be outfitted with the technology as aftermarket safety devices, due to the current high cost of the technology. There are significant benefits to having the technology and messaging “baked in” into a vehicle’s architecture rather than providing additional displays or alerts that can sometimes be more distracting than beneficial.

Overall, for the project deployment, there has been a tremendous value that has been leveraged by further initiatives, testing and outcomes because of the corridor and project identification. The economic impact is great. The 33 SMC has provided tremendous benefits to the local community and the state of Ohio as a whole.

Table 15 illustrates the goal areas and performance measures for the applications that were based upon information collected using varying data methods, data sources, data collection time periods, and sample sizes.

Table 15: Goals Areas and Performance Measures

Goal Area	Performance Measure	Data Method	Data Source	Data Collection Time Period	Sample Size
Improved Safety	41% of end users experienced safety benefits from CV technology	CV User Experience Survey	Survey response	3 months post-deployment	N=75
Improved Safety	***2.01***: Average rating of RLWV application’s effectiveness. (1 – minimal to no effectiveness; 5 – highly effective)	CV User Experience Survey	Survey response	3 months post-deployment	N=75

Goal Area	Performance Measure	Data Method	Data Source	Data Collection Time Period	Sample Size
Improved Safety	***1.68***: Average rating of Lane Closure Warning effectiveness. (1 – minimal to no effectiveness; 5 – highly effective)	CV User Experience Survey	Survey response	3 months post-deployment	N=75
Improved Safety	***1.77***: Average rating of Curve Speed Warning effectiveness. (1 – minimal to no effectiveness; 5 – highly effective)	CV User Experience Survey	Survey response	3 months post-deployment	N=75
Improved Safety	***2.08****:* Average rating of Ped. In Crosswalk Warning effectiveness. (1 – minimal to no effectiveness; 5 – highly effective)	CV User Experience Survey	Survey response	3 months post-deployment	N=75
Improved Safety	***1.81*****:** Average rating of CV technology making user more or less attentive to driving task and environment.	CV User Experience Survey	Survey response	3 months post-deployment	N=75
Improved Safety	**13,930**: Total number of 5 OBU Safety Application events recorded during evaluation period	Automatic Event Recording Logs	AWS OBU Event Records	Operational Test Period (5/1/22 to 5/1/23)	N=34,887
Reduced Congestion and/or Improved Mobility	US 33 2022 Road Construction (resurfacing project) data from Honda equipped vehicles to determine how they were impacted.	Field (vehicle probe data)	Honda	2020-2023	257 Honda Equipped Vehicles

Goal Area	Performance Measure	Data Method	Data Source	Data Collection Time Period	Sample Size
Accelerated deployment of V2I and other advanced technologies	92%: RSU average uptime.	Dashboard	RSU Ping Uptime from RSU Integrator	5/18/23 – 5/31/23	N/A
Accelerated deployment of V2I and other advanced technologies	207: Number of OBUs using the system (per log file)	Field (vehicle probe data) and other sources/ initiatives	AWS OBU Event Records and Interview with DriveOhio	Operational Test Period (5/1/22 to 5/1/23)	N=207
Accelerated deployment of V2I and other advanced technologies	Number of unique testers/users that are using the infrastructure, including industry organizations and events	Documentation/ Stakeholder Interviews	Interview with DriveOhio	N/A	N/A
Accelerated deployment of V2I and other advanced technologies	Number of other deployments that are leveraging the technology infrastructure installed under the grant	Documentation/ Stakeholder Interviews	DriveOhio Interview/ Project Documentation	3 months post-deployment	N/A

Appendix A. Connected Vehicle Technology User Experience Survey and Responses

Appendix A contains the questions and responses to the Connected Vehicle Technology User Experience Survey. There are fourteen questions on the survey.

1. Which public agency do you represent/work for?

Table 16: Responses to Question 1

Options	Responses
Union County	13
City of Dublin	34
City of Marysville	28
TOTAL	**75**

2. What role do you serve in your agency? (Example: Fire, Police, School, Public Works, Transit, etc.)

Table 17: Responses to question 2

User-entered Responses	Responses
Public Works	34
Police	13
Transit	6
Other	22
TOTAL	**75**

3. From your perspective, what benefits of the Connected Vehicle (CV) system were experienced? Check all that apply.

Table 18: Responses to question 3

Options	Responses
Improved Safety: Fewer Crashes	6
Improved Safety: Increased Driver Awareness	21
Improved Safety: Fewer “near misses”	4
Improved Mobility: Accurate Information on Driving Environment	8
NO RESPONSE	36
TOTAL	**75**

4. How easy or difficult was it to learn and use the CV features in the vehicle?

Table 19: Responses to question 4

Options	Responses
Extremely Easy	6
Somewhat Easy	8
Neutral	32
Somewhat Difficult	5
Extremely Difficult	16
No Response	8
TOTAL	**75**

5. How reliable was the CV technology in terms of the devices working as intended?

Table 20: Responses to question 5

Options	Responses
Very Reliable	3
Somewhat Reliable	11
Neither Reliable or Unreliable	16
Somewhat Unreliable	12
Extremely Unreliable	32
No Response	1
TOTAL	**75**

6. How reliable was the CV technology in terms of providing accurate, timely, or relevant information (i.e. no false positives)?

Table 21: Responses to question 6

Options	Responses
Very Reliable	4
Somewhat Reliable	15
Neither Reliable or Unreliable	13
Somewhat Unreliable	9
Extremely Unreliable	32
No Response	2
TOTAL	**75**

7. How likely are you to retain or recommend the CV technology in the vehicle?

Table 22: Responses to question 7

Options	Responses
Very Likely	5
Somewhat Likely	1
Neutral	17
Somewhat Unlikely	8
Very Unlikely	41
No Response	3
TOTAL	**75**

8. Rate the effectiveness of: Red Light Warning (Intersection Warning and Collision Avoidance Application). Scale of 1 to 5. 1 is minimal to no effectiveness and 5 being highly effective.

Table 23: Responses to question 8

Options	Responses
1	38
2	12
3	11
4	8
5	4
No Response	2
AVERAGE	**2.01**

9. Rate the effectiveness of: Reduced Speed Zone Warning/Lane Closure Warning. Scale of 1 to 5. 1 is minimal to no effectiveness and 5 being highly effective.

Table 24: Responses to question 9

Options	Responses
1	46
2	14
3	7
4	2
5	4
No Response	2
AVERAGE	**1.68**

10. Rate the effectiveness of: Curve Speed Warning. Scale of 1 to 5. 1 is minimal to no effectiveness and 5 being highly effective.

Table 25: Responses to question 10

Options	Responses
1	45
2	10
3	11
4	4
5	3
No Response	2
AVERAGE	**1.77**

11. Rate the effectiveness of: Pedestrian in Crosswalk Warning. Scale of 1 to 5. 1 is minimal to no effectiveness and 5 being highly effective.

Table 26: Responses to question 11

Options	Responses
1	35
2	10
3	18
4	7
5	3
No Response	2
AVERAGE	**2.08**

12. On a scale of 1 to 5, with 1 being no change or not effective and 5 being highly effective, did the CV technology make you more or less attentive to the driving task, your driving environment and other vehicles and pedestrians?

Table 27: Responses to question 12

Options	**Responses**
1	45
2	10
3	11
4	4
5	4
No Response	1
AVERAGE	**1.81**

13. On a scale of 1 to 5, with 1 being very dissatisfied and 5 being very satisfied, what was your overall experience with the CV technology?

Table 28: Responses to question 13

Options	**Responses**
1	41
2	12
3	12
4	3
5	3
No Response	4
AVERAGE	**1.80**

14. What was the biggest challenge in using the CV technology? (Optional, write-in answer).

Table 29: Responses to question 14

Response Coded	**Responses**
Interface (light and sound) were distracting	20
Warnings were false positives	19
Lack of training or information on technology	15
Rarely gave warnings	13
Other	6
No Response	2
Total:	**61**

Appendix B. RSU Uptime Percentage Table

Table 30 provides information on RSU uptime used in the project including information on the manufacturers, model number of unit, the site where the unit was placed as well as the IP address.

Table 30: RSU Uptime by Unit

RSU S/N	Manufacturer	Model	Site	Uptime	IP
PFS00092	Kapsch	Kapsch RIS-9160	R-1	99.73%	10.30.1.60
19000371	Danlaw	Danlaw RouteLink	R-10	99.85%	10.30.10.60
PFS00098	Kapsch	Kapsch RIS-9160	R-11	99.85%	10.30.11.60
19000309	Danlaw	Danlaw RouteLink	R-12	100.00%	10.30.12.60
19000378	Danlaw	Danlaw RouteLink	R-13	99.99%	10.30.13.60
19000310	Danlaw	Danlaw RouteLink	R-14	99.92%	10.30.14.60
19000374	Danlaw	Danlaw RouteLink	R-15	99.86%	10.30.15.60
PFS00110	Kapsch	Kapsch RIS-9160	R-16	100.00%	10.30.16.60
19000382	Danlaw	Danlaw RouteLink	R-17	99.99%	10.30.17.60
19000379	Danlaw	Danlaw RouteLink	R-18	99.99%	10.30.18.60
19000030	Danlaw	Danlaw RouteLink	R-19	98.76%	10.30.19.60
19000372	Danlaw	Danlaw RouteLink	R-2	99.85%	10.30.2.60
19000377	Danlaw	Danlaw RouteLink	R-20	100.00%	10.30.20.60
19000373	Danlaw	Danlaw RouteLink	R-21	99.99%	10.30.21.60
19000449	Danlaw	Danlaw RouteLink	R-22	100.00%	10.30.22.60
PFS00101	Kapsch	Kapsch RIS-9160	R-23	100.00%	10.30.23.60
19000440	Danlaw	Danlaw RouteLink	R-24	99.99%	10.30.24.60
19000438	Danlaw	Danlaw RouteLink	R-25	99.99%	10.30.25.60
19000390	Danlaw	Danlaw RouteLink	R-26	100.00%	10.30.26.60
19000448	Danlaw	Danlaw RouteLink	R-27	100.00%	10.30.27.60
19000427	Danlaw	Danlaw RouteLink	R-28	100.00%	10.30.28.60
PFS00099	Kapsch	Kapsch RIS-9160	R-29	99.97%	10.30.29.60
19000383	Danlaw	Danlaw RouteLink	R-3	99.85%	10.30.3.60
19000429	Danlaw	Danlaw RouteLink	R-30	99.99%	10.30.30.60
19000452	Danlaw	Danlaw RouteLink	R-31	99.89%	10.30.31.60
19000451	Danlaw	Danlaw RouteLink	R-32	100.00%	10.30.32.60
PFS00094	Kapsch	Kapsch RIS-9160	R-33	100.00%	10.30.33.60
19000441	Danlaw	Danlaw RouteLink	R-34	100.00%	10.30.34.60
19000435	Danlaw	Danlaw RouteLink	R-35	99.99%	10.30.35.60
19000443	Danlaw	Danlaw RouteLink	R-36	57.04%	10.30.36.60
19000442	Danlaw	Danlaw RouteLink	R-37	68.25%	10.30.37.60
PFS00097	Kapsch	Kapsch RIS-9160	R-38	86.72%	10.30.38.60
19000433	Danlaw	Danlaw RouteLink	R-39	99.99%	10.30.39.60
19000380	Danlaw	Danlaw RouteLink	R-4	99.85%	10.30.4.60
19000437	Danlaw	Danlaw RouteLink	R-40	99.99%	10.30.40.60

RSU S/N	Manufacturer	Model	Site	Uptime	IP
19000450	Danlaw	Danlaw RouteLink	R-41	99.93%	10.30.41.60
PFS00107	Kapsch	Kapsch RIS-9160	R-42	85.77%	10.30.42.60
19000391	Danlaw	Danlaw RouteLink	R-43	87.17%	10.30.43.60
19000436	Danlaw	Danlaw RouteLink	R-44	87.05%	10.30.44.60
19000430	Danlaw	Danlaw RouteLink	R-45	87.17%	10.30.45.60
19000444	Danlaw	Danlaw RouteLink	R-46	86.91%	10.30.46.60
PFS00102	Kapsch	Kapsch RIS-9160	R-47	99.99%	10.30.47.60
19000375	Danlaw	Danlaw RouteLink	R-48	99.98%	10.30.48.60
19000425	Danlaw	Danlaw RouteLink	R-49	99.98%	10.30.49.60
19000381	Danlaw	Danlaw RouteLink	R-5	99.85%	10.30.5.60
19000432	Danlaw	Danlaw RouteLink	R-50	99.97%	10.30.50.60
19000424	Danlaw	Danlaw RouteLink	R-51	99.23%	10.30.51.60
19000447	Danlaw	Danlaw RouteLink	R-52	99.27%	10.30.52.60
19000426	Danlaw	Danlaw RouteLink	R-53	99.48%	10.30.53.60
19000423	Danlaw	Danlaw RouteLink	R-54	99.55%	10.30.54.60
19000439	Danlaw	Danlaw RouteLink	R-55	99.55%	10.30.55.60
PFS00108	Kapsch	Kapsch RIS-9160	R-56	93.14%	10.30.56.60
19000445	Danlaw	Danlaw RouteLink	R-57	93.14%	10.30.57.60
19000431	Danlaw	Danlaw RouteLink	R-58	26.73%	10.30.58.60
19000434	Danlaw	Danlaw RouteLink	R-59	93.10%	10.30.59.60
PFS00095	Kapsch	Kapsch RIS-9160	R-6	99.85%	10.30.6.60
19000366	Danlaw	Danlaw RouteLink	R-60	92.77%	10.30.60.60
PFS00096	Kapsch	Kapsch RIS-9160	R-61	99.99%	10.30.61.60
19000360	Danlaw	Danlaw RouteLink	Delaware Ave (US36) @ Watkins Road	0.00%	10.30.62.60
19000360	Danlaw	Danlaw RouteLink	R-62	0.00%	10.30.62.60
19000400	Danlaw	Danlaw RouteLink	Delaware Ave (US36) @ Watkins Road	93.03%	10.30.63.60
19000400	Danlaw	Danlaw RouteLink	R-63	93.03%	10.30.63.60
19000446	Danlaw	Danlaw RouteLink	R-7	99.85%	10.30.7.60
19000376	Danlaw	Danlaw RouteLink	R-8	99.85%	10.30.8.60
19000387	Danlaw	Danlaw RouteLink	R-9	99.85%	10.30.9.60