Wrong Way Driver Prevention
Pilot Program and Peer Exchange

Summary Report

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Developed by:

INTEGRAL BLUE
COMMUNICATIONS ENGINEERING & SYSTEMS INTEGRATION

Exclusively for:

MDOT
Michigan Department of Transportation

In collaboration with:

FDOT

Continental

TAPCO
Safe travels.

MICHIGAN STATE POLICE

Integral Blue
1060 Centre Rd
Auburn Hills, MI 48326
www.integral-blue.com

Wrong-Way Driving Prevention Peer Exchange Summary Report

Submitted to:

Michele Mueller
Sr. Project Manager Connected, Automated and Electrification
Michigan Department of Transportation
18101 W. Nine Mile Road, Southfield, MI 48075
Muellerm2@michigan.gov
Cell Phone: 248 431-1443

Prepared by:

Ted Sadler
Connected Vehicle Specialist
Integral Blue
1060 Centre Rd, Auburn Hills, MI 48326
tsadler@integral-blue.com
Cell Phone: 810 542-1012

In collaboration with and enormous thanks to:

Brandy Solak
Safety and Operations Engineer
Federal Highway Administration, MI Division

Josh Billotti
SEMTOC ITS Construction Engineer
MDOT Metro Region

Joshua Carey
Traffic Safety and Operations Engineer
MDOT Metro Region

Eliseo Gutierrez
ITS Engineer
MDOT ITS Program Office

Mark Bott
Traffic and Safety Manager
MDOT Transportation Systems
Management Operations Division

Megan Arasteh
TSM&O Program Engineer
FDOT D7 Traffic Operations

Jeremy Dilmore
TSM&O Program Engineer
FDOT D5 Traffic Operations

Peter Hsu
Safety Engineer
FDOT D7 Traffic Operations

Lauren Pearson
D5 RTMC Manager
FDOT D5 Traffic Operations

Edith Wong
State Arterial Management Engineer
FDOT Traffic Engineering and Operations Office

Caitlin Day
Connected and Automated Vehicles Engineer
MDOT Metro Region

Jonathan Stone
Head of Smart Infrastructure Systems Platform
Continental Automotive Systems

Kenneth Gollinger
Technical Project Manager
Continental Automotive Systems

Scott Hogden
National ITS Service Manager
TAPCO

Michael Long
Manager of Product Management
TAPCO

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BACKGROUND **INFORMATION**

Introduction & Context

The threat posed by a wrong-way driver (WWD) is perhaps one of the most frightening and potentially deadly of those a driver may encounter. While relatively uncommon compared to other types of incidents, WWDs have exponentially higher fatality rates: from 2011 to 2020, Florida Department of Transportation (FDOT) recorded 535 wrong-way driver incidents, 21% of which were fatal with 58% being caused by impaired drivers.[1] There is no one particular cause of WWD incidents, either: darkness, unfamiliarity with the area, unclear or misleading pavement markings or signage, age demographic, and intoxication are all contributing factors.[2] To prevent this type of deadly incident, many state DOTs have started looking to technology for a solution.

Michigan DOT (MDOT) has long been an advocate for and early-adopter of Intelligent Transportation Systems (ITS) and a believer in their promise to improve mobility, safety, and sustainability for everyone. With the Big Three automakers in their backyard, MDOT has aggressively deployed many ITS solutions over the years including some WWD prevention and detection systems. In the past, these systems have been infrequently deployed, as off-the-shelf products hadn't become readily available yet and the ad-hoc solutions that were available had mixed results when tested. However, wrong-way tragedies in recent years have spurred MDOT to renew their examination of the available options. This report details MDOT's recent vendor partnerships, pilots, and peer-exchange with FDOT to pursue a statewide solution to this deadly problem.

Continental Partnership

In January of 2019, the Abbas, a family of five from Metro Detroit, were tragically killed in a wrong-way crash in Kentucky.[3] Jonathan Stone, the head of IoT and Connected Services Innovation at Continental Automotive Systems at the time and a family friend of the Abbas, directed his team toward the adaptation of their vehicular radar sensor (normally used for adaptive cruise control and similar applications) for use as a means of detecting wrong-way drivers. Combined with an intelligent machine-learning algorithm, the intelligent radar solution was designed for accuracy while avoiding the false positive detections that typically plague radar-based systems. Work on prototyping began shortly thereafter, with a demonstration being performed in October of that year at Continental's Brimley, MI test track facility, attended by MDOT, Wayne State University, the Road Commission for Oakland County, and other representatives from both public and private sectors.

Coincidentally, when coming home from the Brimley demonstration, Continental's development team encountered a wrong-way driver on I-75, notifying 911 who dispatched Michigan State Police (MSP) and thankfully stopped the wrong-way driver. This event led to workshops between Continental, MDOT, and MSP on WWD prevention and execution of pilot testing to train the prototype system's machine learning algorithms. After testing in downtown Auburn Hills and on the I-75 mainline, Continental partnered with TAPCO and MDOT to install a wrong-way detection and alerting system using Continental's intelligent radar prototype as the detection mechanism alongside FLIR thermal cameras for comparison.

The pilot system was installed in December of 2021 at the end of the I-75 northbound exit ramp to Joslyn Rd., and Continental spent the next several months recording real-world field data and performing iterative development of their wrong-way detection algorithms. In August of 2022, Continental switched the system from activation by FLIR thermal sensors to activation by Continental radar sensors after optimizing the Continental sensors' performance. Later that month, on August 30th, the ramp was closed to traffic and Continental conducted a live wrong-way vehicle test in collaboration with TAPCO, MDOT, Integral Blue, Michigan State Police, Auburn Hills Police, and Oakland County. Following this test, a 60-day burn-in validation period was conducted on the system. Details on the system components and test results can be found in the following section.

JOSLYN RD. **WWDS PILOT**

System Overview

The TAPCO / Continental Wrong-Way Driver System (WWDS) is located at the end of the off-ramp from Northbound I-75 to Joslyn Rd. in Auburn Hills, MI. This system was constructed by TAPCO and Continental in late 2021 with the intent of piloting Continental's innovative vehicle radar system adapted for infrastructure-side wrong-way vehicle detection. Following installation and a period of calibration, a test plan was developed and executed on August 30th, 2022 in cooperation between TAPCO, Continental, MDOT, Integral Blue, Michigan State Police, Auburn Hills Police, and Oakland County to verify the expected functionality of the WWDS using a variety of vehicles. The results of this test will help MDOT determine potential future specification details for statewide WWD systems and integrations between MDOT ITS infrastructure and external data-sharing mobility partners like Waze and HAAS-Alert.

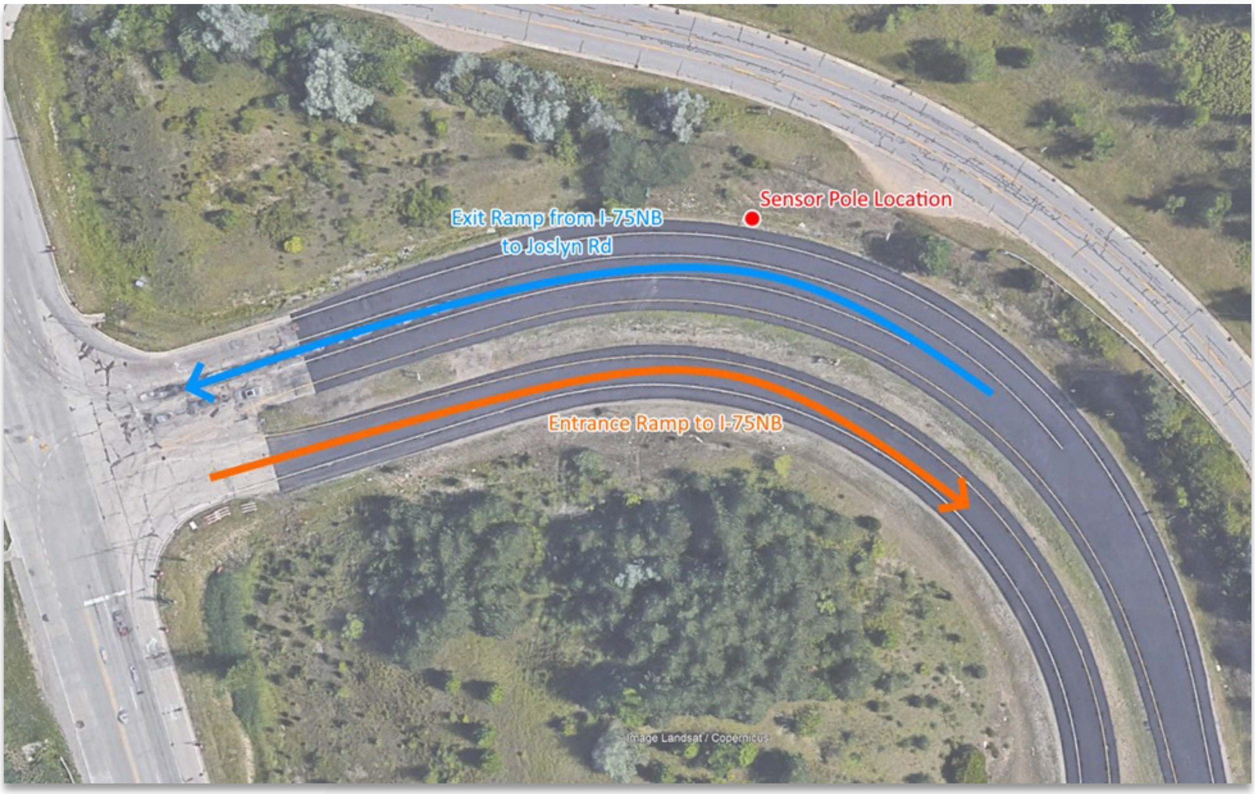

Figure 1 - Overview of System Location & Ramps

System Components

The WWDS consists of several poles along the off-ramp, one including detection sensors, one including a solar panel array, and several others with wireless radio-activated, solar-powered blinking alert signs. The system operates by monitoring for wrong-way vehicles moving up the ramp, notifying the driver via blinking signs of their wrong direction, verifying that the vehicle is continuing in the wrong direction, and alerting BlinkLink subscribers that detection was activated by a potential wrong -way driver. TAPCO provided input on the design and location-specific pole placement for the system, consulting with MDOT, contractors, and project stakeholders prior to installation. The following sections contain additional details on the primary components and functions of the system. Most of these components are common to all WWD system vendors, with some variety of combination.

FLIR Thermal Cameras

In most TAPCO WWDS installations, vehicle detection is performed by dual FLIR thermal cameras at the top of the primary sensor pole. These sensors use thermal imaging to detect motion of vehicles in the wrong direction and trigger a wrong-way event. Initially, the FILIR cameras were used to trigger the blinking signs and system notifications and establish baseline performance for comparison to the Continental radar sensors. Eventually, the system's blinking signs and notifications were switched over to be triggered by the Continental radar sensors.

Figure 2 - FLIR Cameras

Continental Radars

Detection of wrong-way vehicles and activation of the local system are performed by dual radar units developed by Continental and adapted for use on infrastructure, installed on the primary sensor pole. The radars use heatmap-based analytics to "learn" baseline behavior of objects on the roadway and detect anomalies from that baseline such as vehicles moving the wrong way.

Figure 3 - Continental Radars

AXIS Surveillance Cameras

Also included on the sensor pole are two AXIS HD surveillance cameras which provide video feeds, snapshots, and clips through BlinkLink when vehicle events are detected. This provides operators with local imagery to verify that detection was triggered by a true wrong-way vehicle. Depending on subscription levels, BlinkLink can also provide live video feeds for operators on-demand. This same imagery can be sent directly to a state ATMS if BlinkLink is not used.

Figure 4 - AXIS Cameras

White LED Lights

When wrong-way driver events are detected at night, two lights on the primary sensor pole activate to provide lighting to illuminate wrong-way vehicles and enable operators to better identify wrong-way vehicle characteristics in photos or video.

Figure 5 - White LED Lights

BlinkerSign Warning Alert Poles

Along the ramp are several sets of R5-1a Wrong Way BlinkerSigns to alert the driver that they are going the wrong way. By default, the signs are unlit, but when triggered by the sensors detecting a wrong-way vehicle, the LEDs on the sign border flash to maximize conspicuity. On top of these poles are an integrated solar engine with a radio which communicates with the system controller and receives activation triggers. The primary sensor pole also includes one BlinkerSign directly connected to the Control Cabinet.

Figure 6 - Wrong-Way BlinkerSign

Control Cabinet

Mounted on the primary sensor pole is a small aluminum cabinet, the size of a typical ITS Pole Mounted Cabinet. Inside the cabinet are various control and logic modules used in activation of the system, a Layer 2 Ethernet Switch, a CloudLink cellular modem, a radio module, solar power inverters, and an array of batteries connected to the solar array (not pictured). Note, Continental also installed an auxiliary control box on the pole containing their own remote access modem and the primary compute module for analyzing radar data and detecting wrong-way events.

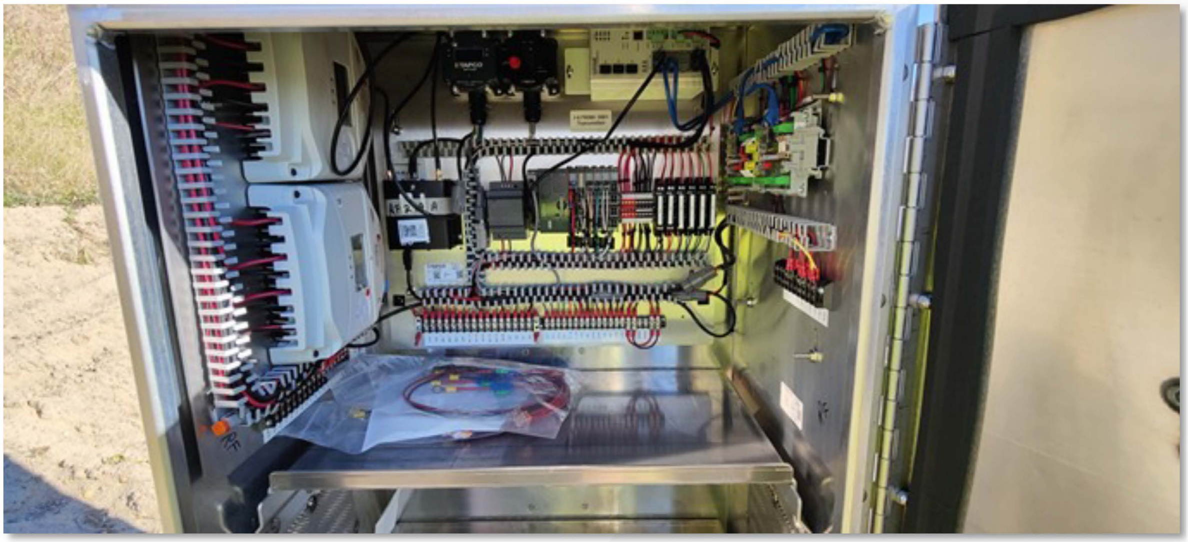

Figure 7 - Control Cabinet

Continental Control Box

Mounted below the Continental sensor unit is an additional weatherproof box containing a cellular router, AC/DC power converter, analytics processor, and remote debug electronics to aid in the development and testing of the system. The network communications components are not core to the sensing solution; however, in deployments where an existing communications path such as TAPCO's control cabinet or existing MDOT infrastructure are not available, communications technology is required to appropriately relay event information.

Figure 8 - Continental Box

Solar Array

Adjacent to the primary sensor pole is another pole with 8 solar panels installed on it forming a single array. This array connects via underground conduit to the primary sensor pole and Control Cabinet, providing power to the cabinet and charging batteries for backup power during nighttime and days with minimal sun exposure.

Figure 9 - Solar Array

BlinkLink Event Management Software

Operations and management of the system is performed from a head-end cloud platform developed by TAPCO called BlinkLink. This system receives data from the local WWDS and provides notifications to subscribed users such as DOT personnel and first responders during certain events. It is capable of monitoring the health of the system and its components, sending emails and text messages, providing access to on-demand video or event clips, and other functions. BlinkLink also logs system activity and alert resolutions, providing ongoing data for operational reporting, trend analysis, and safety metrics. Users can log into its web console to perform these functions and control or monitor the system. Additionally, BlinkLink can be integrated with an existing Advanced Traffic Management System (ATMS) over web API.

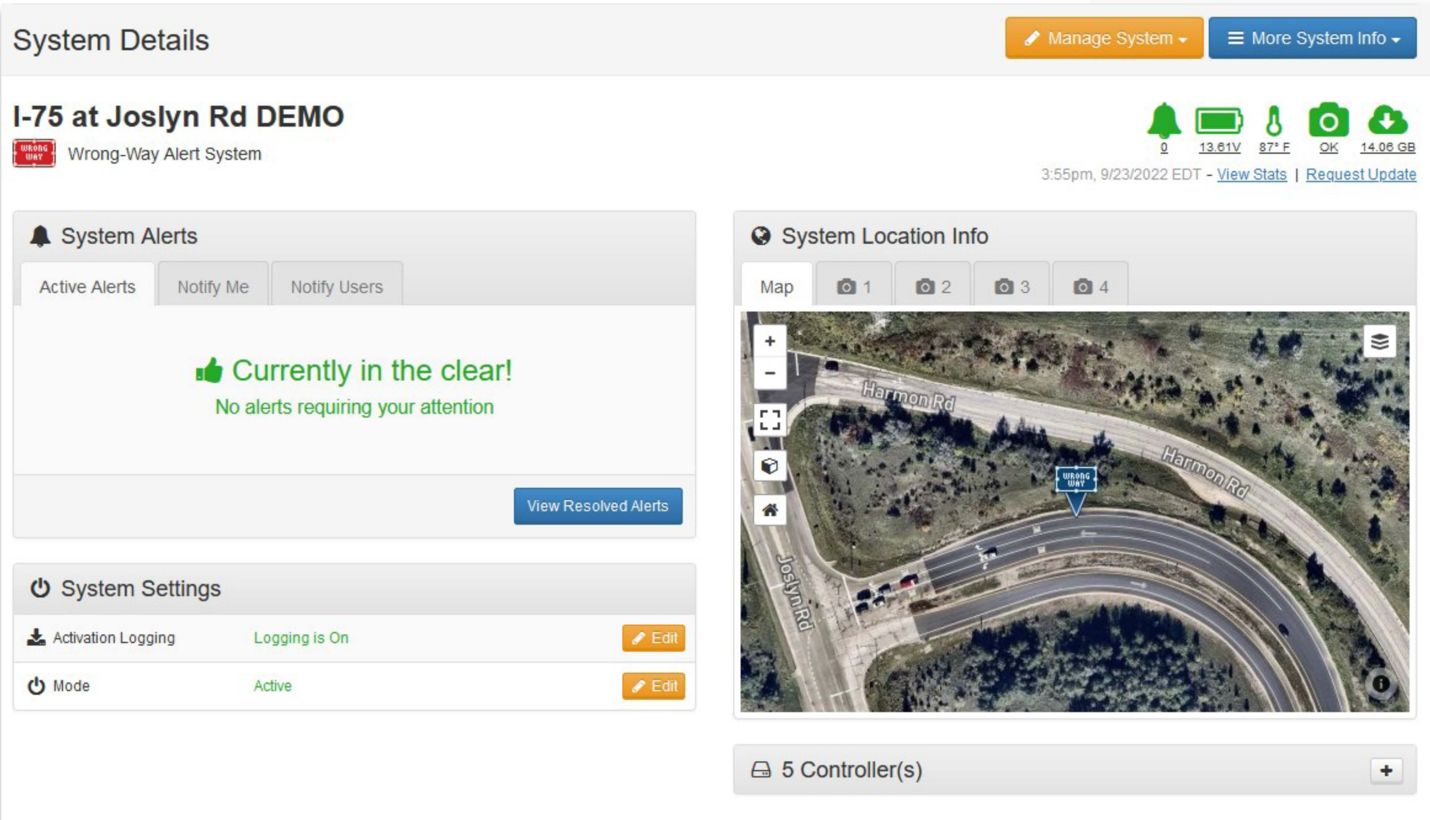

Figure 10 - BlinkLink Web Console

Operational Functions

The WWDS components work together to detect objects moving the wrong way and help confirm whether those detections are true wrong-way driver events. Any potential wrong-way driver is warned that they are going the wrong way while system subscribers are only notified if the detected object moves far enough up the ramp, indicating a real WWD event is likely.

The radars are arranged so that one faces forward, monitoring for wrong-way vehicles entering the ramp, and the other faces backwards, monitoring for vehicles continuing up the ramp, as shown in Figure 11.

Figure 11 - Radar Orientation (Note: may not accurately depict entire detection areas.)

The assembled system's operational functions are summarized as follows:

1. Forward-facing Continental radar detects a potential wrong-way vehicle moving up the ramp from the intersection stop bar:
    a. BlinkerSigns activate, visually alerting driver
    b. A system Activation is logged in BlinkLink
    c. No high-priority alert or images are sent to BlinkLink or subscribers, in case the event is a false positive or the driver self-corrects after seeing the signs
2. Rear-facing Continental radar detects the vehicle continuing up the ramp past the sensor pole, confirming that the vehicle has not self-corrected:
    a. Supporting white LED lights activate
    b. AXIS camera rewinds buffer to just before the detection event, then prepares, compiles, and relays event imagery
    c. High-priority alert and corresponding images are sent to BlinkLink and subscribers confirming a wrong-way event has occurred

Should a driver turn around at any point, the sensors it has triggered thus far will still activate appropriately. System users should always respond to alerts to confirm either a wrong-way event or a self-correction.

Ramp Closure Test

On August 30th, 2022, Oakland County closed the I-75N to Joslyn Rd. exit ramp from 9am to 3pm to facilitate system testing. Testing included validation of sign activation and notifications, the absence of notifications during self-correction events, accuracy in detection across vehicle types, sizes, and speeds, and accuracy in detection despite erratic vehicle behavior. In total, 72 WWD vehicle passes were performed on the system.

This testing went incredibly well and proved the efficacy of Continental's radar solution and TAPCO's local and remote notification system through the use of real wrong-way vehicles in a controlled environment.[4]

Burn-In Validation Period

Following the on-site testing, MDOT performed a 60-day operational "burn-in" test of the system to observe detection accuracy, false positive alerts, and communications stability over time. Requirements for this burn-in period included:

1. *False Positive Prevention:* 95%+ of wrong-way event notifications received by SEMTOC from BlinkLink (if any) must be from actual wrong-way drivers.
2. *Detection Accuracy:* 98%+ of wrong-way drivers at the I75N/Joslyn exit ramp reported by the public or observed by SEMTOC operators in the I75/Joslyn CCTV must have corresponding events and notifications in BlinkLink.
3. *System Stability:* The system must not lose communication with BlinkLink for more than 24 consecutive hours and must be able to self-restore without local intervention.

To perform these measurements, the project worked with the Southeast Michigan Transportation Operations Center (SEMTOC), who performed thrice-daily validations of the system. Validation included:

- Continual monitoring of the ITS cameras closest to the Joslyn Rd exit ramp for potential undetected WWD events,
- Monitoring of MSP and MDOT communications for WWD reports,
- Confirmation of healthy system status within BlinkLink, including battery voltage, temperature, and camera/controller communications status,
- Logging of any real, invalid (landscapers activating the system, emergency vehicles, etc.), or false positives, and
- Daily reporting on the above back to the project team.

Key observations from the burn-in were as follows:

- There were no real wrong-way events observed over the course of the burn-in.
- Only one false positive was experienced over the course of the burn-in.
- Systems comm loss was observed but recovered each time within 24hrs without requiring manual intervention.

The burn-in requirements specified that 95% of observed events must be real events, as a metric for measuring false positives. However, after pilot group discussion and system observation, it was decided to forego this requirement given the few total events overall. If real WWD events are undesirable, they should not be used as a comparison point for calculating false positive metrics; instead, it would have been better to measure false positives overall without comparing them to real events. With that in mind, one false positive over 60 days was determined by the group to be an acceptable performance metric. It is also worthwhile to note that Continental sourced the false positive cause to a power issue with a component they were using and already have a plan to remedy the problem.

With all of this considered, it is the pilot project's recommendation to accept the system's burn-in as satisfactory and move toward collaboration with ITS Maintenance for system acceptance.

FDOT'S WWD **DEPLOYMENT**

Background & Initial Pilots

The Joslyn Rd. installation wasn't the first WWD system to be recently proposed; other MDOT projects were beginning to install ad-hoc WWD systems using different vendor solutions, but none that unified into any kind of cohesive ecosystem. Wanting to prevent a large collection of disparate, un-integrated systems from forming, MDOT began looking for other states that had pursued large-scale WWD system deployments, eventually meeting with FDOT who presented briefly on what they had accomplished over the last several years.

Following this presentation, MDOT began working with FDOT and FHWA on a peer exchange in which the two departments would meet in person to discuss MDOT's WWD user needs and detail what solutions FDOT ended up implementing, how they arrived at those selections, and the lessons they learned throughout the process. This peer exchange occurred from August 22-24th and included staff from FHWA, MDOT, FDOT's Districts 5 and 7, Integral Blue, and other supporting consultants.

FDOT Organizational Architecture

Similarly to MDOT, FDOT is divided into seven districts: D1 (Bartow), D2 (Jacksonville), D3 (Chipley), D4 (Ft. Lauderdale), D5 (Orlando), D6 (Miami), and D7 (Tampa). FDOT itself is headquartered at their Tallahassee Central Office, analogous to MDOT's ITS Program Office in Lansing, providing general budgetary guidance, setting policy, and publishing project specifications and special provisions. Beyond this, the Districts have a rather large amount of autonomy over their networks, ATMS software, daily operations, ITS budgets, projects, and special provisions that build upon or alter the ones provided by Tallahassee.

Dissimilarly to MDOT, FDOT has an Approved Products List (APL) for their projects, including ITS devices and systems.[5] The APL is maintained by Central Office's Traffic Engineering Research Laboratory (TERL), a controlled test environment where FDOT can test vendors and components that are submitted for inclusion on the APL. This mechanism streamlines the project submittal process and ensures that FDOT projects install systems that are confirmed to be compatible with their existing infrastructure and compliant with their system requirements.

All of FDOT's ITS devices, including their WWD systems, integrate with their Advanced Traffic Management System (ATMS) known as SunGuide.[6] SunGuide was developed specifically for FDOT by the same company behind LoneStar, Texas DOT's ATMS. While initial deployments of WWD systems in Florida did not at first integrate with SunGuide, and some new systems under assessment may not yet either, FDOT is committed to integrating all of their WWD systems into SunGuide and now requires APL applicants to provide APIs or drivers compatible with it.[7]

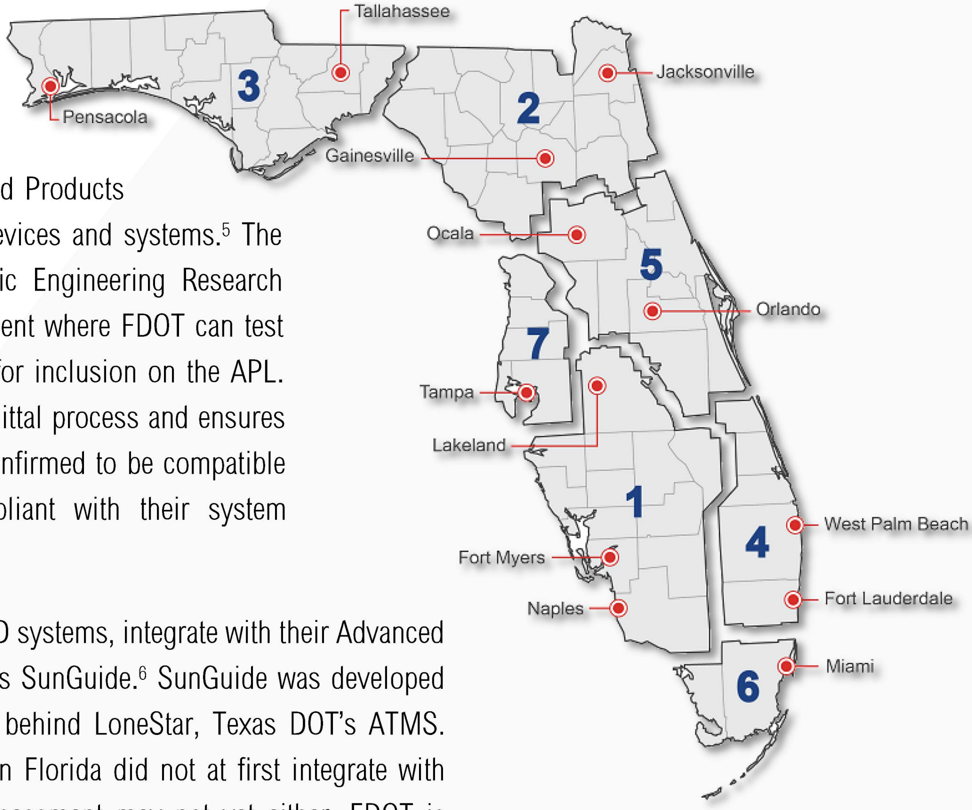

Figure 12 - FDOT District Map

When a WWD system is integrated with SunGuide, it will report on the presence of a confirmed wrong-way driver and generate an event in SunGuide's Incident Detection Subsystem (IDS), immediately popping up to notify operators of the incident, who are unable to dismiss or ignore the alert without processing it. Within the alert are 10 snapshots from the WWD system's local surveillance cameras, providing operators with on-the-ground perspective to confirm if the event is real or not. To further assist with rapid response, SunGuide automatically executes presets on nearby freeway ITS cameras to positions focused on the ramp and approaches associated with that local WWD system. Finally, should an alert be legitimate and not a false positive, operators are presented with a single-click button to automatically post Dynamic Message Sign (DMS) warnings upstream and downstream from the WWD location to alert drivers of the incident. Without this ATMS integration, operators would be forced to log into the WWD system directly, manually find and move SunGuide cameras in search of the WWD vehicle, and manually post DMS warnings, significantly increasing the response time and potentially missing the window of opportunity for warning or interception of the driver. In many ways, SunGuide is the most important factor contributing to the successful deployment and operation of FDOT's statewide WWD systems.

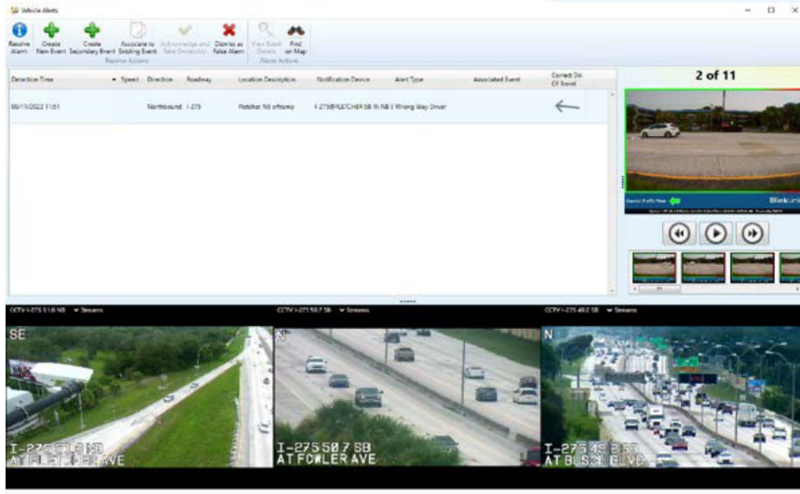

Figure 13 - SunGuide IDS with Wrong-Way Event (Source: FDOT)

WWD Task Force Formation

In 2014, four students from University of South Florida (USF) were killed by an intoxicated wrong-way driver on I-275.[8] The gruesomeness of the incident and youth of the victims catapulted the media coverage to national levels; in response, FDOT began looking at improvements that could be made to their own infrastructure to prevent tragedies like this from occurring. In months that followed, additional WWD incidents only cemented FDOT's commitment to finding a solution. Forming a statewide WWD task force with representatives from FDOT, local agencies, and law enforcement, FDOT performed studies using Crash Analysis Reporting System (CARS) database statistics to identify priority deployment areas based on incident frequency and piloted improvements to determine what solutions, both technical and non-technical, would have the most impact on preventing them. This task force still meets biweekly to review statewide WWD incidents, responses, proposed specification or testing improvements, and other action items.

Figure 14 - WUSF Article on 2014 WWD Incident

Several studies were conducted by FDOT following the formation of the task force. Two of the most informative studies included one analyzing wrong-way crash locations and factors throughout the state's freeway system and one assessing the effectiveness of different wrong-way driver deterrents.

2015 Statewide Crash Study

Using a sample size of 280 crashes spread over five years (from 2009-2013), FDOT analyzed the patterns and factors contributing to wrong-way incidents on freeways and expressways throughout Florida, culminating in a series of recommended countermeasures and a statewide implementation plan. Of these 280 crashes, over half (51%) caused serious injury and 18% were fatal.[9]

Major contributing factors highlighted by the study included:[10]

- Time, with weekends (Friday, Saturday, Sunday) and early morning (12am to 6am) being the most common.
- Involvement of alcohol or other intoxicants (45%), a frequency more than 16x the average for other freeway crashes in FL.
- Lighting, with 71% of crashes occurring in dark conditions (compared to 29% of other freeway crashes).
- Age, with 42% of drivers involved being younger than 30 and 4.6% being older than 75. Note, drivers younger than 30 normally constitute 50% of other freeway crashes but drivers older than 75 only contribute to 1.4% of other crashes, meaning older drivers are at higher risk for wrong-way incidents than younger.
- Location, with wrong-way crashes occurring more often in urban areas.
- Entry points, with most drivers entering the freeway the wrong way from an exit ramp.
- Interchange geometry, with partial cloverleaf, full diamond, half diamond, and buttonhook ramps being among the most susceptible to wrong-way movements.

Both Districts 5 and 7 also noted in their individual presentations to MDOT that their respective entertainment districts suffered from high amounts of wrong-way incidents compared to other urban locations. The presence of bars and other intoxicant vendors seems to greatly exacerbate the number of local wrong-way drivers, consistent with the statistically higher percentage of intoxicant presence in wrong-way incidents.

2017 CUTR Study Comparing WWD Countermeasures

By 2017, several FDOT Districts had already deployed multiple WWD technology pilots but there was no real scientific consensus on which mitigation technologies were most effective. To determine the answer to this question and help prioritize deployment goals throughout the Districts, FDOT commissioned the Center for Urban Transportation Research (CUTR) to evaluate different wrong-way driving countermeasures including both technical and non-technical solutions.

Several countermeasures were assessed by the study, including improved pavement markings, signage enhancements, and various types of local flashing alerts. Summary recommendations from this study were, in order of prioritization:[11]

Pavement Marking, Signage, & Lighting Enhancements

Improvements to pavement markings, extension of markings and delineators, replacement and enhancement of signage, and lighting improvements were all cited by the study as being immediately effective and cost-efficient deterrents to WWD movements.

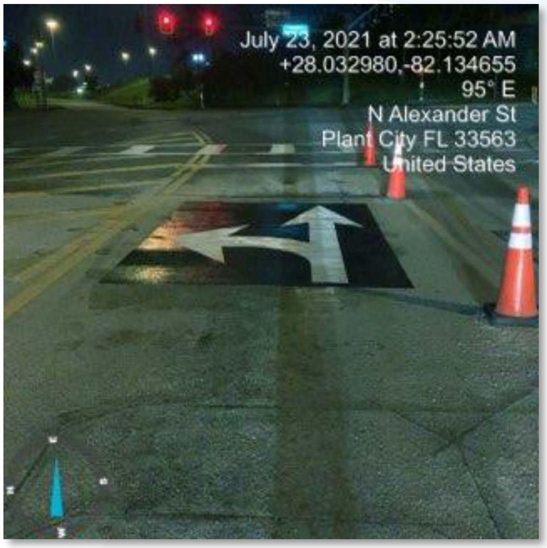

Figure 15 - Enhanced Left-Turn Arrow (Source: FDOT)

Figure 16 - Wrong-Way Sign with RRFB

Red Rectangular Flashing Beacons (RRFB)

Wrong-way signs mounted with RRFB lights proved to be the most effective deterrent for wrong-way drivers in the study. However, due to their potential to be mistaken for an emergency or law enforcement vehicle's lights, FDOT's local and state law enforcement partners requested that RRFBs not continue to be deployed, instead favoring other flasher types.

LED-Bordered Wrong-Way Signs

The third priority countermeasure favored by the study was LED-bordered wrong-way signs. Due to partner advisement against RRFB deployment, these types of signs are the ones now most commonly installed on new projects and are deployed by all of the vendors currently on FDOT's APL for WWD systems.

Figure 17 - LED-Bordered Wrong-Way Sign

Initial WWD System Pilots

Once the 2015 crash study was completed, an implementation plan was presented that targeted the recommended geographical areas, ramp geometries, and recommended countermeasures such as pavement marking, signage enhancements, and technology deployments.[12] Using this information, the different Districts began planning pilot deployments using different solution combinations: these pilots were preliminary experiments that in turn informed the 2017 CUTR countermeasures comparison study. As the FDOT/MDOT WWD Peer Exchange was conducted with Districts 5 and 7, along with the Florida Turnpike Enterprise (FTE), this report will focus on the solutions piloted by those agencies.

District 5 (Orlando) and FTE[13]

District 5 and FTE started experimentation with WWD systems around the same time as District 7. Starting with radar-based TAPCO systems at 18 locations, they had good initial success but the high number of false positive detections proved problematic. Through additional deployments, D5 found that thermal camera-based detection worked more consistency and offered enough of an accuracy improvement over radar that they decided to move forward with thermal image sensors exclusively wherever possible.

For their second pilot phase, D5 teamed up with D7 for experiments with Rectangular Red Flashing Beacons (RRFB) at 18 locations. Results were promising for these types of active signs but law enforcement was concerned about their resemblance to first responder lights. Because of this, RRFBs are no longer used on new installations although they do still exist where they were first installed. D5 noted that to date, no WWD crashes have occurred within the second phase RRFB pilot area.

For both phase 1 and phase 2, D5 used cellular communications and solar power for their WWD installations. While in their experience the cellular communications worked well enough, they have since started using fiber and utility power wherever possible on new expansions to the WWD system due to long-term performance and recurring cost concerns. Ongoing expansion projects are planned in D5 from now into 2025.

District 7 (Tampa)[14]

District 7 initially focused on pavement marking enhancements. Florida features some unique interchange designs compared to Michigan, and in some cases, ambiguous markings and signage could be interpreted as instructions to enter the exit ramp. In 2016, D7 executed a markings and signage overhaul project on many of their interchanges, focusing on improving the location and frequency of arrow indicators and adding freeway shields with bound indications where possible. An important observation made by D7 during these marking and signage initiatives was that the majority of WWD events occur at night, making such improvements pointless without adequate lightning. Signs and markings must be properly illuminated at all times to be effective, and in some cases this meant changing the lightning design or even intersection geometry to maximize signage and marking visibility.

Another type of marking and signage improvement made by FDOT came in the form of reflective pavement markings. Pilot marking projects were performed on off ramps and intersection approaches identifying the direction of travel based on the color of the reflector, with white indicating the correct direction and red indicating the wrong direction.

Specification Development

Using the results of the experimental pilots and various studies executed by the Districts, CUTR, and other partners, FDOT's Central Office developed a series of specifications around Wrong-Way Driver Systems.

FDOT Standard Specifications for Road and Bridge Construction (July 2022):[15]

- Section 660: Vehicle Detection System
    - ◊ 660-2.2.1.4: defines what a WWDS is and what function it serves in the context of vehicle detection.
    - ◊ 660-3.7: defines how WWDS are to be installed, but simply references the Contract Documents and manufacturer's recommendations for the given project.
    - ◊ 660-4.4: defines requirements for development and submission of a field acceptance test (FAT) plan including a detection accuracy test and false positive test for each location.
    - ◊ 660-5: defines warranty requirements.
    - ◊ 660-6: defines the method of pay item measurement and scope / material requirements of each unit price.
    - ◊ 660-7: defines the pay item list for all vehicle detection systems including WWDS.

- Section 995: Traffic Control Signal and Device Materials
    - ◊ 995-2.1: defines general component marking, materials, cabinet, and environmental requirements for all traffic control signal and device materials including WWDS components.
    - ◊ 995-2.7.1: defines WWDS configuration and management requirements including software, clocks, zone parameters, memory, and API requirements.
    - ◊ 995-2.7.2: defines WWDS communication requirements including serial, Ethernet, wireless, cellular, monitoring interfaces, and SunGuide compatibility.
    - ◊ 995-2.8: defines WWDS power specifications including solar performance and battery duration requirements.
    - ◊ 995-2.11: defines WWDS performance requirements including accuracy and mandates conformance testing by the FDOT Traffic Engineering Research Lab (TERL) as a precondition for listing on the APL.

FDOT Design Manual (FDM, January 2022)[16]

- Section 230: Signing and Pavement Marking
    - 230.4: defines requirements for deploying enhanced signing and pavement markings for reducing wrong-way movements, including height, color, reflectors, and other details. Both FDOT's Standard Plans Index 700-101 and the federal MUTCD section 2A.21 for wrong-way sign columns are referenced within the specification.
        - ◊ 230.4.1: defines signing and pavement marking countermeasure standards for exit ramp intersections specifically for discouraging wrong-way movements. Count, placement, size, color, reflectors, separation distance, and other details are included. Wrong-way vehicle detection systems are also called out as a requirement, including at least one pair of LED-border highlighted signs.
        - ◊ 230.4.2: defines wrong-way sign and marking details for diverging diamond intersections.
        - ◊ 230.4.3: defines wrong-way sign and marking details for divided arterials and collectors.
        - ◊ 230.4.4: defines wrong-way sign and marking details for one-way pairs and divided arterials/collectors with one-way egress.

- ◊ 230.4.5: defines wrong-way sign and marking details for undivided one-way streets.
- ◊ 230.4.6: defines sign and marking details for two-way signalized intersections.

The FDM also includes multiple sign placement typical detail drawings for different ramp and road geometries for reference. As mentioned elsewhere in this report, Districts may choose to expand upon or alter the Central Office specifications depending on their project need, preferences, or other reasons. Typically, reasons for deviation are provided back to Central Office for consideration in future specification revisions.

Public Outreach & Education

Throughout processes of research and system piloting, FDOT maintained a steady stream of communication and outreach to the public on wrong-way driver prevention, including details on the types of mitigations and countermeasures being installed throughout the state. If signage and pavement marking improvements are the best local wrong-way driver prevention method, public outreach and education are the best system-wide method for preventing them.

Public Outreach

Realizing that laboratory testing and product cutsheets can only provide so much information, FDOT and their research partners performed public outreach and response surveys to gather feedback on specific countermeasures. For example, CUTR surveyed public opinion on Red Rectangular Flashing Beacons in different combinations of Wrong Way signage, beacon positions, and illumination levels.[17] Respondents were asked to choose which combination of lights, position, and illumination they found "most effective and informing" and report if they understood the flashing lights to be a wrong-way warning signal when first encountering them. Respondents were also given questions relating to what conditions they expected wrong-way events to occur under, how they would personally respond to the realization they were driving the wrong way, opinions on driving under the influence, and various demographic questions. All of this information was used by FDOT in selecting countermeasures and targeting specific public messaging on wrong-way driving.

Educational Efforts

Following the research and deployment efforts of the Wrong-Way Driving Task Force, FDOT published a public page detailing the research, countermeasures, educational resources, and frequently asked questions about wrong-way driver prevention on their departmental website.[18] Videos and graphics supplement the data to make it easily understandable and the public is given specific "What You Need to Know" instructions on how to react if either a) you find yourself driving the wrong way or b) you encounter a wrong way driver while going the correct way. Sign examples and their meanings are listed along with applicable actions to take when encountering them such as those shown in Figure 18. Multiple types of printable media are also provided to make printing and distributing wrong-way prevention information easy. There are even graphical illustrations of wrong-way driver detection systems demonstrating how those systems work to notify FDOT and the public of wrong-way driver events.

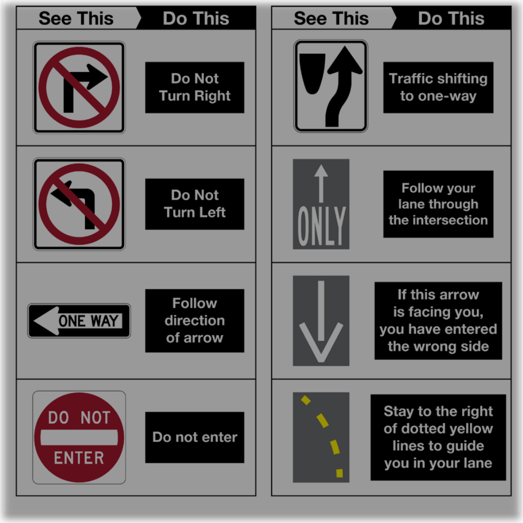

Figure 18 - Wrong Way Signage Instructions (Source: FDOT)

TECHNOLOGY **COMPARISONS**

APL Vendors & Deployment Feedback

Following the deployment of pilot installations and research studies on the efficacy of different systems, FDOT's Central Office and TERL established the Approved Products List (APL) requirements for Wrong Way Driver Systems and subsequently began accepting and testing applicant vendors. The APL requirements do not specify detection technologies or local alerting methods, but those specifications are usually made by the relevant District executing the project; both Districts 5 and 7 had plenty of feedback to offer on those specifics which are outlined in this report.

APL Vendors

Thus far, four WWD system vendors have been certified for inclusion on the APL:[19]

TAPCO

TAPCO is approved for both their thermal camera and radar-based systems. In general, TAPCO is FDOT's preferred vendor as their product is the most mature, has the most consistent results, and has the most robust feature set (especially when packaged with BlinkLink). However, TAPCO is also by far the most expensive, both to install and to maintain over time if opting for the BlinkLink subscription. To mitigate some of these costs, FDOT has worked extensively with TAPCO to integrate their local installations directly with SunGuide; the only feature disparities between them now are BlinkLink's video clip recordings, extensive system logging, email and SMS/call notifications, and browser-based system management.

GovComm

GovComm uses a combination of optical and thermal cameras, with thermal being the primary detection mechanism and optical used for rear-facing confirmation. District 7 has almost as many GovComm installations as they do TAPCO, but these installations are much newer than the TAPCO ones, and so they have not had as long of a time to be operationally proven.

K&K Systems

K&K is a relatively new player in the WWD space. Their system uses a combination of off-the-shelf security cameras with object detection and custom software running on an edge processor to create a vehicle tracking system. It is also worth noting that the cameras rely on desktop software, which runs on K&K's edge processor and requires Windows to operate.

Carmanah Technologies

Neither FDOT districts participating in the peer exchange had any comments or information on the Carmanah WWD systems, as neither have had opportunity to deploy them yet.

APL Testing Requirements

Once approved, component details from the time of testing are published along with any relevant drawings or other documents on FDOT's APL index website. Of note are the following tests that each vendor must pass for APL acceptance:[18]

- Detection accuracy of 100% with zero false positive readings with a sample size of 200 vehicles under controlled test conditions at the TERL facility
- Solar power operation time of at least 10 days without sunlight under an assumed load of 5 system activations per day

Vehicle testing at TERL includes multiple vehicle types and sizes, so it is generally not expected for on-site installation tests to include multiple varieties. However, it should be noted that due to the controlled nature of these tests, false positive sensitivity testing is not realistically possible at the TERL facility. Long-term exposure to real traffic patterns is required to know with certainty how prone a system is to false activation.

The APL requirements also outline the protocols with which the WWD must be capable of interfacing with the SunGuide ATMS, including different mechanisms for SunGuide to poll the system or for the system to push data to SunGuide immediately.[19]

Deployment Feedback

Having performed many deployment installations and integrated WWD response into their daily operations, Districts 5 and 7 provided additional feedback on the effectiveness of various technologies beyond the statewide studies.

Prevention

Ultimately, all of FDOT's studies found overwhelmingly conclusive evidence that the most effective way to avoid WWD incidents was to prevent them from occurring at all through the use of improved pavement markings and signage. Clear and repeated arrow indicators for ramp entrances, shield markings indicating the path to the freeway, bollards, extended chevron patterns, and hashed guide lines to direct drivers are just some of the effective improvements FDOT implemented. Highlighting the correct path to take is just as important, if not more so, than providing warnings about the wrong way; Figure 19 shows arrow improvements and shield markings employed by FDOT at a particularly complex interchange.

Figure 19 – Marking Improvements (Source: FDOT)

Moreover, public outreach and education about wrong-way drivers, systems deployed to prevent them, advised actions to take when encountering one (or discovering that you are one yourself), and definitions for signage are incredibly helpful tools for both highlighting the serious problem of wrong-way driving and ensuring that the public is equipped to avoid and appropriately respond to wrong-way driver occurrences.

Detection

FDOT has experimented in multiple districts with various detection technologies, including radar, video analytics, thermal imagery, in-pavement loops, and microwave vehicle detection (MVDS). Of these, thermal imagery has proven to be the most effective detection method with the least number of false positives compared to other methods. Radar and MVDS, conversely, produce some of the highest amounts of false positive detections; even when combined with pinhole verification cameras, radar systems still suffer from false positives due to how easily the pinhole cameras are interfered with by light or obstruction. Both districts noted, however, that depending on the location and ramp / intersection geometry, different detection technologies or even a combination of them may be necessary. Some new installations in D7 use radar for local sign activation and thermal cameras for the confirmation zone that sends alerts, maximizing activation sensitivity while minimizing disruption by false alerts.

Figure 20 - Thermal FLIR Cameras (top of pole)

Figure 21 - Pelco Wind Collar Pole Accessory

One recommendation made by D7's ITS Maintenance Contractor was the use of wind collars on the sensor poles. These collars help absorb the vibrations caused by wind and keep the sensor devices (cameras or radar) still, preventing false positive activations. A special note made by both D7 and D5 was that they actually modify the Central Office specification and require cabinets to be ground or riser-mounted instead of pole-mounted. Central Office spec requires pole-mounted cabinets to be installed 11ft in the air, but mounting such a large weight so high on the pole causes severe vibration and shaking issues. Both Districts try to avoid pole -mount cabinet installations altogether now, especially when also considering the available space for batteries and communications equipment.

D7 has also performed experimentation with video analytics on I-275's Howard Frankland Bridge, which uses six static Cohu gun-style cameras to provide real-time video feeds over fiber to a Telegra server at D7's TMC. According to D7, there is little to no delay difference between the processed feeds and other video feeds, alleviating concerns over edge versus central processing network latency.

Local Alerting

The primary purpose of a WWD system is, ultimately, on-site notification to the driver that they are going the wrong way, prompting corrective action. Secondary to this purpose are the mechanisms of TMC alerting and police dispatch. As part of their studies, FDOT assessed different methods of on-site notification including:

- Rectangular Red Flashing Beacons (RRFB)
- "Wig-Wag" flashing beacons
- LED border-illuminated wrong-way signs
- Blank-out wrong-way signs

Of these, the LED border-illuminated signage proved to be one of the most effective methods and has become FDOT's preference for ongoing and future deployments. FDOT also found that having at least two pairs of illuminated signs was required for real effectiveness; ideally, illuminated pairs should be interspersed with pairs of un-illuminated signs as well.[20]

Communications

Both districts prefer to keep their systems on fiber optic infrastructure instead of relying on cellular modems. Where modems are still used however, District 5 uses their own FDOT-owned modems connected to a private APN service, simplifying communications management and minimizing their BlinkLink subscription costs. District 7 had also experimented with wireless links but in general found their performance to be too poor and unreliable to depend on for real-time WWD notifications.

TMC Alerting

Key to successful operation of FDOT's statewide WWD system is their District or Regional Traffic Management Centers (RTMCs, or just TMCs). Generally speaking, FDOT has used two different methodologies for bringing real-time WWD event notifications and data into the TMC: cloud-based vendor systems and their statewide ATMS.

All of the initial pilots detailed by FDOT during the peer exchange used TAPCO-developed systems. These systems have local equipment for detection and driver alerting but then rely on TAPCO's cloud-based BlinkLink platform for generating alerts, monitoring the health of the system, and storing historical logs and recordings. While these features are incredibly useful, especially for inter-agency cooperation on WWD event response, FDOT has invested in SunGuide ATMS integration over BlinkLink to maximize the interoperation between all of FDOT's ITS systems and now requires all APL vendors to provide drivers or APIs compatible with SunGuide.

SUNGUIDE **ATMS**

Integrated WWD Operations

Perhaps the most powerful tool at the center of FDOT's WWD response operations is SunGuide, their statewide ATMS. SunGuide serves as the central integration point and management interface for incidents and other traffic operations throughout all of Florida's freeway and arterial transportation system. While some WWD system vendors, such as TAPCO, provide their own WWD response and management interfaces, FDOT chooses to use SunGuide for its ability to integrate WWD alerts and imagery with the other ITS resources at FDOT's disposal.

System Architecture

SunGuide was developed specifically for FDOT by the same company that developed Texas DOT's LoneStar ATMS platform. FDOT maintains a close working relationship with the SunGuide vendor, holding regular stakeholder meetings to discuss improvements, enhancements, and the individual Districts' experiences.

While MDOT's ATMS platform is located centrally within Lansing, Michigan's capitol, leveraging leased circuits and other mediums to access individual Regions' ITS infrastructure, each FDOT District houses a local installation of SunGuide at their RTMC that communicates with the ITS devices on that District's local ITS network. This architecture allows each District to maintain their own network security, prevents technical complications, and improves performance compared to a monolithic central system model. Each District is able to work directly with the SunGuide development team to request and pilot enhancements, which if successful, become automatically pushed to the other Districts' installations.

Operational Workflow

Both D5 and D7 incorporate SunGuide WWD response into their daily operations. Neither District has dedicated WWD response staff, instead choosing to allow any available operator to respond to a WWD event that occurs. The FDOT WWD operational workflow is executed as follows:

1. The local WWD system sends a notification to SunGuide if a vehicle passes through the first (Activation) zone and into the second (Confirmation) zone.
2. SunGuide creates an event in the Incident Detection Subsystem (IDS) module, which pops up obtrusively until acknowledged by an operator.
    a) Ten 1-second snapshots are displayed in the IDS event after being received from the local WWD system cameras
    b) SunGuide automatically activates presets on a predetermined set of nearby freeway cameras that move to ideal perspectives around the relevant ramp
    c) The operator uses the WWD system snapshots and nearby cameras to confirm the presence of a real WWD
3. If the incident is real, the operator immediately responds by:
    a) Posting a precomposed WWD warning message to nearby DMS through 1-click activation
    b) Notifying Florida Highway Patrol (FHP) dispatch of the incident

An illustration of this workflow can be found below, provided by FDOT:

Figure 22 - D7 WWD Response Workflow
(Source: FDOT)

FDOT's Operational goal is to have messages posted within 2 minutes of the initial event being created. This is usually achieved in less than 30 seconds on average.

Law Enforcement Cooperation

FHP also emphasized the importance of DOT and law enforcement cooperation. With state police providing system efficacy feedback to FDOT, FDOT can make improvements to their system or operational processes. FDOT also uses law enforcement and media outlets to provide outreach, education, and feedback mediums to the public to increase awareness of WWD events and the solutions FDOT is employing to prevent them. FHP uses a specific dispatch code for WWDs, "Signal-12 Whiskey", to differentiate between WWDs and other types of reckless driving (for which Signal-12 is the code). However, manpower can present significant issues as there are not always troopers near the WWD incident able to immediately divert to that location—in fact, D5 stated that the rate of successful WWD police intercepts was only 1%. Whether immediate local police response is available or not, being able to issue a "Be On The Lookout" (BOLO) notice with detailed description of the vehicle is essential. Clear communication, rapid BOLO broadcast, and collaborative feedback prevent FDOT and FHP from operating in silos and help ensure successful outcomes.

SunGuide—Key to Operational Success

FDOT attests to the centrality of alert timing, image accessibility, and automation of systems to the success of their WWD response operations. SunGuide seamlessly integrates the alerts, images, and response actions so there is no need for the operator to manually locate the appropriate camera or DMS, removing unnecessary delays. SunGuide is also able to process the same types of data as BlinkLink, using SNMP to receive alert traps and HTTP for image transfer; it is even able to receive and display health alerts for battery voltage, temperature, and component communications similarly to BlinkLink.[21] However, there are tradeoffs to consider when using SunGuide alone versus using the packaged BlinkLink platform:

- SunGuide is a local application only accessible to FDOT staff, while BlinkLink allows an agency to create multiple users and stakeholders with granular access from anywhere. FHP finds great value in using BlinkLink directly when performing WWD response and post-incident investigation, so FDOT is working on a SunGuide enhancement that will provide a web browser -based dashboard for law enforcement to view incidents.
- SunGuide does not store video recordings, instead being limited to the snapshot imagery provided by the WWD system. Due to FOIA regulations and other liability concerns, FDOT's ITS systems do not record video. However, BlinkLink does, making it immensely convenient for viewing full-resolution clips of WWD incidents and keeping them stored for reference.
- SunGuide is incapable of sending email or SMS-based alerts. IDS alerts are only visible within the application and require an operator local to the TMC to respond. Conversely, BlinkLink is able to send email, SMS, and automated call alerts to any number of addresses and phone numbers based on specific alert types. However, all of FDOT's TMCs are manned 24/7, so the likelihood of an IDS alert going unnoticed is low.

Even with these tradeoffs acknowledged, FDOT is still moving forward with requiring SunGuide integration for all new WWDs being installed and has included this requirement in their APL testing. Districts 5 and 7 both stated during the peer exchange that recurring subscription fees were something they wished to avoid and that their goal is to grow their own cohesive ecosystem without relying on third-party platforms.

LESSONS LEARNED

Deployment Feedback

Throughout the peer exchange, FDOT shared lessons and advice relating to every stage of their WWD initiative from its inception to ongoing maintenance and operations.

Programmatic Lessons

FDOT's success is due largely to their collaborative relationship with each other and with their Central Office. The WWD Task Force commissioned at the beginning of their initiative set the tone for all of the Districts and provided a conduit for feedback and representation from each of them. Having a team dedicated to researching, piloting, and assessing WWD systems was enormously helpful as it allowed them to establish a common plan, propose solutions, and oversee implementation. The resulting specifications and APL requirements developed following the pilots help streamline implementation and provide an excellent foundation on which the Districts can easily build their own context-specific requirements. Without this centralized guidance, each District could have quickly ended up with very different or even incompatible systems early into the project.

SunGuide also provides a central anchor on which to secure the systems being deployed. Each WWD system, regardless of vendor, is expected to interface with SunGuide and provides operators in all Districts with a "single pane of glass" from which to manage WWD incidents. Operators are not forced to jump from browser window to browser window looking for the correct WWD system when an alert is received. Moreover, SunGuide's IDS automations take the manual work out of finding the driver's location and alerting the public. With SunGuide, FDOT is incentivized to avoid constructing a set of disparate, proprietary, incompatible systems. Likewise, the installation of FDOT-owned fiber optic infrastructure both paves the way for future ITS investment in the same area and allows FDOT to avoid recurring communications fees from carriers and other vendors.

Design

Interestingly, one of FDOT's most important lessons for MDOT did not relate to technology: pavement marking and signage improvements can have immensely positive effects on WWD prevention. Before technology is deployed as a solution, markings, signs, and lightning should all be assessed to see if the frequency and demographic of WWDs in that area could be mitigated by such enhancements. In some cases, the frequency may be too high to solve without technology, but technology should always be a secondary solution.

When designing a WWD installation, FDOT emphasized the importance of assessing distance from the stop bar, presence of potentially obstructive curves, presence of utility power and existing communications, potentially reflective objects, potential for vehicle strikes on the infrastructure, sunlight exposure for solar power, and other factors. No two WWD installations are exactly alike and each must be designed with the peculiarities of the location and its geometry in mind.

FDOT also learned some lessons through the first iterations of their statewide specification. For example, the statewide spec requires pole-mounted cabinets to be installed 11ft in the air, but this causes severe vibration issues on the pole. Instead, Districts are opting more often for ground or riser-mounted cabinets. Also, original projects would list the WWD system as a single monolithic pay item, causing confusion around what constituted a complete system and when that system could be considered delivered. Districts are now providing feedback suggesting WWDS be divided into pay items for detection, processing, communications, and other components separately.

Deployment

As with any new technology initiative, FDOT experienced several installation and integration difficulties early on, including:

- Establishing a definition for providing "10 seconds of snapshots" from the WWD to SunGuide. Some vendor systems would send them immediately as they were taken. Others would only send them when all of the snapshots were captured, causing a 10 second delay before operators could see what was going on at the ramp.
- Some vendors require remote access to the systems for integration or maintenance support. IOOs should be prepared to either provide a secure method of access or accept the potentially expensive costs of local support visits.
- In some cases, FDOT found 5" poles to provide more stability than the 4" poles called out by Central Office specification.
- FDOT has decided to avoid solar installations where possible because of battery space and maintenance requirements.
- Even when vibration or weather-related false positives are dialed in, operators should be prepared for landscaping crews, emergency vehicles, and stopped / partially-reversing vehicles on the ramp to be a frequent cause of false alerts.
- Radar is generally unreliable and too prone to false positives, although it may be useful for sign-only activation with thermal cameras used for confirmation alerts. (Despite this feedback, FDOT was very interested in MDOT's ongoing pilot project with Continental and the potential success of radar when combined with machine learning algorithms.)
- The industry is also still figuring out how to price these systems in a sustainable way, so price fluctuations should be expected from vendor to vendor or even from the same vendor over time.
- Closing a ramp for WWD testing is greatly expensive and time consuming. However, some WWD system vendors will refuse to certify the system unless a certain number of actual WWD vehicles are tested on-site. Construction closure schedules may also present novel opportunities to concurrently test. It should also be noted that depending on the detection technology used, testing at night may yield different results than testing during the day.
- A high level of coordination and cooperation between FDOT, the contractor, and the vendor is required to ensure that all parties have the same expectations and are working with the same definitions of terms. Detection, activation, alerting, etc. must be defined and all parties must have a mutual understanding of the goal and purpose of the system. Otherwise, projects can be delayed by failures and blame-shifting.

Maintenance

Consensus between the Districts regarding WWD system maintenance was that it is expensive, so good vendor relationships and a healthy body of spare inventory are essential. Moreover, methods for maintaining detection accuracy are still being tested:

- Some may consider push-button activation of the system to be a reliable indicator of system health. However, proper system operation cannot be confirmed with certainty unless tested against real-life WWD vehicles.
- Even with off-the-shelf systems, it is advised to purchase spare parts for different WWDS components.
- Over time, solar batteries are very expensive and cumbersome to maintain.
- Software license requirements for edge processors and desktop software should be considered when choosing a system.

SUMMARY CONCLUSION

Status & Next Steps

MDOT's peer exchange with FDOT proved to be highly valuable for both parties and provided an excellent foundation on which to build MDOT's statewide wrong-way system specification and implementation plan. Moreover, the Joslyn Rd. WWD system pilot test results should provide a reasonable baseline for both system performance and integrated TOC WWD operations.

MDOT's next steps for the wrong-way system development effort include:

- Integration of the pilot system into daily operations at the Southeast Michigan Transportation Operations Center (SEMTOC)
- Exploration of use cases for WWD alert dissemination including to non-automated vehicles, Michigan State Police dispatch, local law enforcement, 911 call centers, and navigation service providers
- Development of a statewide special provision for Wrong-Way Driver Systems, including their components and integration requirements

During the coming months, MDOT will be executing several projects throughout the Metro Detroit area that incorporate wrong-way driver systems of different variety, mostly consisting of ad-hoc, multi-vendor pilot systems. These systems will be assessed in their long-term performance in context of the information gathered in this peer exchange and will be used as additional datapoints during development of the statewide WWDS specification.

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