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Arizona Department of Transportation
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Interstate 17 Wrong-Way Vehicle Detection Pilot Program

Systems Technology Group

ADOT

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Prepared by:
Arizona Department of Transportation
Transportation Systems Management & Operations Division
Systems Technology Group
206 S. 17th Avenue
Phoenix, AZ 85007

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Phoenix, AZ 85007

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Acronyms and Abbreviations

ADOT	Arizona Department of Transportation
CCTV	closed-circuit television
DMS	dynamic message sign
DPS	Arizona Department of Public Safety
DSS	decision support software
EB	eastbound
IT	Information Technology
ITS	intelligent transportation system
LED	light-emitting diode
NB	northbound
SB	southbound
SPUI	single-point urban interchange
TOC	traffic operations center
WB	westbound
WWD	wrong-way driving

EXECUTIVE SUMMARY

Wrong-way crashes are a nationwide problem. Despite being relatively uncommon, these types of crashes are more likely to be deadly: An 11-year analysis of wrong-way crashes in Arizona showed that 25 percent of all wrong-way crashes were fatal, compared to 1 percent of crashes overall that occurred on divided highways. A total of 91 people died and many more were injured in 245 wrong-way crashes in Arizona from 2004 through 2014 (Simpson and Bruggeman 2015).

Although no strategy can prevent wrong-way crashes completely, there are countermeasures that can impact driver behavior and help make roadways safer. The Arizona Department of Transportation (ADOT) has been a national leader in researching and implementing strategies to combat wrong-way driving, focusing on the use of technology and other countermeasures to reduce the risk of wrong-way crashes.

Building on the results of previous research, ADOT incorporated several promising technologies into the design of an integrated, corridor-level system for detecting wrong-way vehicles, notifying law enforcement, and warning both wrong-way drivers and right-way traffic. The first such system in the nation, the Interstate 17 Wrong-Way Vehicle Detection Pilot System became operational in January 2018. The design, construction, and integration of the $4.2 million system were funded by the Maricopa Association of Governments, the Metropolitan Planning Organization for the greater Phoenix region.

The pilot system, which covers a 15-mile stretch of I-17 between I-10 and State Loop 101, is also the first in the nation to track wrong-way vehicles in real time. The system uses thermal cameras for primary detection of wrong-way vehicles along exit ramps and at other potential points of entry onto the freeway's mainline lanes. Video clips generated by the cameras allow ADOT dispatchers and Arizona Department of Public Safety troopers stationed in ADOT's Traffic Operations Center (TOC) in Phoenix to visually verify and track wrong-way vehicles.

Enhanced warning signage is also part of the I-17 system. Along with oversized and lowered static Wrong Way and Do Not Enter signs, the pilot project installed new illuminated wrong-way signs with flashing red LED lights around their borders. These signs, installed approximately 600 feet from an exit ramp's stop bar, were selected for testing because most incursions by wrong-way drivers occur at night. Set to activate when a thermal camera detects a wrong-way vehicle entering an exit ramp, the signs are designed to gain the attention of a wrong-way driver. The pilot project documented a significant number of drivers who self-corrected on a freeway exit ramp without entering I-17, some of whom may have been influenced by the sign-related countermeasures.

The backbone of the I-17 pilot system is a custom-built decision support software (DSS) package. When a wrong-way vehicle is detected by the system, a TOC dispatcher first verifies the detection by viewing a video clip from the thermal camera. Through the DSS, this verification triggers the automatic deployment of several countermeasures:

- Notification of law enforcement.
- Repositioning of traffic cameras to help TOC dispatchers track the wrong-way vehicle.

- Activation of warning messages for right-way drivers on upstream freeway message signs.
- Holding the signals on upstream ramp meters at a steady red indication to discourage traffic from entering the freeway.

The pilot project has been an effective test of a corridor-level system of wrong-way driving countermeasures. To help assess the system's performance, ADOT collected and analyzed data about wrong-way driving incidents in the pilot area from January 2018 to December 2019. Key findings included:

- An overwhelming percentage of wrong-way drivers made self-correcting turns on freeway exit ramps and did not enter the I-17 mainline lanes. During the two-year data collection period, 109 wrong-way vehicle incursions were identified within the pilot project's limits. Within those incursions, 88 percent of drivers self-corrected on an exit ramp. Of the remaining 12 percent of incursions, only one resulted in a wrong-way vehicle injury crash. A second injury crash documented within the system's boundaries involved a detected vehicle that originated outside the test area and crashed just over 1 minute after entering the pilot corridor.

- The ability to dispatch law enforcement quickly and effectively has been the most significant benefit of the wrong-way detection pilot program. In 2018, the detection system resulted in more than a threefold increase in wrong-way vehicle detections in the pilot area compared with traditional means (911 calls) alone. Of the detected incursions that were also reported to 911, the detection system reported the incursion much faster—an average of 1 minute, 38 seconds before a 911 call was received.

Overall, the system components worked well together and performed as intended. As the technology was initially installed and deployed, ADOT encountered a few issues with individual components, and staff refined the installations to address those issues and improve future deployments. For example, the thermal cameras initially registered false-positive detections due to wind, pedestrians, truck occlusions, birds, and other factors; this was addressed through improved mounting locations and adjustments to the cameras' detection zones and algorithms. Other minor hardware and software issues were resolved with standard troubleshooting procedures.

As noted above, driver interaction with the system was generally positive. ADOT made one adjustment based on feedback from the public, changing the standard message on the dynamic message signs to read "Wrong Way Driver Ahead—Exit Freeway"—giving drivers clear direction on what action to take.

Finally, although the steady red lights at ramp meters functioned as intended, drivers who encountered a red light at a ramp meter during non-peak hours tended not to comply with it, despite an active public awareness program. ADOT has chosen not to include ramp meter pre-emption in its initial plans for future deployments.

Based on the evaluation of the I-17 system, ADOT has developed a plan for expanding the use of some of the system's countermeasures, including thermal cameras and illuminated wrong-way signs, to other highways in Arizona. The expanded deployment will focus on the components of the pilot system that yielded the most significant benefits, with a primary objective of installing wrong-way detection devices where feasible and cost-efficient.

Two approaches were developed to guide future deployments of technology on urban freeways and on rural highways. Deployment locations will be prioritized through the evaluation of historical crash data and data on police contacts with wrong-way drivers, and installations will occur as funding becomes available. ADOT currently has a number of projects in construction that are incorporating wrong-way detection. These will provide additional coverage of several freeway segments within the Phoenix metro area.

The current deployment plan for urban freeways calls for the implementation of thermal camera detection systems at points of entry along the mainline, ramps, and frontage roads, as well as installation of illuminated wrong-way signs on exit ramps where funds allow. The detection-activated wrong-way signs are included in the urban plan because urban areas have historically had higher rates of ramp incursions by wrong-way drivers. The plan also includes notification of TOC dispatchers and law enforcement via DSS; integrated traffic cameras to assist with tracking wrong-way vehicles; and automatic dynamic message sign alerts for right-way drivers (pending verification by a TOC dispatcher). The urban plan includes an option to extend the detection system by installing additional thermal cameras on existing dynamic message signs. These signs, typically spaced 2 to 3 miles apart across much of the Phoenix-area freeway system, are connected to ADOT's fiber network—a feature that would allow lower-cost installation of the additional thermal cameras.

The current deployment plan for rural highways calls for installation of thermal cameras at the top of exit ramps at selected interchanges that already have oversized Wrong Way and Do Not Enter signs in place. The chosen locations will provide early notification but typically will not include the lighted wrong-way signs with flashing LED borders. The rural plan also includes installation of thermal cameras on selected existing dynamic message signs. Although these message signs are spaced farther apart than in urban areas, additional thermal cameras will still improve the resolution of the detection system in rural Arizona. In the rural plan, warning messages will be posted manually by TOC operators if dynamic message signs are nearby, and state troopers in the TOC control room will coordinate with troopers in the field via radio dispatch.

In conclusion, ADOT has accomplished its goal of deploying an effective corridor-level pilot project for wrong-way vehicle detection and warning. The data gathered and lessons learned during this pilot project will provide a valuable knowledge base as ADOT looks to apply cost-effective wrong-way driving countermeasures on urban freeways and rural highways throughout the state.

CHAPTER 1. INTRODUCTION

BACKGROUND

Wrong-way crashes are a nationwide problem. Despite being relatively uncommon, these types of crashes are more likely to be deadly: An 11-year analysis of wrong-way crashes in Arizona showed that 25 percent of all wrong-way crashes were fatal, compared to 1 percent of crashes overall that occurred on divided highways. A total of 91 people died and many more were injured in 245 wrong-way crashes in Arizona from 2004 through 2014 (Simpson and Bruggeman 2015).

Although no strategy can prevent wrong-way crashes completely, there are countermeasures that can impact driver behavior and make roadways safer. The Arizona Department of Transportation (ADOT) began researching strategies to combat wrong-way driving in 2010. First, the department investigated methods for detecting wrong-way vehicles as they enter the highway system. A proof-of-concept research project evaluated five detection technologies: microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors (Simpson 2013). ADOT installed the detection equipment at exit ramps along the highway. The study confirmed that wrong-way vehicles can be detected using readily available equipment that is relatively easy to deploy.

Following that study, ADOT continued testing, monitoring, and evaluating two wrong-way detection stations. These two sites use radar to detect wrong-way vehicles and instantly notify the ADOT Traffic Operations Center (TOC).

In 2015, ADOT evaluated several camera-based detection systems and determined that thermal detection camera technology was the most reliable. When strategically placed at highway entry points, the thermal camera could quickly identify wrong-way vehicles, and the system had less equipment to install and maintain than other systems.

At the same time, ADOT was also investigating new methods for warning drivers when they are traveling in the wrong direction. In a test project, six sites at highway exit ramps were equipped with oversized, low-mounted wrong-way signing, and large arrows with reflectors were added to the pavement to indicate the correct direction of travel. After six months, ADOT expanded the program to 50 locations in both rural and urban areas and began using the oversized wrong-way signing on new design projects involving exit ramp design.

ADOT also tested an even more attention-getting approach: illuminated wrong-way signs with a flashing border that give wrong-way drivers a real-time warning before they enter the highway. When activated, the wrong-way signs flash with high-intensity light-emitting diode (LED) lights.

With promising technologies identified, ADOT initiated a research study to lay the groundwork for a corridor-level pilot project that had three goals: detect and track wrong-way vehicles, alert both wrong-way drivers and other motorists who could be in danger, and notify law enforcement (Simpson and Bruggeman 2015). The research team reviewed national crash data and countermeasures and examined the characteristics of Arizona's wrong-way crashes. They then made recommendations for the system's configuration and the location of the pilot project.

PILOT PROJECT OVERVIEW

Based on researchers' recommendations, a 15-mile segment of Interstate 17 between I-10 and State Loop 101 in metro Phoenix was selected as the location for ADOT's Wrong-Way Vehicle Detection System pilot project. This segment of I-17 was identified as having the highest potential for future wrong-way incursions, based primarily on the historical number of wrong-way vehicle crashes along that corridor. The location of the pilot system is shown in Figure 1.

Figure 1. Wrong-Way Detection Pilot System Location

(Map data: Google Maps)

To meet ADOT's system goals, the wrong-way vehicle detection pilot project had three key components: **vehicle detection**, **warning** (for both right-way and wrong-way vehicles), and **law enforcement notification**. The pilot system was designed to utilize existing power and communication systems along I-17. The pilot system uses 90 thermal cameras positioned throughout the 15-mile corridor to detect wrong-way vehicles; wrong-way signs with flashing LED lights to alert wrong-way drivers; and dynamic message sign advisories to warn right-way drivers. Decision support software provides immediate vehicle identification and notification to law enforcement and traffic dispatchers.

PILOT PROJECT GOALS

The pilot project had the following objectives:

1. **Detect** wrong-way vehicles at the point of incursion using detection equipment located at the end of each ramp along I-17 between I-10 and Loop 101.
2. **Alert** wrong-way drivers that they are traveling the wrong way using a custom-manufactured wrong-way sign with a flashing LED border.
3. **Inform** the ADOT TOC immediately, and then notify the Arizona Department of Public Safety (DPS) once the presence of a wrong-way vehicle is confirmed with real-time video.
4. **Confirm** entry onto the freeway system at the ramp connection with the freeway mainline using secondary detection.
5. **Warn** right-way drivers about the approaching wrong-way vehicle using dynamic message sign (DMS) warnings.
6. **Restrict** right-way vehicles from entering the freeway mainline by using a red-light ramp meter warning system.
7. **Track** errant vehicles using mainline detection to assist DPS in apprehension.

The design, construction, and integration of the $4.2 million system were funded by the Maricopa Association of Governments, the Metropolitan Planning Organization for the greater Phoenix region. Work began in 2017, and the pilot project became operational in January 2018. The pilot project is the first in the nation to track wrong-way vehicles in real time.

This report describes the details of ADOT's I-17 Wrong-Way Vehicle Detection System pilot project. Individual system components are described in greater detail in Chapter 2. Chapter 3 discusses how the various components operate and function together to detect wrong-way vehicles. Chapters 4 and 5 summarize the data collected and lessons learned, and Chapters 6 through 8 provide design recommendations, describe plans for future deployments, and summarize conclusions from the study. Four appendices offer additional detail about the pilot system and provide cost estimates for future deployment options.

CHAPTER 2. SYSTEM COMPONENTS AND FUNCTIONALITY

This chapter describes the components of the I-17 Wrong-Way Vehicle Detection System pilot project and gives a brief overview of their operation. The system consists of seven elements:

- Thermal cameras for detection.
- Wrong-way signs with flashing LED borders for wrong-way driver notification.
- Decision support software for immediate recording, notification, verification, and communication.
- Red-light ramp meters to restrict right-way vehicles from entering the freeway.
- Closed-circuit traffic cameras for tracking errant vehicles.
- Dynamic message signs for right-way vehicle notification.
- TOC dispatchers and DPS troopers based at the TOC for operation of the wrong-way system and coordination with law enforcement.
- Law enforcement personnel for interception and apprehension.

Except for the customized lighted wrong-way signs, all of the technology applied to the pilot project has been used by transportation agencies for decades as stand-alone components. All other hardware components used in the pilot system are commercially available, off-the-shelf products commonly used for traffic signals and intelligent transportation systems. The pilot system takes these time-proven components and assembles them in a new and innovative configuration.

THERMAL CAMERAS

By detecting differences in infrared energy (heat) between objects and their surroundings, thermal cameras can reliably detect incidents such as crashes, stopped vehicles, and wrong-way drivers, even in challenging lighting and weather conditions. The use of thermal cameras for wrong-way vehicle detection allows a single device to recognize wrong-way activity, record video clips, and trigger other actions such as activating ramp meters to restrict entry for right-way vehicles. Thermal cameras can easily be installed at locations that utilize inductive loop or video detection hardware. Figure 2 depicts a FLIR thermal camera.

Figure 2. Thermal Camera

ILLUMINATED WRONG-WAY SIGNS WITH FLASHING LED BORDER

ADOT collaborated with a vendor to design the project's illuminated wrong-way signs. Each sign is a larger version of the type of illuminated street name sign that is commonly attached to traffic signals. The flashing LED border is a commonly used component designed to enhance the visibility of signs (such as stop signs). The sign is larger than standard wrong-way signs (48 by 36 inches) and complies with the Federal Highway Administration's Manual on Uniform Traffic Control Devices. Figure 3 shows the sign in operation at night. Unlike standard retroreflective signs, this sign does not require a light source such as headlights in order to be visible.

Figure 3. Illuminated Wrong-Way Sign with Flashing LED Border

DECISION SUPPORT SOFTWARE

The I-17 system's decision support software provides staff at ADOT's TOC with real-time video and system entry information for each wrong-way vehicle detected, which allows dispatchers to track the vehicle's location and direction. Figure 4 shows a screenshot of the system's dashboard. When a wrong-way vehicle is detected, the dashboard displays an interactive key-map of the pilot system, 15-second video clips of thermal images, real-time video from nearby traffic cameras, a street map, and a list of system status events. The decision support software also provides critical time savings by providing a one-click system activation of DMS messages, traffic camera tracking, and red-light ramp meter indications at ramps upstream of the errant vehicle. See Appendix A for more detail on the software's operations.

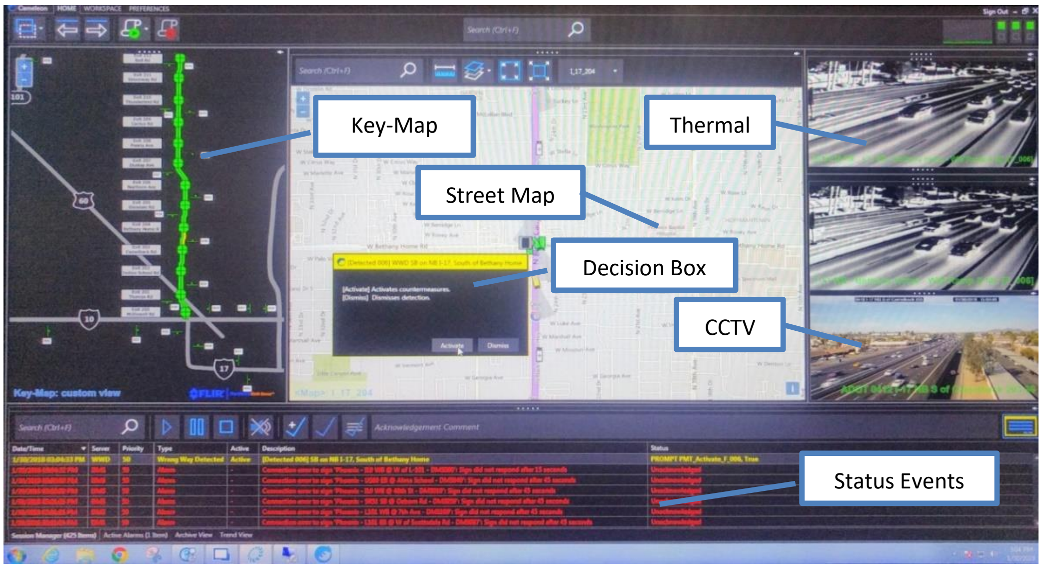


Figure 4. Screenshot of Decision Support Software

RAMP METERS

Pre-existing ramp meters line the I-17 corridor to mitigate rush hour traffic congestion. Tying standard settings in the ramp meter controller to the decision support software allows for emergency pre-emption of signals to solid red indications. Figure 5 shows a conceptual representation of what a right-way driver will encounter at a freeway entrance ramp if approaching a wrong-way vehicle along I-17.

Figure 5. Ramp Meter with Solid Red Indications

The emergency red signal will be automatically engaged at ramp meters upstream of the wrong-way vehicle in an attempt to hold right-way traffic on the ramps and out of the path of the errant vehicle. The meters return to pre-event operation after the errant vehicle has passed.

CLOSED-CIRCUIT TELEVISION (CCTV) CAMERAS

ADOT has CCTV cameras at roughly one-mile increments along the Phoenix urban freeway system. These are controllable with pan, tilt, and zoom controls used by TOC dispatchers and the DPS trooper and are able to stream live video for traffic and incident monitoring. When the I-17 wrong-way detection system is triggered, the cameras automatically reposition to view the wrong-way vehicle, and their video feeds are seamlessly integrated into the system's decision support software to facilitate tracking. This offers a faster visual display for dispatchers while still allowing them to manually control each camera for continuous monitoring. Figure 6 shows a side-mounted CCTV camera on I-17.

Figure 6. CCTV Camera

DYNAMIC MESSAGE SIGNS (DMS)

ADOT has DMS coverage on most freeways throughout the state. Overhead DMS units display information such as travel times, safety messages, and alerts for the traveling public. Figure 7 shows an example of a message that would be displayed ahead of an approaching wrong-way vehicle. When the wrong-way detection system is activated, preprogrammed messages appear on the DMS, alerting drivers in the path of the wrong-way vehicle to proceed with caution and exit the freeway where possible. This serves as the primary means of communication to right-way drivers. If needed, TOC dispatchers can manually edit the messages to add more detailed information.

Figure 7. DMS with Wrong-Way Vehicle Warning Message

The pilot project utilizes 11 pre-existing DMS locations along the I-17 corridor, as well as numerous other DMS locations surrounding the test area.

TRAFFIC OPERATIONS CENTER AND DEPARTMENT OF PUBLIC SAFETY PERSONNEL

The TOC is staffed 24 hours per day, 365 days per year, by ADOT dispatchers who monitor traffic and respond to incidents. Figure 8 shows the video wall behind the dispatchers' consoles. In 2015, a permanent DPS trooper workstation was added to the center. This DPS presence in the control room integrates the two agencies and reduces response times by utilizing the expertise of the trooper to assist dispatchers.

Figure 8. TOC Control Room

When a wrong-way vehicle is detected, a warning is immediately displayed on the TOC video wall that is visible to both ADOT and DPS staff. While the TOC dispatchers verify and track the event, the DPS trooper coordinates the response with DPS dispatchers by utilizing thermal camera video clips and CCTV footage. Prior to the I-17 pilot project, when wrong-way events occurred, law enforcement relied on 911 calls from the public to prompt corrective action.

In combination, these seven elements make up a comprehensive wrong-way vehicle detection, warning, and tracking system. Figure 9 shows the layout of the devices used in the pilot project, and Chapter 3 provides more detail on the system's operations.

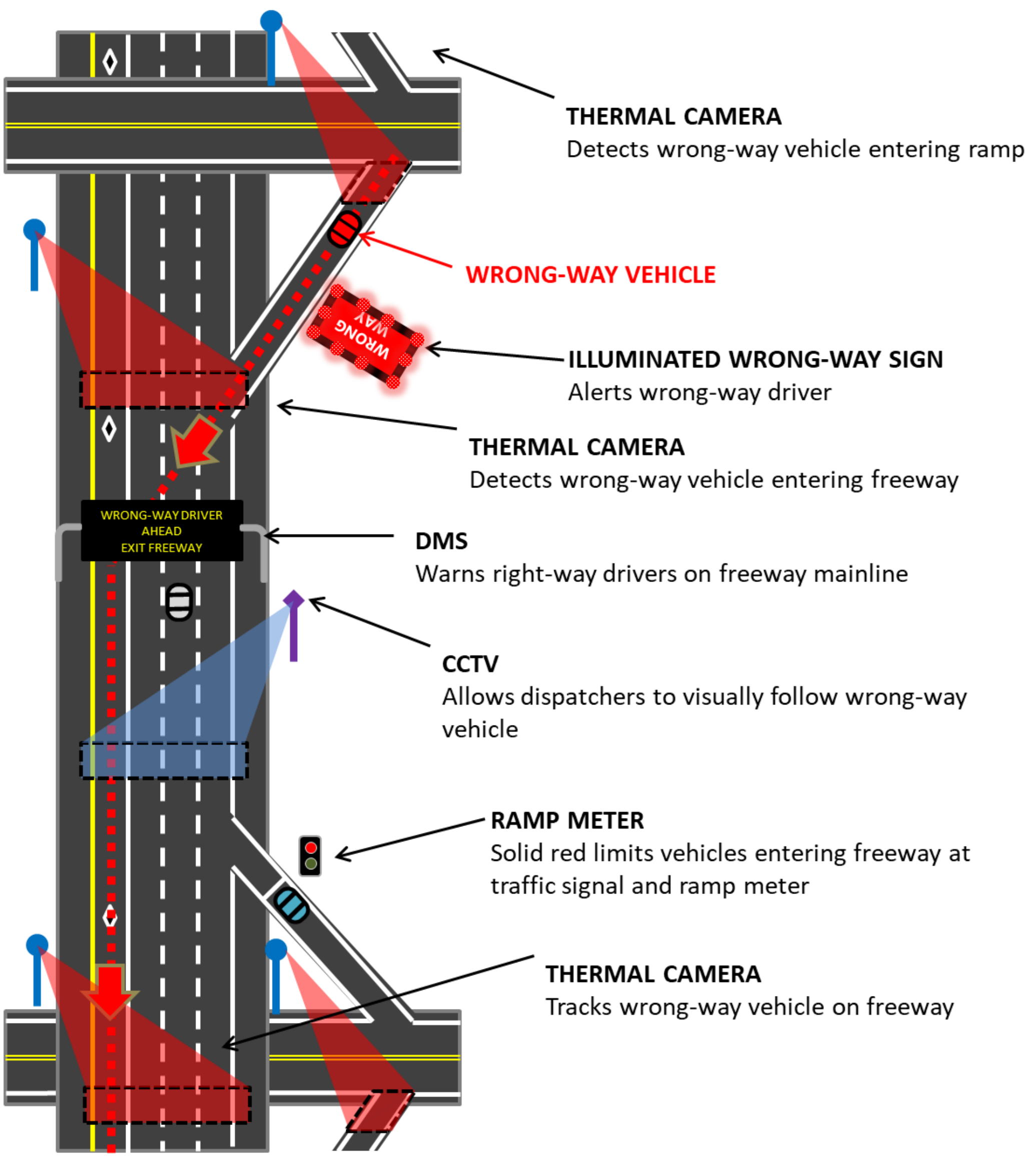


Figure 9. Pilot System Device Layout

CHAPTER 3. SYSTEM OPERATIONAL PROCESS

This chapter describes the operational process for the I-17 wrong-way detection pilot system. The operational process describes how the different components of the system interact with each other. These components are thermal cameras, illuminated wrong-way signs with flashing LED borders, decision support software (DSS), dynamic message signs (DMS), CCTV cameras, ramp meters, and traffic dispatchers and state troopers.

OPERATIONAL PROCESS

Thermal cameras are equipped with presence detection zones and inverse detection zones. The pilot system uses inverse detection to detect vehicles traveling the wrong way, opposing typical traffic flow. Inverse detection zones were set up to provide full coverage of the potential wrong-way entry points along the pilot corridor. At exit ramps, thermal cameras were placed on the opposite side of the roadway facing toward the stop bar to allow a wide view of the exit ramp and optimum detection and tracking of wrong-way incursions.

The wrong-way detection system's operational process consists of the following steps:

1. Detection by a thermal camera of a vehicle entering an exit ramp the wrong way immediately triggers an illuminated wrong-way sign with a flashing LED border.

2. The thermal camera software (Flux) activates the system's decision support software, alerts ADOT TOC staff (TOC dispatchers and the DPS trooper stationed in the TOC) to the wrong-way vehicle, and provides a 20-second recorded video of the incursion and live video from the thermal camera. Capturing the recorded video introduces some latency into the process. The thermal camera software immediately triggers the DSS system to automatically reposition highway cameras downstream of the wrong-way vehicle, allowing the TOC dispatchers to track the vehicle and provide DPS dispatchers with real-time information about the vehicle's location.

A key step in the process that introduces latency is the TOC dispatcher visually confirming the presence of a wrong-way vehicle using the recorded and live video provided through the DSS. Once the wrong-way vehicle is confirmed, the TOC dispatcher uses one-click functionality within the DSS to simultaneously activate three automated countermeasures:

1. Warn other freeway drivers in the area through posting of "WRONG WAY DRIVER/AHEAD/EXIT FREEWAY" advisories on overhead dynamic message signs.

2. Alert DPS dispatchers.

3. Limit potential conflicting vehicles entering the freeway by pre-empting ramp meter signals to display solid red indications.

If the wrong-way vehicle continues onto the freeway, additional CCTV and thermal cameras placed at one-mile intervals detect and help track the location of the wrong-way vehicle.

The flow diagram in Figure 10 identifies each of the decision points that the system progresses through, from the initial vehicle detection at the top left to full operations along the bottom.

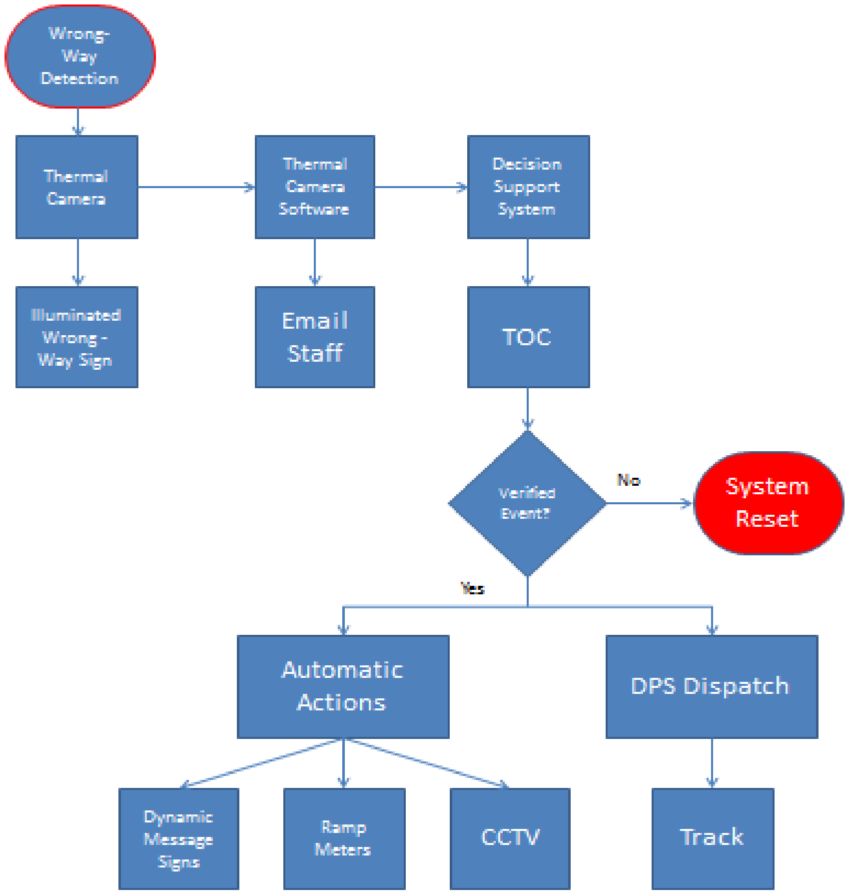


Figure 10. System Operations Flow Chart

For a more detailed breakdown of this process, see Appendix A.

CHAPTER 4. SYSTEM PERFORMANCE

To help evaluate the effectiveness of the I-17 wrong-way detection pilot system and gather more information about wrong-way driving in the pilot corridor, ADOT gathered data on wrong-way driving events during the pilot's initial two-year operation period from January 2018 to December 2019.

Detailed information on every wrong-way incursion is stored in the thermal camera software (Flux) and logged into a database. This information is available to ADOT staff for analysis, specifically to note trends and assist in identifying best practices for implementation of the system components. For each incursion, the database includes date, time, day/night, location (GPS coordinates), event type, point of origin (how the wrong-way vehicle entered), lane entered onto, and 15 seconds of saved video. ADOT also collected other relevant data, such as law enforcement data on 911 calls and crashes. Data on all wrong-way events during the pilot project are provided in Appendix B.

Several of the key trends identified during the pilot system's initial two-year operation period are discussed below.

PERFORMANCE RESULTS

Data were collected on the monthly and annual number of wrong-way incursions detected during the pilot study. An incursion was defined as a vehicle traveling the wrong way on the freeway exit ramp or mainline and detected at a point of entry into the pilot study area.

Table 1 presents the total number of wrong-way incursions that occurred during 2018 and 2019, while Table 2 presents the wrong-way vehicles that entered the mainline freeway. In 2018, 54 incursions were detected, of which four continued to the mainline; there was also one mainline entry from downstream (outside the study area). In 2019, 55 incursions were detected, with nine continuing to the mainline.

Table 1 includes wrong-way vehicles detected by any camera within the pilot project, including wrong-way vehicles on the exit ramp that self-corrected. Mainline entries are counted in both tables unless the vehicle entered the pilot area via the downstream freeway mainline. Both tables exclude emergency and construction vehicles, vehicles reversing to change lanes (e.g., while stopped at an intersection), duplicate detections of the same vehicle, and intentional short-distance wrong-way driving (i.e., driving the wrong way on the frontage road from one business driveway to another).

Table 1. Total Wrong-Way Incursions Detected

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2018	4	5	7	1	5	2	9	1	4	5	5	6	**54**
2019	3	1	5	3	5	2	6	7	7	3	4	9	**55**

Table 2. Wrong-Way Vehicle Entries onto the Mainline

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2018	0	0	0	0	0	0	2	1	0	0	0	1	**4**
2019	1	0	2	0	0	0	0	3	1	1	0	1	**9**

These data show that an overwhelming percentage of wrong-way drivers made self-correcting turns on freeway exit ramps and did not enter the I-17 mainline lanes. During the two-year data collection period, 109 wrong-way vehicle incursions were identified within the pilot project's limits. Within those incursions, 88 percent of drivers self-corrected on an exit ramp. Of the remaining 12 percent of incursions, only one resulted in a wrong-way vehicle injury crash. A second injury crash documented within the system's boundaries involved a detected vehicle that originated outside the study area and crashed just over 1 minute after entering the pilot corridor.

EVENT ANALYSIS

Data on the characteristics of each wrong-way event were recorded, including date, time, location, interchange type, and point of origin. These data were used to help identify trends such as times of day when wrong-way driving is more frequent or interchange geometries that may benefit from additional signage or striping.

The following trends were identified:

- In 2018 the highest number of incursions occurred on Friday and Saturday, while in 2019 the highest number of incursions occurred on Saturday and Sunday. Table 3 provides a breakdown of events by day of the week.

Table 3. Events by Day of Week

Day	2018	2019
Sunday	8	13
Monday	7	5
Tuesday	4	7
Wednesday	4	8
Thursday	6	5
Friday	14	1
Saturday	11	16
Total	**54**	**55**

- Using the criteria for night and day based on civil twilight (see Appendix C), 83 percent of the incursions in 2018 and 87 percent of the incursions in 2019 took place at night. Table 4 provides a breakdown of events by time of day.

Table 4. Events by Time of Day

Year	Night Incursions	Night %	Day Incursions	Day %
2018	45	83%	9	17%
2019	48	87%	7	13%

- There are three types of traffic interchanges within the pilot corridor: diamond interchange underpasses, diamond interchange overpasses, and single-point urban interchange (SPUI) overpasses. Diamond overpasses experienced the highest frequency of events proportionate to the number of diamond overpasses in the study area. Table 5 provides a breakdown of events by interchange type.

Table 5. Events by Interchange Type

	2018		2019	
Type	**Incursion**	**Mainline Entry**	**Incursion**	**Mainline Entry**
Diamond Underpass	20	1	17	2
Diamond Overpass	15	0	15	1
SPUI Overpass	11	0	10	2
Non-Interchange*	4	3	4	4
Total	**50**	**4**	**46**	**9**

* Non-interchange events are access points along the freeway frontage roads and mainline.

- Point of origin describes where a vehicle was first detected by the thermal cameras, and indicates how the vehicle entered the exit ramp or mainline freeway segment going the wrong way. Origins can be via frontage roads, intersections (left or right turns and through movements), or other parts of the freeway system outside the pilot area. Unknown origins were indeterminate based on the limits of the camera angle. Most vehicles entered into the inverse direction through right- or left-turn movements. Table 6 provides a breakdown of events by point of origin.

Table 6. Events by Point of Origin

	2018		2019	
Point of Origin	**Incursion**	**Mainline Entry**	**Incursion**	**Mainline Entry**
Frontage Road	4	0	0	0
Intersection - Left Turn	21	0	18	3
Intersection - Through	2	2	10	4
Intersection - Right Turn	18	1	18	2
Mainline	0	1	0	0
System Ramp	1	0	0	0
Unknown	4	0	0	0
Total	**50**	**4**	**46**	**9**

The most significant data set compares the wrong-way event detection time with the time that the first 911 call was received regarding the wrong-way driver. Figure 11 shows the difference between thermal camera detections and 911 call times recorded for 2018 events. Of 54 incursions, 15 (28 percent) were matched to 911 calls. The average elapsed time is 1 minute, 38 seconds between the thermal camera detection and the first 911 call. The wrong-way detection system has significantly reduced DPS troopers' response time to wrong-way driving incidents compared with waiting for 911 calls from the public.

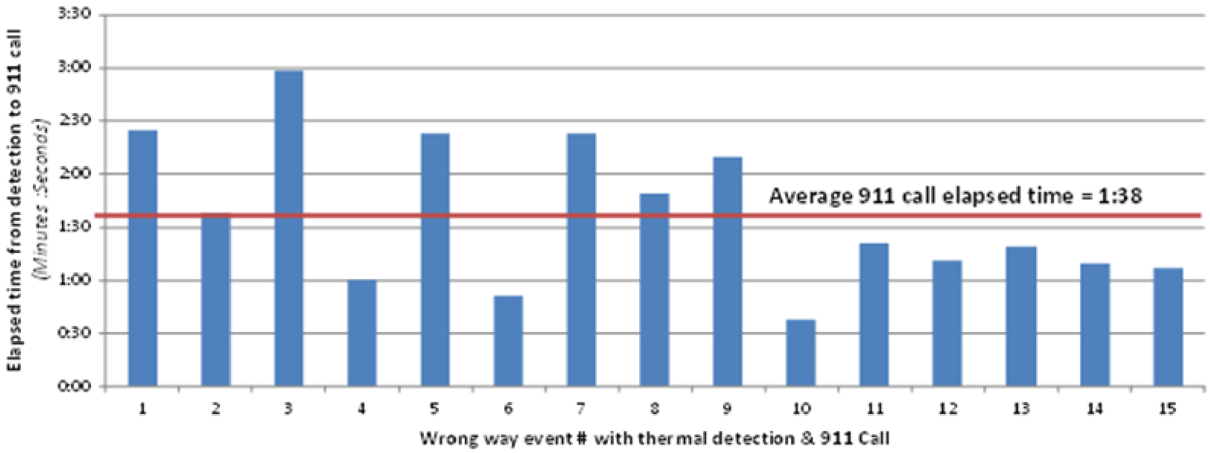


Figure 11. Wrong-Way Events Detected by Thermal Camera and with 911 Calls

In conclusion, the ability to dispatch law enforcement more quickly and effectively has been the most significant benefit of the wrong-way detection pilot program. The pilot system's thermal detection cameras detected 54 incursions in 2018. Of those incursions, only 15 were also reported by traditional means (via 911 calls). Thus, within the I-17 pilot corridor, the wrong-way detection system resulted in more than a threefold increase in errant vehicle detections during 2018. The system has significantly enhanced ADOT's and DPS's ability to respond to all incursions detected within the I-17 pilot study area. Figure 12 graphically depicts the increase in detection of wrong-way events provided by the pilot system in 2018.

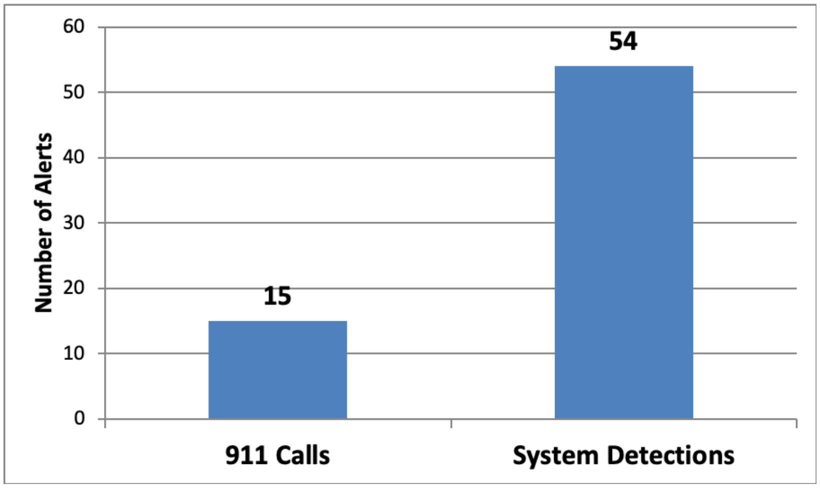


Figure 12. Wrong-Way Events Detected via 911 Calls vs. by the Pilot System in 2018

CHAPTER 5. SYSTEM DEPLOYMENT AND IMPLEMENTATION FINDINGS

The components of the I-17 pilot system were installed over a six-month period during 2017, and the system went live in January 2018. To help inform future deployments, this chapter discusses a few issues that the project team encountered during implementation, as well as how each issue was resolved.

THERMAL CAMERAS

ADOT initially deployed thermal cameras on existing mounting platforms where available, and on new equipment for mainline and ramp detection where existing equipment was not available. Following this initial deployment, some thermal cameras detected false calls for wind, pedestrians, truck occlusions, birds, flying debris, windshield reflections, and vehicle grille distortions. ADOT made several adjustments to minimize false detections, including adjustments to the camera's detection zones and modifications to stabilize the mounting platforms.

Detection

- Detection placement is critical to enable the thermal camera to view and capture the entire length of each exit ramp. While this was the intent, it was not feasible to achieve at all locations.
- Mast and luminaire arms are flexible and move slightly with the wind, and the initial mounting on mast and luminaire arms introduced false detections caused by movement of the mounting platforms.
- Using the same camera for presence and inverse detection did not work well. To capture left-turn movements at SPUI intersections, the angle of the inverse detection zone is sensitive to shaking movements. The dual-function configuration is not in conformance with the manufacturer's recommendations.
- Setting up the sensitivity of detection zones to capture inverse movements was challenging. It was found that setting up one inverse zone per travel lane made this process easier.
- In some locations, placement of the inverse detection zones introduced non-wind-related false detections. These false detections were caused by windshield reflections, trucks making wide turns (occlusion), exhaust stacks from cross-traffic trucks, and pedestrians. ADOT determined that the inverse detection zone should be set up as a nonstandard zone in these cases, including in SPUI left-turn applications (due to pedestrian traffic).

Camera Stability

As noted above, mounting the thermal detection cameras on mast arms and luminaire arms led to a high incidence of false calls due to wind. These scenarios were prominent when inverse detection was being utilized by the same camera as signalized intersection presence detection. Mounting the cameras on traffic signal masts led to fewer false calls, and mounting on a stand-alone pole was found to be most effective for resolving shaking impacts.

- To provide a more stable mounting platform, ADOT modified the camera mount riser using a pipe fitting rather than the smooth aluminum riser supplied with the camera.
- A new shaking algorithm was deployed on all thermal cameras in the system in September 2019. The shaking algorithm utilizes a no-shaking zone to subtract out detected movements. The no-shaking zone is defined in each camera view and encompasses objects that are stationary, like buildings, within the field of view. If those fixed objects are seen as moving, that same motion is removed from the wrong-way detector zones. All new thermal detection cameras have the algorithm as part of the standard software.
- Newly installed H-poles for mainline detection zones experienced shaking from wind, causing false detections. The sensor sensitivity was adjusted and pole vibration dampeners were applied, but this did not prevent the shaking. When the new shaking algorithm was installed, this substantially diminished the false calls due to wind, but it did not eliminate them. ADOT plans to use a more rigid pole for future mainline deployments.

Conclusion: To minimize false detections, the inverse detection should be located separately from the traffic signal presence detection at a more stable location, such as on a traffic signal mast or a stable stand-alone pole. For SPUI applications, a two-camera installation would provide better coverage, with one camera faced toward the stop bar and one facing up to the gore location.

ILLUMINATED WRONG-WAY SIGNS WITH FLASHING LED BORDERS

Illuminated wrong-way signs with flashing LED borders were deployed at all exit ramps throughout the pilot system corridor. The signs were installed approximately 600 feet from the exit ramp stop bar. During the pilot project, ADOT made adjustments to resolve a few minor issues:

- At times, the signs would activate and not turn off. In most instances, this was caused by the inverse detection system registering repeated wind-related false calls.
- Consistent grounding of the thermal camera hardware is needed for consistent activation and deactivation of the signs. A challenge within the pilot system was that there were different cabinet types throughout the pilot corridor, with varying ages and manufacturers. Understanding the cabinets' different grounding requirements was key to differentiating between logic ground, equipment ground, cabinet ground, and equipment neutrals.
- However, not all activation problems were caused by grounding issues; sometimes the camera processor cards merely needed to be replaced.
- A time-delay relay was added to the contact closure circuit to ensure that sign activation or deactivtion would not induce voltage that might interfere with the operation of traffic signal controllers or ramp meter controllers.

Conclusion: Where feasible, a stand-alone wrong-way detection system is recommended to ensure that the signs do not negatively impact traffic signal and or ramp meter operations.

DECISION SUPPORT SOFTWARE

The thermal camera manufacturer and the operating software providers for the CCTV and DMS systems worked with ADOT staff to develop customized, unique decision support software that notifies ADOT TOC and DPS personnel of each wrong-way event. See Appendix A for more detail on the software's cycle of operations.

Agencies considering developing a similar system should plan for the time and money required to develop the software, including mapping out the cycle of operations based on current procedures and the functionality of existing equipment. In addition, continuous software updates require Information Technology (IT) staffing to maintain functionality.

ADOT noted one minor issue with the pilot system's decision support software. Occasionally, images on the TOC video wall did not display as intended. IT staff were able to troubleshoot and fix the software issue causing the display problem.

Conclusion: The decision support software developed for ADOT is unique, customized to the agency's selected components. The DSS system requires regular updates to maintain software integrity.

RAMP METERS

The ramp meter component of the pilot system is designed to restrict vehicles from entering the freeway mainline through signal pre-emption, holding the signals at ramp meters and signalized ramp intersections at a red-light indication when a wrong-way vehicle is detected. This component was deployed later in the project, because the DSS needed to be in place before this functionality could be added.

ADOT was able to integrate the ramp meters with the wrong-way detection system because the ramp meters were equipped with the same model of controller throughout the corridor. These components were pre-existing along the corridor. Following a software update to each controller to allow the DSS to activate, the ramp meters functioned effectively.

Although the ramp meters worked as intended, driver noncompliance with steady red ramp meter indications during nonpeak hours limited their effectiveness. ADOT issued public service announcements in an attempt to educate the public to be aware of the steady red indications.

Conclusion: Designers are advised to follow the ADOT ITS Design Guidelines for ramp meter design. The ramp meter software can be configured to integrate with the wrong-way system. Additional public outreach may improve compliance with the steady red indications.

CCTV

In the pilot system, the existing CCTV traffic cameras supplement the mainline thermal cameras to help in tracking wrong-way vehicles. When an incursion is detected, the system's DSS automatically repositions nearby CCTV cameras to face the oncoming wrong-way vehicle. The TOC dispatcher can then refine each camera's position to follow the wrong-way vehicle as it passes. These CCTV cameras were pre-existing along the pilot corridor.

Conclusion: By automatically repositioning nearby CCTV cameras to face detected wrong-way vehicles, the pilot system makes it easier for TOC personnel to track these vehicles and relay their location to law enforcement in real time. Designers are advised to follow the ADOT ITS Design Guidelines for CCTV design.

DYNAMIC MESSAGE SIGNS

The pilot system uses DMS messaging to warn right-way drivers of an approaching wrong-way vehicle. DMS installations were pre-existing along the pilot corridor, spaced approximately 3 miles apart. DSS actuates standard wrong-way messaging on the three upstream DMS closest to where the incursion originates.

Establishing an appropriate message to post on the DMS was critical to this component's success. ADOT Communications was consulted to develop a standard message. Initially, the message was posted as "WRONG WAY DRIVER AHEAD." Based on driver response, it was determined that the message did not provide right-way drivers with enough direction on what to do. The message was revised to "WRONG WAY DRIVER/AHEAD/EXIT FREEWAY."

Conclusion: Existing DMS are valuable tools to communicate warnings to right-way drivers. The message content is critical; it must be clear and provide instruction. Designers are advised to follow the ADOT ITS Design Guidelines for DMS design.

TOC/DPS PERSONNEL

Traffic operations center staff—both the TOC dispatchers and the DPS trooper stationed at the center—are a critical part of the wrong-way detection pilot system. When an incursion is detected, TOC personnel must visually confirm the presence of a wrong-way vehicle in order to activate the full functionality of the system through the DSS. Proper training on all aspects of the system is important.

Conclusion: Because the system relies on human decisions to verify and activate the DSS, it is important to have TOC staff that is well trained on the system and the decisions to be made. As a result, the system encourages essential communication dialogue between TOC and DPS staff with each event, which enhances DPS's ability to respond efficiently and with minimal delay to intercept wrong-way vehicles.

OPERATIONAL PERSONNEL

Many steps are required to operate, manage, and monitor the Flux operating system. These include identifying and coding incursions, adjusting wrong-way detection zones, coordinating with maintenance staff when components are not functioning correctly, reactivating equipment replaced due to knockdowns, developing and continuously updating a rollout plan for future sites, bringing new sites online as they become available, preparing monthly performance data, preparing presentations for management, providing design guidance, reviewing construction project plans, developing a standard operating procedures manual, and coordinating with the FLIR liaison.

As ADOT expands its deployment of wrong-way detection equipment to include additional locations, more documentation will be needed to ensure effective, consistent operation throughout the system. This includes:

- An operational staffing plan that defines standard work processes to ensure program functionality. The plan will include training for key operational functions.
- A standard operating procedures manual that provides guidelines and instructions for the routine tasks involved in monitoring and responding to wrong-way events. Developed as a resource for TOC dispatchers and operational staff, the manual is designed to allow ADOT to scale and improve processes, improve performance and efficiency, and ensure quality.

Conclusion: As ADOT's wrong-way detection system is expanded, an operational plan will be developed that will include training for operational functions.

MAINTENANCE PERSONNEL

To ensure smooth operation of the wrong-way detection system, it is important to adhere to a maintenance schedule that includes general, preventive, and emergency maintenance of field components and software. Maintenance personnel should be trained on all aspects of the system.

Conclusion: As the wrong-way detection system is expanded, a maintenance program will be developed that includes general, preventive, and emergency maintenance functions.

CHAPTER 6. DESIGN RECOMMENDATIONS

Based on ADOT's experiences with the deployment of the I-17 wrong-way detection pilot project and ongoing analysis of wrong-way driving events in Arizona, ADOT has developed a set of design recommendations for future deployments. This chapter discusses the design recommendations for each system component and provides conceptual design layouts for three interchange types and a mainline installation.

SYSTEM COMPONENT DESIGN RECOMMENDATIONS

These recommendations provide an overview of key design considerations for each component of a wrong-way detection and notification system. These guidelines are based on the system design used in the I-17 pilot project and are current as of the publication date of this report. For additional design details and current policy guidance, designers should consult the ADOT ITS Design Guidelines and standard drawings.

Thermal Cameras

The thermal cameras deployed in the pilot project were the FLIR TrafiSense 345 (10-7034), TrafiSense 335 (10-7036), TrafiSense 325 (10-7047), TrafiSense 345 (10-7044) Ethernet, and TrafiSense2 645. Vehicle detection technology is evolving rapidly, and detection equipment with equivalent capabilities may be considered for future deployments. (Note that federally funded projects require a letter of justification for the inclusion of proprietary items, such as if a particular brand of thermal camera is specified in the design plans.)

To provide stability and minimize false detections due to camera shaking, thermal cameras should be mounted on a rigid stand-alone pole where feasible. Guidelines for specific interchange types include:

- **Full diamond overpass or underpass:** One thermal camera should be positioned to detect wrong-way vehicles at the point of entry and send an alert to the TOC. The camera should be mounted on a traffic signal mast or a stable stand-alone pole. The camera lens and alignment should be selected to maximize the field of view so that the camera can record the initial entry path, provide tracking on the ramp, and if possible, detect whether the vehicle enters the mainline.

- **SPUI:** Two thermal cameras should be located on a stable stand-alone pole at the midpoint of the exit ramp. One of the cameras should face the stop bar at the cross street intersection to detect the initial entry path and send an alert to the TOC. The second camera should face the mainline gore to track the errant vehicle and determine whether the driver self-corrects or continues onto the mainline.

- **Diverging diamond interchange:** While the I-17 pilot project did not include diverging diamond interchanges, it is anticipated that one thermal camera should be located on a stable stand-alone pole facing the cross street intersection to detect wrong-way vehicles at the point of entry and send an alert to the TOC.

- **Roundabout:** While the pilot project did not include roundabout interchanges, it is anticipated that one thermal camera should be located on a stable stand-alone pole facing the exit ramp to detect wrong-way vehicles at the point of entry and send an alert to the TOC.

Pole Type and Mounting Restrictions

- Aluminum H-poles should not be used to mount thermal cameras under any circumstances.
- Mast arms and luminaire arms should not be used for mounting when inverse detection is being utilized with traffic signal presence detection; a separate stand-alone pole should be used instead.
- Detectors may be placed on traffic signal masts if the mounting height allows the camera to capture all possible wrong-way vehicle entry points.
- When a stand-alone pole is used for mounting, designers should ensure that the pole meets the minimum specification provided in the ADOT ITS Design Guidelines for CCTV camera poles regarding movement. Poles should not exceed 40 feet in height.

Illuminated Wrong-Way Signs with Flashing LED Borders

- When a wrong-way detection system with inverse detection cameras is installed on an exit ramp, an illuminated wrong-way sign should be part of the system where feasible.
- Sign placement should be determined based on the interchange configuration. The driver must be able to view and comprehend the sign's message and still have time and distance to take the required corrective measures before reaching the mainline. Corrective measures could include turning around on the ramp or making a tight right turn onto the freeway.
- Where feasible, a stand-alone wrong-way detection system is recommended to ensure that sign activation does not induce voltage that might interfere with the operation of traffic signal controllers or ramp meter controllers. Under a stand-alone system, the sign would only interact with the inverse detection thermal camera.

Ramp Meters

- Designers are advised to follow the ADOT ITS Design Guidelines for this component. If ramp meter pre-emption is included as part of a wrong-way detection system, the ramp meters must be integrated into the wrong-way detection system's DSS. In addition, public outreach about the purpose of the ramp meter pre-emption should be conducted as a strategy to increase driver compliance with steady red indications during wrong-way events.

Decision Support Software (DSS)

- The DSS developed for ADOT is unique and is not transferable to other agencies. The system currently integrates the FLIR detection equipment, Bosch CCTV cameras, DMS, and the TOC video wall using software provided by Camera Cameleon. The DSS requires regular updates to maintain the Cameleon software.
- Periodic training should be required for staff that utilize the DSS.

CCTV Cameras

- ADOT has CCTV camera coverage across the Phoenix metro area. If the wrong-way detection system is deployed elsewhere, CCTV cameras may need to be installed in those locations for vehicle tracking. To enable tracking capabilities, CCTV cameras would need to be placed at multiple locations, at spacing that takes into account existing terrain, typically at 1- or 2-mile intervals along a corridor.
- Designers are advised to follow current ADOT ITS Design Guidelines and standard drawings for the installation of CCTV cameras.

DMS

- DMS messaging to warn right-way drivers of the presence of a wrong-way driver is an important part of the wrong-way detection system. It is critical that the message provides clear direction to motorists on what action to take.
- Since all existing DMS have communication links that can readily use the Camera Cameleon software, it is recommended that this component be included in future deployments throughout the state. This is a cost-effective safety investment with the potential to save lives.
- Designers are advised to follow current ADOT ITS Design Guidelines and standard drawings for DMS installation.

TOC Personnel

- The rapid communication link between ADOT TOC dispatchers and DPS troopers is a critical element of the wrong-way detection system. TOC dispatchers should be well trained on all aspects of the system.

Operational Personnel

- Operational personnel should receive the training required to operate, manage, and monitor all aspects of the wrong-way detection system.

Maintenance Personnel

- Maintenance personnel should receive training and guidance on general, preventive, and emergency maintenance of all aspects of the system, including field components and software.

CONCEPTUAL LAYOUTS

Based on the success of the I-17 pilot project, ADOT expects to expand the current wrong-way detection system to additional locations through future construction and capital projects. To assist with the planning and design of future deployments, four design concepts have been developed to illustrate possible equipment configurations for both rural and urban applications.

Future deployments will vary significantly based on the proximity and availability of power and communications facilities, interchange types and configurations, and the presence of surrounding structures. As described in Chapter 7, these design concepts focus on the components of the wrong-way pilot system that have provided the most significant benefits.

For budgeting purposes, an estimated cost is provided for each concept. These estimates account for the cost of the equipment only, derived from 2019 construction bid items and quotes from equipment suppliers, and should be used with extreme caution. The estimates do not include the costs associated with design preparation, obtaining clearances, mobilization, construction, and other necessary activities that are unique to each situation. More information on estimated costs is provided in Appendix D.

These conceptual layouts are for planning purposes only, and none are intended to be one-size-fits-all. Future wrong-way detection installations should be designed specifically for individual locations. Designers should consult the ADOT ITS Design Guidelines and standard drawings.

Concept 1 – System Interchange

This layout is designed for system interchanges (the intersection of two freeways or highways). A system interchange carries traffic from one freeway to another via a network of ramps and connectors. Figure 13 shows an example of a Concept 1 layout.

- **Thermal detection camera** at each system ramp, mounted on a stand-alone rigid pole to optimize alignment and minimize shaking. The camera model, location, and alignment should be selected based on the ramp geometry to maximize the ability to detect and track wrong-way vehicles.
- **Illuminated wrong-way sign with flashing LED border** at each system ramp (where feasible).
- **DMS warning messages** to other motorists.
- **Notifications to TOC dispatchers and DPS troopers** through DSS.
- **CCTV cameras** to help dispatchers track wrong-way vehicles.

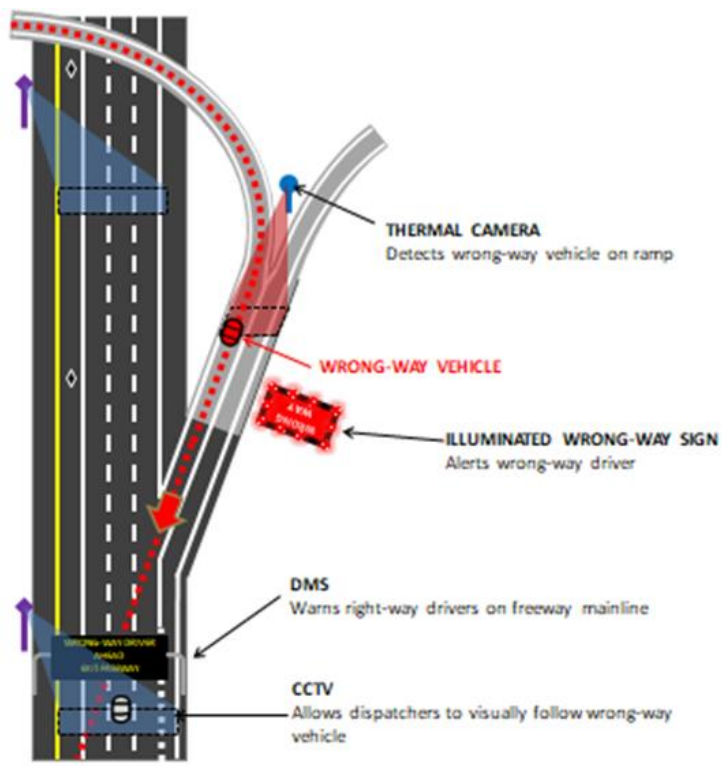


Figure 13. Concept 1: System Interchange

The estimated equipment cost for Concept 1 is $35,000 per ramp based on deploying equipment in an existing cabinet.

Concept 2 – Traffic Interchange

This layout is designed for traffic interchanges, which occur where a freeway or highway intersects with an arterial roadway. These are grade-separated locations, typically designed as diamond interchanges, single-point urban interchanges (SPUIs), diverging diamond interchanges, or roundabout interchanges. As discussed previously, each type of interchange has unique characteristics that must be accommodated during design. Figure 14 shows an example of a Concept 2 layout.

- **Thermal detection camera** at each exit ramp, mounted on a stand-alone rigid pole or an existing traffic signal mast to optimize alignment and minimize shaking. The camera model, location, and alignment should be selected based on the ramp geometry to maximize the ability to detect and track wrong-way vehicles.
- **Illuminated wrong-way sign with flashing LED border** at each exit ramp (where feasible).
- **DMS warning messages** to other motorists.
- **Notifications to TOC dispatchers and DPS troopers** through DSS.
- **CCTV cameras** to help dispatchers track wrong-way vehicles.

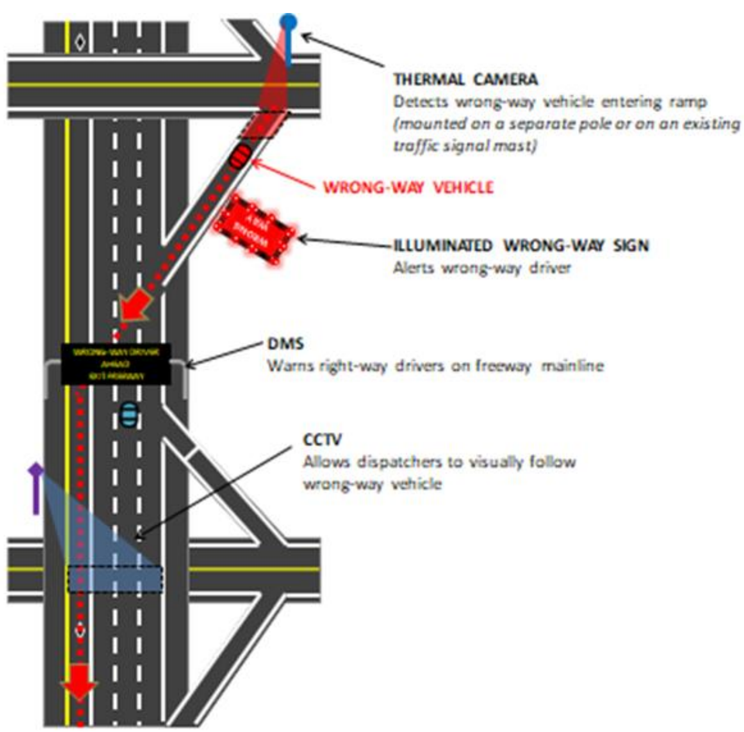


Figure 14. Concept 2: Traffic Interchange

The estimated equipment cost for Concept 2 is $36,000 per ramp.

Concept 3 – At-Grade Intersection

This layout is designed for at-grade intersections, where a highway intersects with a local roadway at the same elevation. Figure 15 shows an example of a Concept 3 layout.

- **Two thermal detection cameras** at each intersection. Cameras can be mounted on available poles or rigid platforms near the intersection. If there are no existing mounting locations that can provide the necessary stability, each camera should be mounted on a stand-alone rigid pole to optimize alignment and minimize shaking. Higher mounting locations are preferable so that the detection zones can be better defined to avoid cross traffic. The camera model, location, and alignment should be selected based on the roadway geometry to maximize the ability to detect and track wrong-way vehicles.
- **Notifications to TOC dispatchers and DPS troopers** through DSS.
- **DMS warning messages** to other motorists on existing message boards (where applicable).

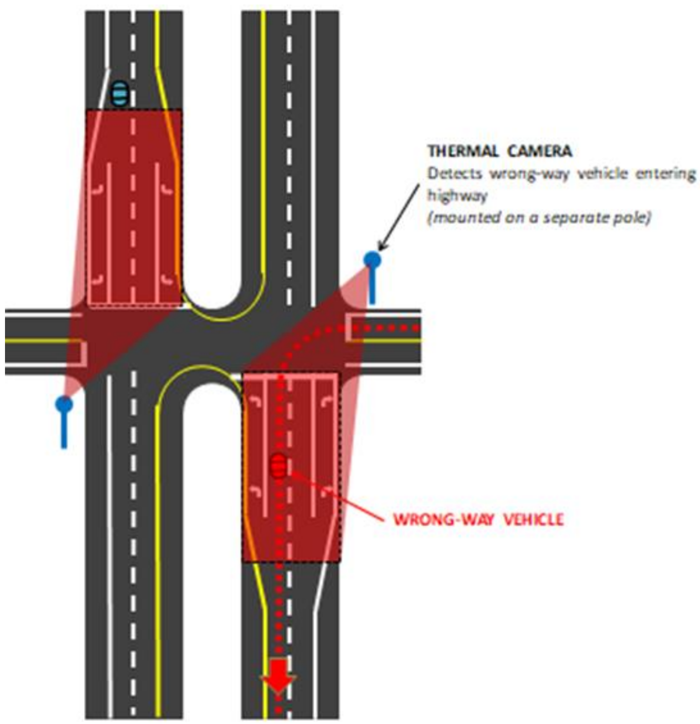


Figure 15. Concept 3: At-Grade Intersection

The estimated equipment cost for Concept 3 is $55,000 per intersection, assuming a signalized at-grade location with communication available. Equipment costs for Concept 3 will vary greatly based on available power and communication connections. Equipment costs for at-grade intersections that are stop-controlled locations will vary substantially based on the geometrics and topography of each location; thus, a cost estimate is not provided.

Concept 4 – Mainline Detection on DMS

This layout is designed for mainline deployments at locations with existing DMS. Figure 16 shows an example of a Concept 4 layout.

- **Thermal detection cameras** mounted on existing DMS using existing power and communication link and stable mounting platform. A pair of thermal cameras may be aligned to detect wrong-way vehicles in both highway directions. Placement of cameras should be such that each camera may achieve the optimal tracking distance based on available sight distances.
- **Notifications to TOC dispatchers and DPS troopers** through DSS.
- **Limited mainline tracking** from the point of detection.
- **DMS warning messages** to other motorists on existing message boards.

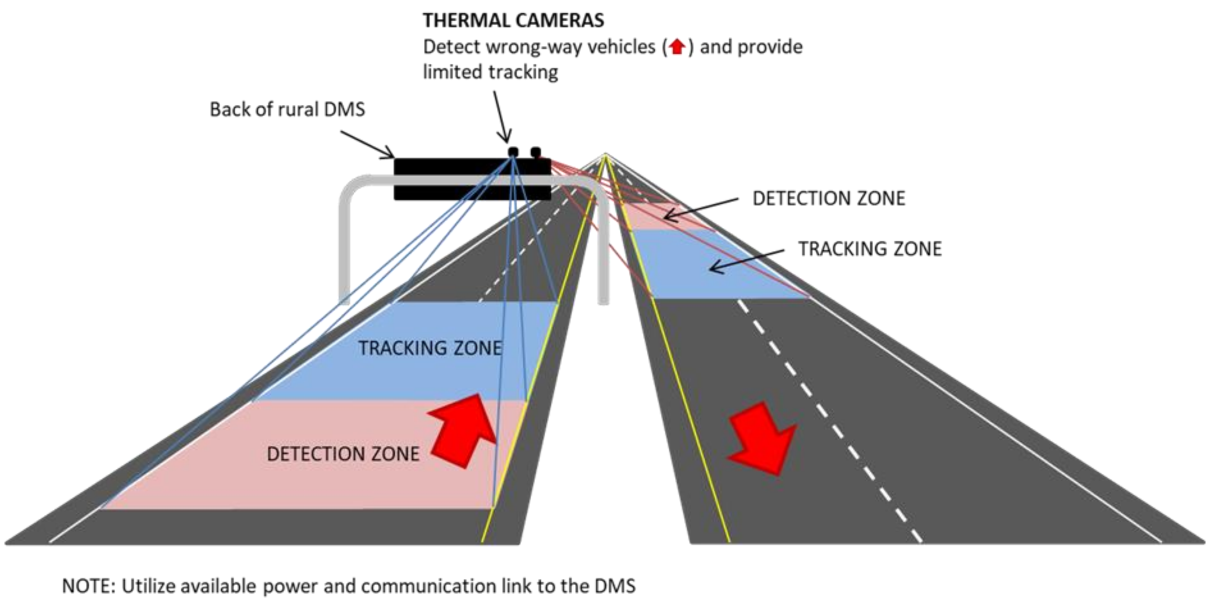


Figure 16. Concept 4: Mainline Detection on DMS

The estimated equipment cost for Concept 4 is $18,000 per DMS location, assuming two cameras per location. Concept 4 is considered a cost-effective application for rural deployment because the wrong-way detection system can be applied to existing DMS locations. Costs for different locations will have less variation because power, communication, and a stationary camera mounting platform are already available at these locations.

CHAPTER 7. FUTURE DEPLOYMENTS

The I-17 wrong-way detection pilot project allowed ADOT to evaluate the effectiveness of an extensive array of wrong-way driving countermeasures as part of an integrated system. Based on two years of operation and data gathering, increased wrong-way vehicle detection and improved notification and coordination between ADOT and DPS were found to be the most significant benefits of the wrong-way system.

As a result, ADOT's initial plans for future deployments will focus on early detection of wrong-way vehicles and timely alerts to law enforcement. Two approaches have been developed to guide future deployments on urban freeways and on rural highways. Future urban and rural deployments will focus on the components of the pilot system that yielded the most significant benefits, with a primary objective of installing wrong-way detection devices where feasible and cost-efficient.

Deployment locations will be prioritized through the evaluation of historical crash data and data on police contacts with wrong-way drivers, and installations will occur as funding becomes available. ADOT currently has a number of projects in construction that are incorporating wrong-way detection. These will provide additional coverage of several freeway segments within the Phoenix metro area.

The deployment plans described in this chapter are current as of the publication date of this report. Plans may be modified to reflect ongoing changes to department budgets and priorities.

URBAN AREA DEPLOYMENT

The current deployment plan for urban freeways calls for the implementation of thermal camera detection systems at points of entry along the mainline, ramps, and frontage roads, as well as installation of illuminated wrong-way signs on exit ramps where funds allow. The detection-activated wrong-way signs are included in the urban plan because urban areas have historically had higher rates of ramp incursions by wrong-way drivers. The plan also includes notification of TOC dispatchers and DPS troopers via DSS; integrated CCTV cameras to assist with tracking the wrong-way vehicle; and automatic DMS alerts for right-way drivers (pending verification by a TOC dispatcher). The urban plan includes an option to extend the detection system by installing additional thermal cameras on existing DMS. These signs, typically spaced 2 to 3 miles apart across much of the Phoenix-area freeway system, are connected to ADOT's fiber network—a feature that would allow lower-cost installation of the additional thermal cameras.

Figure 17 shows a sample conceptual layout of a wrong-way detection system deployment at a typical urban traffic interchange.

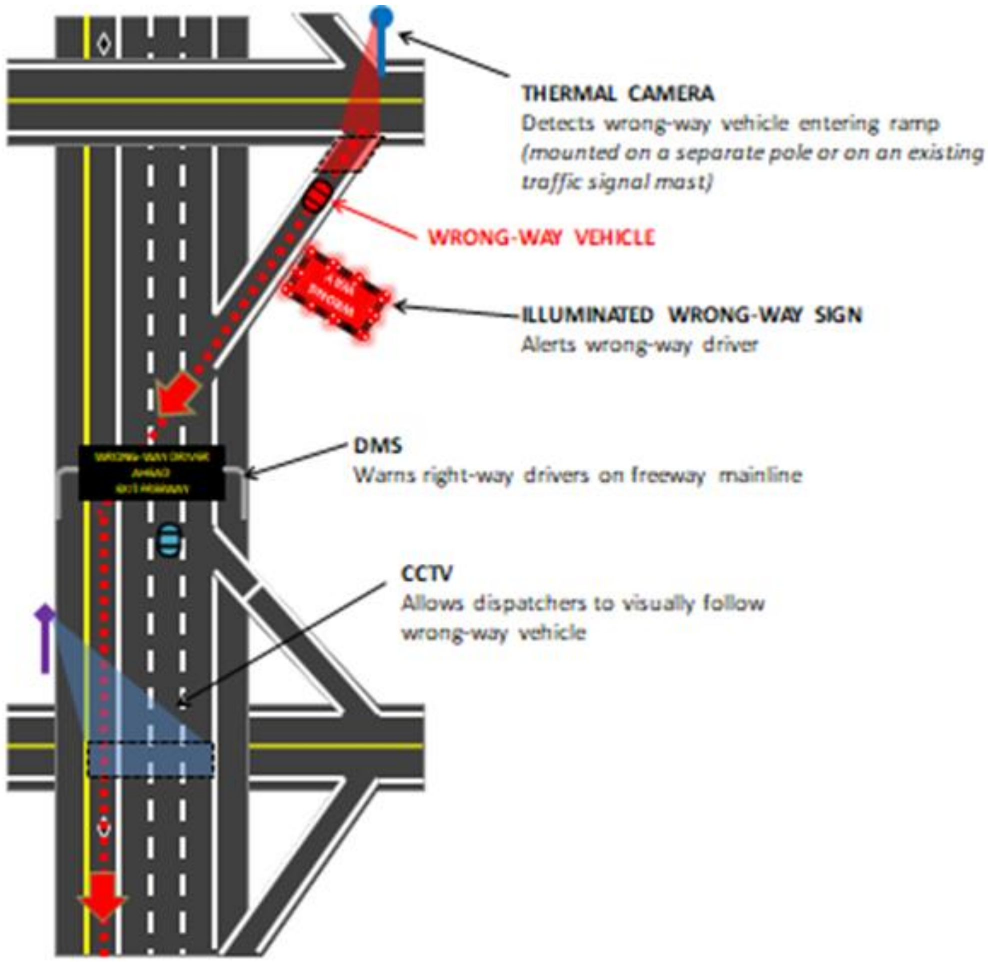


Figure 17. Conceptual Layout of Wrong-Way Detection System at an Urban Traffic Interchange

Figure 18 shows the corridors within the Phoenix metro area where wrong-way detection has been installed and is operational (indicated by green circles). The map also shows the corridors where construction projects incorporating wrong-way detection are underway (highlighted in orange). Corridors where wrong-way detection is currently operational include:

- I-17, from I-10 to Loop 101 (the I-17 pilot project).
- Loop 101, from I-17 to Shea Boulevard and from U.S. Route 60 to Loop 202.
- Loop 202 (South Mountain Freeway), from I-10 in Chandler to I-10 in west Phoenix.
- Loop 303, from I-10 to I-17.

There are also several locations along U.S. 60 in Wickenburg and along State Route 347 (Fiesta Road to Riggs Road).

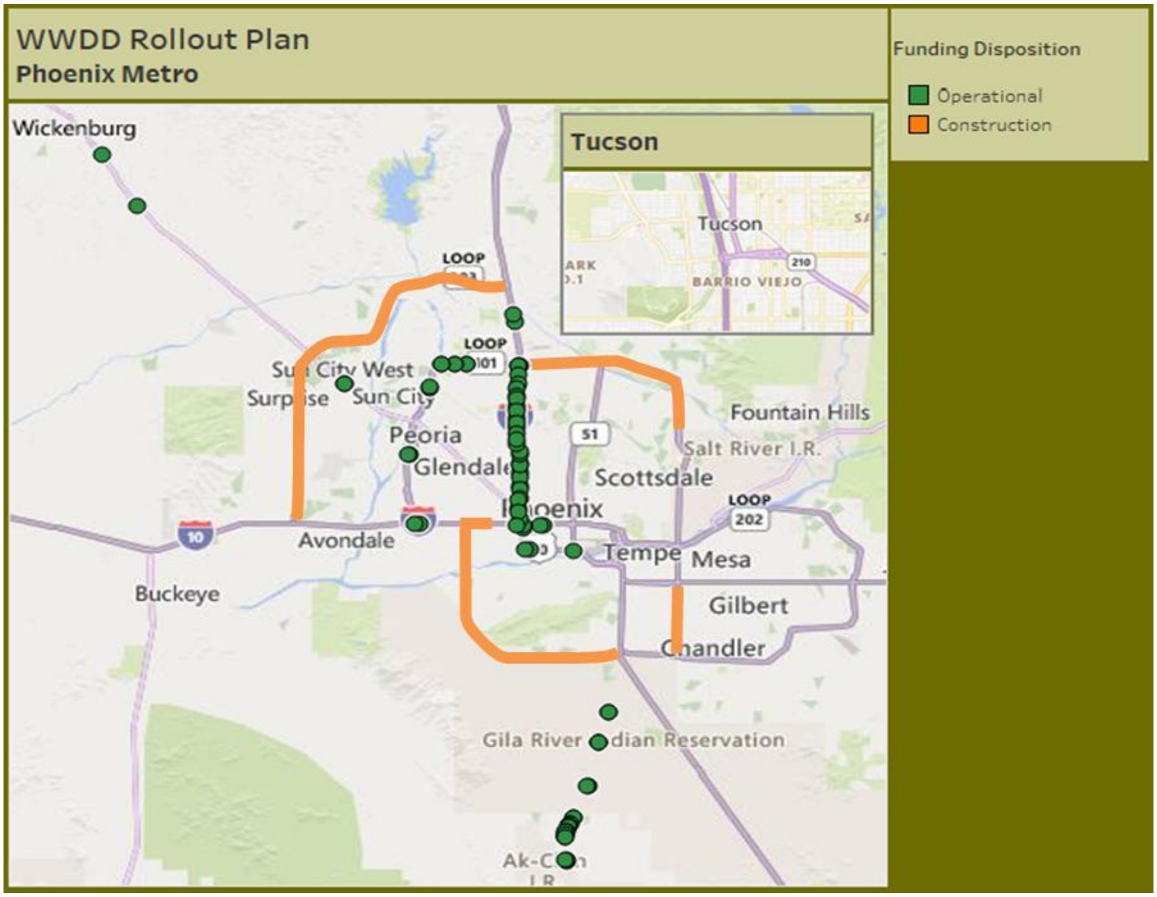


Figure 18. Wrong-Way Detection Systems in Phoenix Metro Area (Operational and Under Construction)

(Map data © OpenStreetMap contributors)

RURAL AREA DEPLOYMENT

The current deployment plan for rural highways calls for installation of thermal cameras at the top of exit ramps at selected interchanges that already have oversized Wrong Way and Do Not Enter signs in place. The chosen locations will provide early notification but typically will not include the lighted wrong-way signs with flashing LED borders. The rural plan also includes installation of thermal cameras on selected existing DMS. Although rural DMS are spaced farther apart than in urban areas, additional thermal cameras will still improve the resolution of the detection system in rural Arizona. In the rural plan, warning messages will be posted manually by TOC operators if DMS are nearby, and state troopers in the TOC control room will coordinate with troopers in the field via radio dispatch.

Figure 19 shows a possible system configuration for a wrong-way detection system installed on an existing DMS. The goal is to place the thermal cameras at a location on the DMS that allows them to detect wrong-way vehicles and then track the vehicles as far as the roadway geometrics and camera alignment will allow.

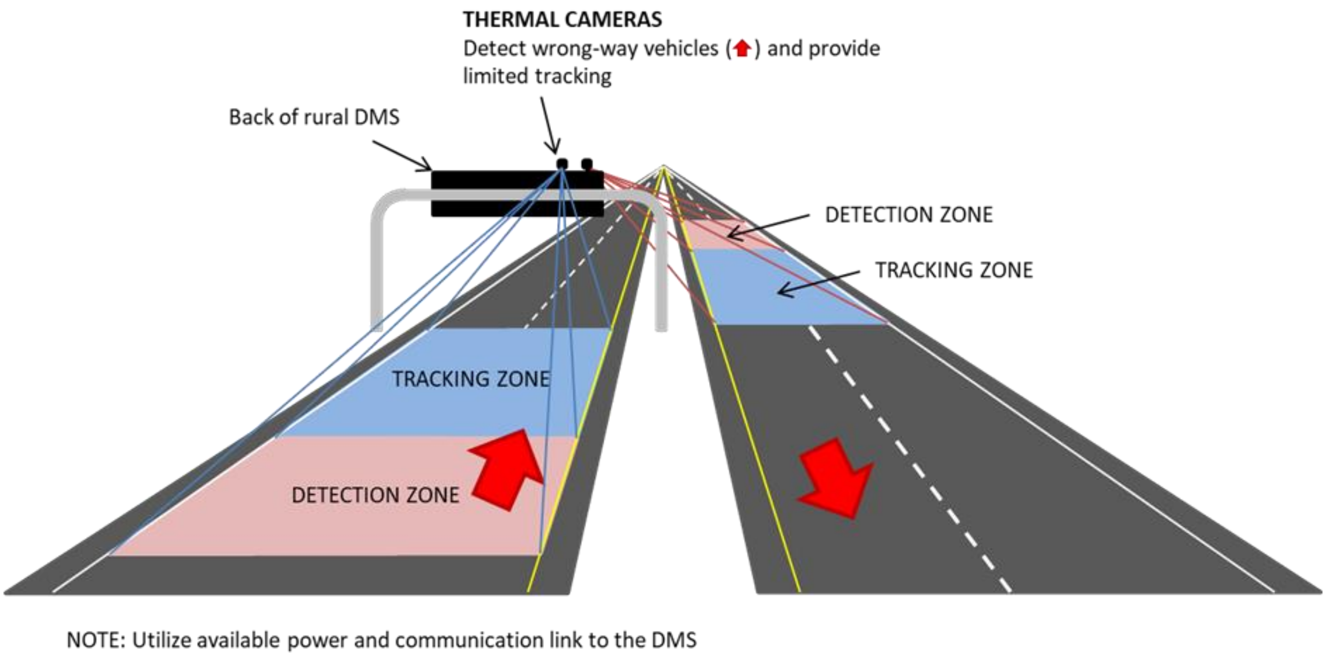


Figure 19. Conceptual Layout of Wrong-Way Detection System Deployment on DMS on a Rural Highway

As appropriate, rural locations should be considered for wrong-way detection system deployment if they are near or within a programmed infrastructure project. However, at locations without existing local power and/or communication connections, installation costs will be higher, and deployment in these locations may depend on funding availability. Each location should be evaluated individually to assess available resources and develop cost estimates.

PRIORITY LOCATIONS

As funding becomes available, additional corridors will be prioritized for deployment of wrong-way detection systems, with a focus on the locations with the highest incidence of wrong-way events. Prioritizing future corridors will require close coordination with DPS to identify the locations experiencing the most wrong-way incidents. Locations will be evaluated for signage, striping, and geometric design conditions that could be contributing to the occurrence of wrong-way incidents, as well as the feasibility of deploying a wrong-way concept.

Table 7 shows 2018 wrong-way driving data provided by DPS for locations with 10 or more events. Three types of wrong-way data are included:

1. **Wrong-way driving (WWD) collisions.** These represent the specific locations that wrong-way vehicles came to rest after a disabling collision. This data set does not identify where the wrong-way vehicles entered the freeway system.

2. **DPS contacts.** These represent the locations that DPS officers made contact with wrong-way drivers prior to a collision. In these cases, the errant vehicle was stopped and the driver was apprehended without incident.

3. **911 calls or detection only.** These represent wrong-way events that did not result in a collision and where no contact was made by a DPS officer. Notification was received by a wrong-way detector or through an unverified 911 report.

Table 7 shows a list of locations that experienced 10 or more wrong-way events during 2018. Locations are identified via 6-mile roadway segments; the complete table of 2018 wrong-way events contains 217 roadway segment locations throughout Arizona.

Table 7. Wrong-Way Events by Location During 2018

Freeway	Cross Street	Milepost	Location	WWD Collisions	DPS Contact with WWD	911 Call or Detection	Total
L101	Bethany Home Road	6	Phoenix	0	11	25	36
I-10	Congress Boulevard	258	Tucson	1	4	16	21
L202	24th Street	0	Phoenix	2	3	14	19
SR 51	McDowell Road	0	Phoenix	1	3	15	19
I-10	7th Avenue	144	Phoenix	1	1	16	18
I-10	Ruthrauff Road	252	Tucson	2	3	11	16
L101	Thunderbird Road	12	Phoenix	1	1	12	14
I-10	Jimmy Kerr Boulevard	198	Casa Grande	0	3	10	13
I-8	CA Border/Giss Parkway	0	Yuma	0	2	11	13
I-8	Avenue 11E	12	Yuma	0	4	9	13
L202	Alma School Road	48	Phoenix	2	3	8	13
I-10	107th Avenue	132	Phoenix	1	2	9	12
I-40	U.S. 93	66	Kingman	1	3	7	11
I-19	Duval Mine Road	42	Sahuarita	1	2	7	10
L101	67th Avenue	18	Phoenix	0	2	8	10
L101	Thomas Road	48	Phoenix	1	1	8	10

Based on these data, five corridors were identified as initial priority locations for deploying wrong-way detection. These locations are:

Phoenix area

- Loop 101 (Agua Fria/Pima), I-10 to Loop 202
- Loop 202 (Red Mountain), SR 51 to I-10
- SR 51 (Piestewa), I-10 to Loop 101
- I-10 (Papago), I-17 to SR 51

Tucson area

- I-10, Ina Road to Kolb Road

This is a dynamic list of priorities, meant to be adjusted as additional data become available, as future funding becomes available, and as future ADOT projects are programmed and scheduled for design and construction.

CHAPTER 8. CONCLUSIONS

ADOT's I-17 wrong-way detection pilot project has been an effective test of a corridor-level system of wrong-way driving countermeasures. As the first wrong-way detection system in the nation to provide real-time tracking of wrong-way drivers, the I-17 pilot served as a proof-of-concept for how traffic operations center dispatchers and law enforcement can work together to swiftly apprehend wrong-way drivers before they cause harm to themselves or others.

Based on analysis of wrong-way driving incidents during the two-year pilot, increased wrong-way vehicle detection and improved notification and coordination between ADOT and DPS troopers have been the most significant benefits of the system. Key results included:

- **Increased detection.** In 2018, the detection system resulted in more than a threefold increase in wrong-way vehicle detections in the pilot area compared with traditional means (911 calls) alone.
- **Improved notification of law enforcement.** The ability to dispatch law enforcement quickly and effectively has been the most significant benefit of the wrong-way detection pilot program. Of the detected incursions during the pilot that were also reported to 911, the detection system reported the incursion much faster—an average of 1 minute, 38 seconds before a 911 call was received.
- **Driver self-correction.** An overwhelming percentage of wrong-way drivers made self-correcting turns on freeway exit ramps and did not enter the I-17 mainline lanes. During the two-year data collection period, 109 wrong-way vehicle incursions were identified within the pilot project's limits. Within those incursions, 88 percent of drivers self-corrected on an exit ramp.

Overall, the system components worked well together and performed as intended. As the technology was initially installed and deployed, ADOT encountered a few issues with individual components, and staff refined the installations to address those issues, capturing their experiences to improve future deployments. Results for individual system components included:

- **Thermal cameras:** The thermal cameras installed at I-17 exit ramps and mainline locations effectively detected wrong-way vehicles. Reviewing video clips from the cameras allowed ADOT TOC dispatchers to analyze wrong-way incursions from the point of entry and begin tracking the vehicles' path onto the freeway system. The thermal cameras initially registered false-positive detections due to wind, pedestrians, truck occlusions, birds, and other factors, but this was addressed through improved mounting locations and adjustments to the camera's detection zones and algorithms.
- **Illuminated wrong-way signs with flashing LED borders:** Placed along each exit ramp, these signs made a positive contribution to the wrong-way detection system. The pilot project documented a significant number of drivers who self-corrected on a freeway exit ramp without

entering I-17, some of whom may have been influenced by the sign-related countermeasures. ADOT plans to include these signs in future deployments where funding allows.

- **Decision support software:** The integration of the DSS has made it possible to rapidly communicate with law enforcement and send automated warning messages to the driving public. This has reduced the time between incursion and apprehension of wrong-way vehicles.

- **Ramp meters:** Although the ramp meter pre-emption functioned as intended, drivers who encountered a red light at a ramp meter during non-peak hours tended not to comply with it, despite an active public awareness program. ADOT has chosen not to include ramp meter pre-emption in its initial plans for future deployments.

- **CCTV cameras:** Providing mainline tracking using thermal and video cameras has been a great benefit to enforcement efforts. Wrong-way vehicles can be tracked within and even outside of the pilot corridor using ADOT's existing CCTV camera network, allowing TOC dispatchers to relay vehicle locations in real-time to DPS troopers.

- **Dynamic message signs:** Driver interaction with DMS warning messages has generally been positive. During the pilot, ADOT adjusted the standard message wording based on feedback from the public, changing the message to read "Wrong Way Driver Ahead – Exit Freeway." This wording gives drivers clear direction on what action to take. Although it is difficult to quantify the impact of the warning messages, because all existing DMS devices in Arizona have the necessary communication links, DMS integration has emerged as a cost-efficient element with the potential to save lives. DMS messaging is recommended as a component of future deployments throughout the state.

- **TOC and DPS partnership:** The co-location of TOC dispatchers and law enforcement within the ADOT TOC has yielded positive results. The TOC dispatchers and state troopers have worked well together, forming a cohesive team with the shared goal of enhancing public safety.

Based on the evaluation of the I-17 pilot project, ADOT will continue to use some of the system's countermeasures, including thermal cameras and illuminated wrong way signs, on other highways in Arizona. Future deployments will focus on early detection of wrong-way vehicle incursions and timely alerts to law enforcement. Two approaches have been developed to guide future deployments of technology on urban freeways and on rural highways. Deployment locations will be prioritized through the evaluation of historical crash data and data on police contacts with wrong-way drivers.

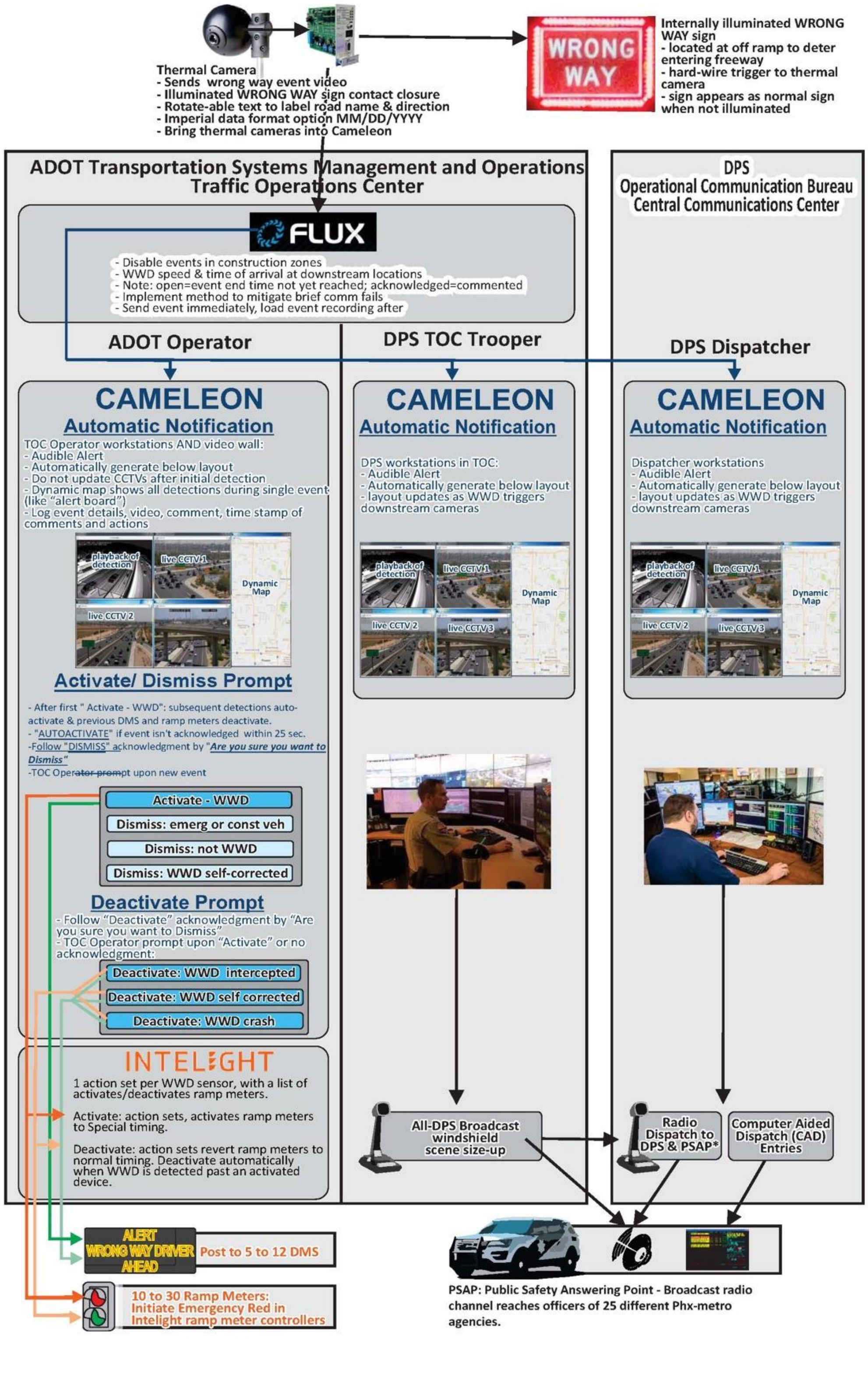
In conclusion, ADOT has accomplished its goal of deploying an effective corridor-level pilot project for wrong-way vehicle detection and warning. The data gathered and lessons learned during this pilot project will provide a valuable knowledge base as ADOT looks to apply cost-effective wrong-way driving countermeasures on urban freeways and rural highways throughout the state.

REFERENCES

Simpson, Sarah A. 2013. *Wrong-Way Vehicle Detection: Proof of Concept.* FHWA-AZ-13-697. Phoenix: Arizona Department of Transportation.

Simpson, Sarah, and Dave Bruggeman. 2015. *Detection and Warning Systems for Wrong-Way Driving.* FHWA-AZ-15-741. Phoenix: Arizona Department of Transportation.

APPENDIX A. CYCLE OF OPERATIONS



Rev. 6/2/2020

Figure A-1. Cycle of Operations for the Wrong-Way Pilot System

APPENDIX B. WRONG-WAY DETECTION EVENT LOG

Table B-1 provides the information logged for each wrong-way incursion. This information is the basis for the data presented within the report. In the table, “WWD” stands for wrong-way driver.

Table B-1. Wrong-Way Event Log

Date	Time	Location	Night or Day	Event Type	Point of Origin	Lane Vehicle Entered	Interchange Type
1/8/2018	12:05:40 AM	I-17 NB exit - Thomas Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
1/17/2018	1:49:00 PM	I-17 NB to SR 101L EB & WB - Mainline	Day	WWD	System Ramp	I-17 NB to SR-101L EB	N/A
1/19/2018	3:21:45 AM	I-17 SB - McDowell Rd - Ramp	Night	WWD - self corrected	Frontage Road	Frontage road	N/A
1/21/2018	5:03:00 AM	I-17 NB exit - Indian School Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Overpass
2/6/2018	1:35:25 AM	I-17 SB exit - Union Hills Dr	Night	WWD - self corrected	Left Turn	Through lane	Diamond Underpass
2/9/2018	9:43:20 PM	I-17 SB - McDowell Rd - Ramp	Night	WWD - self corrected	Frontage Road	Frontage road	N/A
2/10/2018	10:56:15 PM	I-17 SB exit - Bell Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
2/24/2018	11:52:20 PM	I-17 SB exit - Greenway Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
2/25/2018	2:44:50 AM	I-17 NB exit - Greenway Rd	Night	WWD - self corrected	Left Turn	Through lane	Diamond Underpass
3/3/2018	10:18:40 AM	I-17 SB exit - Bell Rd	Day	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
3/4/2018	2:37:25 AM	I-17 NB exit - Dunlap	Night	WWD - self corrected	Right Turn	Through lane	SPUI Overpass
3/9/2018	2:01:20 AM	I-17 NB exit - Peoria Ave	Night	WWD	Through Movement	Through lane	Diamond Underpass
3/23/2018	1:30:10 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Unknown	Through lane	Diamond Overpass
3/23/2018	5:15:56 AM	I-17 SB exit - Thunderbird Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
3/26/2018	12:31:40 AM	I-17 NB exit - Union Hills Dr	Night	WWD - self corrected	Left Turn	Through lane	Diamond Underpass
3/31/2018	3:26:40 AM	I-17 NB exit - Peoria Ave	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
4/17/2018	12:26:31 PM	I-17 SB exit - Glendale Rd	Day	WWD	Left Turn	Through lane	SPUI Overpass
5/9/2018	7:38:30 AM	I-17 SB exit - Thomas Rd	Day	WWD - self corrected	Right Turn	Left turn lane	Diamond Overpass
5/10/2018	12:39:38 AM	I-17 NB exit - Peoria Ave	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
5/11/2018	12:16:33 AM	I-17 SB - Union Hills Dr - Ramp	Night	WWD	Frontage Road	Frontage road	N/A
5/20/2018	6:41:01 AM	I-17 SB exit - Glendale Rd	Day	WWD - self corrected	Unknown	Through lane	SPUI Overpass
5/23/2018	12:38:52 AM	I-17 SB exit - McDowell Rd	Night	WWD	Unknown	Left turn lane	Diamond Overpass
6/18/2018	3:41:43 AM	I-17 NB exit - Glendale Rd	Night	WWD - self corrected	Right Turn	Left turn lane	SPUI Overpass
6/25/2018	6:41:38 AM	I-17 NB exit - Bell Rd	Day	WWD - self corrected	Right Turn	Through lane	Diamond Underpass
7/5/2018	1:11:08 AM	I-17 NB - Union Hills Dr - Mainline	Night	WWD	Mainline	N/A	N/A
7/12/2018	4:22:27 AM	I-17 SB exit - Thomas Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass

Date	Time	Location	Night or Day	Event Type	Point of Origin	Lane Vehicle Entered	Interchange Type
7/14/2018	2:58:15 AM	I-17 SB exit - Thunderbird Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
7/17/2018	5:22:36 AM	I-17 SB exit - Union Hills Dr	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
7/21/2018	3:17:25 AM	I-17 SB exit - Thomas Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
7/21/2018	11:41:38 AM	I-17 NB exit - Bell Rd	Day	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
7/21/2018	1:51:31 PM	I-17 SB exit - Glendale Rd	Day	WWD - self corrected	Right Turn	Left turn lane	SPUI Overpass
7/22/2018	3:49:51 AM	I-17 SB exit - Thunderbird Rd	Night	WWD	Right Turn	Through lane	Diamond Underpass
7/27/2018	10:37:38 PM	I-17 SB exit - Glendale Rd	Night	WWD	Frontage Road	Through lane	SPUI Overpass
8/4/2018	2:41:50 AM	I-17 NB - Cactus Rd - Mainline	Night	WWD	Through Movement	Through lane	N/A
9/14/2018	12:11:44 AM	I-17 NB exit - Yorkshire Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Overpass
9/21/2018	12:30:50 AM	I-17 NB exit - Bethany Home	Night	WWD - self corrected	Unknown	Through lane	SPUI Overpass
9/21/2018	2:26:52 AM	I-17 NB exit - Thunderbird Rd	Night	WWD - self corrected	Right Turn	Through lane	Diamond Underpass
9/28/2018	12:00:00 AM	I-17 NB exit - Peoria Ave	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
10/7/2018	9:37:17 PM	I-17 SB exit - Peoria Ave	Night	WWD	Left Turn	Left turn lane	Diamond Underpass
10/11/2018	7:19:31 PM	I-17 SB exit - Camelback Rd	Night	WWD - self corrected	Right Turn	Left turn lane	SPUI Overpass
10/20/2018	1:48:15 AM	I-17 SB exit - Thomas Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
10/28/2018	9:27:30 AM	I-17 SB exit - Thunderbird Rd	Day	WWD - self corrected	Through Movement	Left turn lane	Diamond Underpass
10/29/2018	2:17:54 AM	I-17 SB exit - Indian School Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
11/1/2018	9:57:01 PM	I-17 SB exit - Thunderbird Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
11/7/2018	11:26:12 PM	I-17 SB exit - Camelback Rd	Night	WWD - self corrected	Left Turn	Left turn lane	SPUI Overpass
11/8/2018	9:59:15 PM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Overpass
11/13/2018	2:24:25 AM	I-17 NB exit - Dunlap	Night	WWD - self corrected	Right Turn	Through lane	SPUI Overpass
11/23/2018	4:23:43 AM	I-17 SB exit - Indian School Rd	Night	WWD	Left Turn	Through lane	Diamond Overpass
12/17/2018	2:09:32 AM	I-17 SB - Thomas Rd - Ramp	Night	WWD	Through Movement	Through lane	N/A
12/21/2018	3:15:59 AM	I-17 SB exit - McDowell Rd	Night	WWD	Right Turn	Through lane	Diamond Overpass
12/21/2018	4:29:12 AM	I-17 SB exit - Dunlap	Night	WWD	Left Turn	Through lane	SPUI Overpass
12/23/2018	9:47:33 PM	I-17 SB exit - Bell Rd	Night	WWD	Right Turn	Left turn lane	Diamond Underpass
12/24/2018	2:18:10 AM	I-17 SB exit - Thomas Rd	Night	WWD	Left Turn	Left turn lane	Diamond Overpass
12/29/2018	3:32:55 AM	I-17 SB exit - Indian School Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
1/7/2019	3:09:12 AM	I-17 NB exit - Camelback Rd	Night	WWD	Left Turn	Left turn lane	SPUI Overpass
1/7/2019	8:59:54 AM	I-17 NB exit - Bell Rd	Day	WWD - self corrected	Right Turn	Right turn lane	Diamond Underpass

Date	Time	Location	Night or Day	Event Type	Point of Origin	Lane Vehicle Entered	Interchange Type
1/12/2019	9:44:41 PM	I-17 SB exit - Dunlap	Night	WWD	Through Movement	Through lane	SPUI Overpass
2/10/2019	3:57:27 AM	I-17 SB exit - Thomas Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
3/12/2019	9:01:21 PM	I-17 SB exit - Bell Rd	Night	WWD	Right Turn	Through lane	Diamond Underpass
3/16/2019	3:26:10 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
3/17/2019	11:42:54 AM	I-17 SB exit - Union Hills Dr	Day	WWD - self corrected	Through Movement	Through lane	Diamond Underpass
3/24/2019	2:02:21 AM	I-17 SB exit - Indian School Rd	Night	WWD - self corrected	Left Turn	Through lane	Diamond Overpass
3/30/2019	4:32:40 AM	I-17 NB exit - Greenway Rd	Night	WWD	Left Turn	Left turn lane	Diamond Underpass
4/20/2019	10:15:21 PM	I-17 SB - Bell Rd - Ramp	Night	WWD - self corrected	Right Turn	Through lane	N/A
4/27/2019	8:43:57 PM	I-17 SB exit - Bell Rd	Night	WWD - self corrected	Right Turn	Through lane	Diamond Underpass
4/28/2019	4:28:35 AM	I-17 SB exit - Bell Rd	Night	WWD	Right Turn	Left turn lane	Diamond Underpass
5/8/2019	9:03:28 PM	I-17 NB exit - McDowell Rd	Night	WWD	Left Turn	Left turn lane	Diamond Overpass
5/11/2019	9:51:17 PM	I-17 SB exit - Bell Rd	Night	WWD	Right Turn	Left turn lane	Diamond Underpass
5/13/2019	2:56:02 AM	I-17 NB exit - Greenway Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
5/18/2019	8:18:20 PM	I-17 NB exit - Yorkshire Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
5/24/2019	10:47:54 PM	I-17 SB exit - Thunderbird Rd	Night	WWD	Right Turn	Through lane	Diamond Underpass
6/16/2019	7:50:24 PM	I-17 NB exit - McDowell Rd	Night	WWD	Through Movement	Left turn lane	Diamond Overpass
6/23/2019	8:01:00 PM	I-17 SB exit - Cactus Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
7/4/2019	12:16:15 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Overpass
7/14/2019	9:39:14 PM	I-17 SB exit - Union Hills Dr	Night	WWD	Through Movement	Left turn lane	Diamond Underpass
7/20/2019	2:26:34 AM	I-17 SB exit - Glendale Rd	Night	WWD - self corrected	Right Turn	Left turn lane	SPUI Overpass
7/27/2019	3:26:52 AM	I-17 SB exit - Glendale Rd	Night	WWD	Through Movement	Through lane	SPUI Overpass
7/28/2019	9:43:21 AM	I-17 SB exit - Northern Ave	Day	WWD	Right Turn	Left turn lane	SPUI Overpass
7/31/2019	12:24:10 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
8/3/2019	1:57:01 AM	I-17 NB - Yorkshire Rd - Mainline	Night	WWD	Through Movement	Through lane	N/A
8/3/2019	4:28:17 AM	I-17 SB exit - Northern Ave	Night	WWD	Right Turn	Left turn lane	SPUI Overpass
8/3/2019	4:28:20 AM	I-17 SB exit - Northern Ave	Night	WWD	Right Turn	Left turn lane	SPUI Overpass
8/7/2019	11:52:57 PM	I-17 SB exit - Greenway Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
8/10/2019	1:03:40 AM	I-17 SB exit - Indian School Rd	Night	WWD	Left Turn	Left turn lane	Diamond Overpass
8/13/2019	1:04:10 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Right Turn	Through lane	Diamond Overpass
8/15/2019	5:41:41 AM	I-17 SB exit - Thomas Rd	Night	WWD	Through Movement	Right turn lane	Diamond Overpass

Date	Time	Location	Night or Day	Event Type	Point of Origin	Lane Vehicle Entered	Interchange Type
9/5/2019	11:17:52 PM	I-17 SB exit - Glendale Rd	Night	WWD - self corrected	Right Turn	Left turn lane	SPUI Overpass
9/10/2019	11:29:55 AM	I-17 SB exit - Camelback Rd	Day	WWD - self corrected	Left Turn	Through lane	SPUI Overpass
9/10/2019	1:38:07 PM	I-17 SB exit - Yorkshire Rd	Day	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
9/11/2019	12:02:06 AM	I-17 SB exit - Glendale Rd	Night	WWD - self corrected	Left Turn	Through lane	SPUI Overpass
9/12/2019	8:24:41 AM	I-17 SB exit - Bell Rd	Day	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass
9/23/2019	5:12:10 AM	I-17 NB exit - Peoria Ave	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Underpass
9/30/2019	9:34:42 PM	I-17 SB - Thomas Rd - Mainline	Night	WWD	Through Movement	Through lane	N/A
10/1/2019	1:28:16 AM	I-17 NB exit - Greenway Rd	Night	WWD - self corrected	Through Movement	Through lane	Diamond Underpass
10/2/2019	2:26:48 AM	I-17 NB - Yorkshire Rd - Mainline	Night	WWD	Through Movement	Through lane	N/A
10/13/2019	3:24:29 PM	I-17 SB exit - McDowell Rd	Day	WWD - self corrected	Right Turn	Through lane	Diamond Overpass
11/9/2019	3:22:08 AM	I-17 NB exit - Indian School Rd	Night	WWD	Left Turn	Left turn lane	Diamond Overpass
11/14/2019	12:11:30 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
11/19/2019	1:26:09 AM	I-17 NB exit - Northern Ave	Night	WWD - self corrected	Left Turn	Through lane	SPUI Overpass
11/23/2019	3:18:26 AM	I-17 SB exit - Thomas Rd	Night	WWD - self corrected	Left Turn	Left turn lane	Diamond Overpass
12/1/2019	2:45:16 AM	I-17 NB exit - McDowell Rd	Night	WWD - self corrected	Right Turn	Through lane	Diamond Overpass
12/1/2019	2:45:19 AM	I-17 NB exit - Glendale Rd	Night	WWD - self corrected	Through Movement	Through lane	SPUI Overpass
12/8/2019	10:07:08 PM	I-17 SB exit - Union Hills Dr	Night	WWD	Through Movement	Left turn lane	Diamond Underpass
12/8/2019	10:07:24 PM	I-17 SB - Union Hills Dr - Ramp	Night	WWD - self corrected	Through Movement	Through lane	N/A
12/14/2019	4:41:20 AM	I-17 NB - Thunderbird Rd - Ramp	Night	WWD	Through Movement	Through lane	N/A
12/18/2019	3:08:20 AM	I-17 SB exit - Indian School Rd	Night	WWD	Left Turn	Left turn lane	Diamond Overpass
12/18/2019	4:01:41 AM	I-17 SB exit - Indian School Rd	Night	WWD - self corrected	Left Turn	Through lane	Diamond Overpass
12/25/2019	1:32:31 AM	I-17 SB exit - McDowell Rd	Night	WWD - self corrected	Right Turn	Through lane	Diamond Overpass
12/31/2019	11:32:58 PM	I-17 NB exit - Cactus Rd	Night	WWD - self corrected	Right Turn	Left turn lane	Diamond Underpass

APPENDIX C. DAY/NIGHT CRITERIA FOR WRONG-WAY EVENTS

In the pilot project event log, wrong-way events were categorized as either daytime or nighttime events, with the time interval defined as civil twilight marking the division between day and night (civil twilight was categorized as night). Figure C-1 shows a 2019 sun graph for Phoenix, which provides a visual representation of daytime and nighttime hours throughout the year, along with sample detail for one day (February 15, 2019). An interactive version of this graph is available at https://www.timeanddate.com/sun/usa/phoenix.

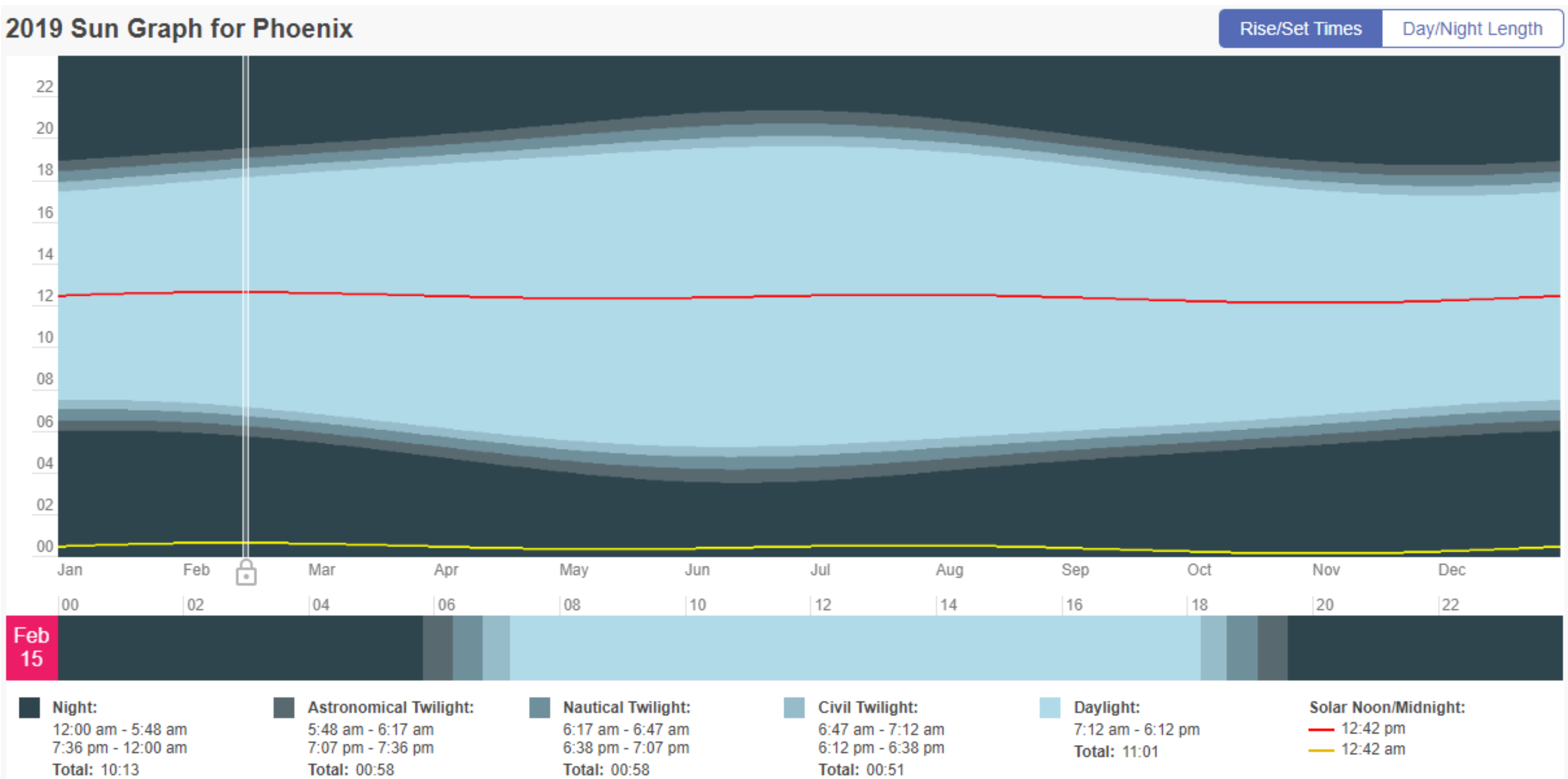


Figure C-1. 2019 Sun Graph for Phoenix
(Source: timeanddate.com)

APPENDIX D. COST ESTIMATES FOR WRONG-WAY DETECTION DESIGN CONCEPTS

Table D-1 details the estimated equipment costs for the four wrong-way detection design concepts described in Chapter 6. These estimates account for the cost of the equipment only, derived from 2019 construction bid items and quotes from equipment suppliers. These costs are ***estimates only***, provided for general planning purposes, and should be used with extreme caution. The estimates do not include the costs associated with design preparation, obtaining clearances, mobilization, construction, and other necessary activities that are unique to each location.

Because every interchange is unique, the estimated costs for Concepts 1 and 2 are provided as per-ramp costs. For full coverage of the entire interchange, multiply the per-ramp cost by the number of ramps.

Table D-1. Estimated Costs for Wrong-Way Detection System Design Concepts

Item		**Concept 1**		**Concept 2**		**Concept 3**		**Concept 4**	
	Estimated Cost	**System Interchange**		**Traffic Interchange**		**At-Grade Intersection**		**Mainline on DMS**	
	Per unit	Qty	Cost per ramp	Qty	Cost per ramp	Qty	Cost per intersection	Qty	Cost per location
Thermal camera	$5,000	1	$5,000	1	$5,000	2	$10,000	2	$10,000
Camera card cage, cards & misc.	$4,000	1	$4,000	1	$4,000	2	$8,000	1	$4,000
Cabinet	$1,000	0	$0	1	$1,000	1	$1,000	0	$0
Pole (30 ft) and foundation for camera	$6,000	1	$6,000	1	$6,000	2	$12,000	0	$0
Illuminated wrong-way sign	$4,000	1	$4,000	1	$4,000	0	$0	0	$0
Pole and foundation for sign	$2,000	1	$2,000	1	$2,000	0	$0	0	$0
Conduit (350 ft)	$10,000	1	$10,000	1	$10,000	2	$20,000	0	$0
Communications	$4,000	1	$4,000	1	$4,000	1	$4,000	1	$4,000
Total			**$35,000**		**$36,000**		**$55,000**		**$18,000**
Full coverage for typical interchange			× 4 ramps		× 2 ramps		× 1		× 1