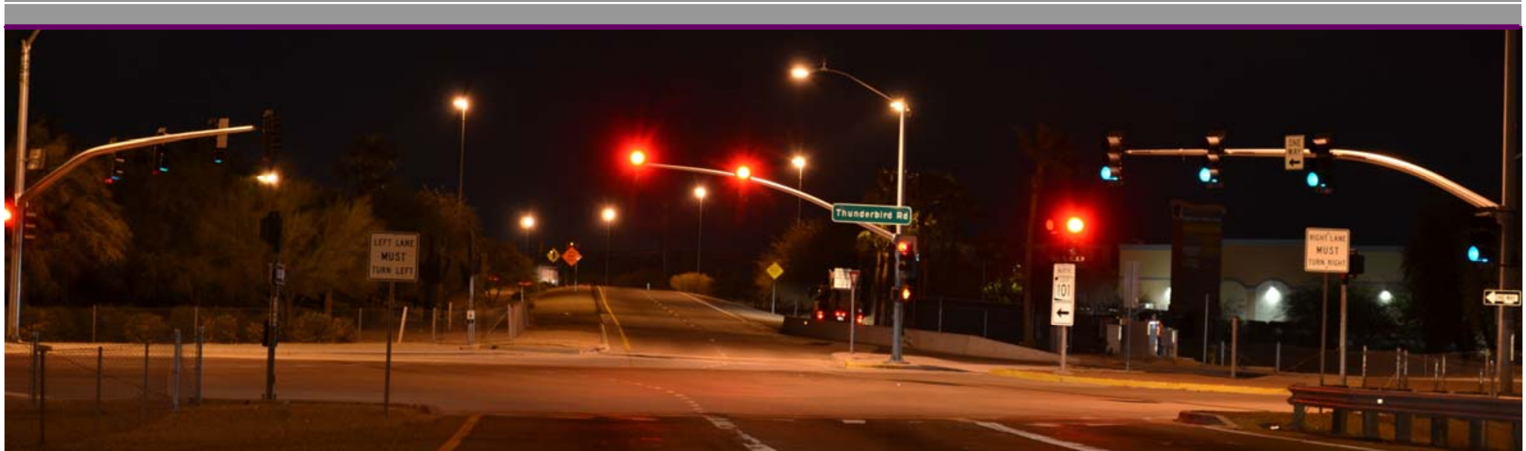
Wrong-way Vehicle Detection: Proof of Concept

Final Report 697
March 2013



Arizona Department of Transportation
Research Center

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March 2013

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16. Abstract

Vehicles that enter freeway exit ramps going the wrong way present one of the most serious traffic hazards on Arizona's urban freeways. Moler cites a study that finds on average 350 people are killed annually in the United States as a result of wrong-way crashes (Moler 2002). This typically occurs due to one or more of these reasons: (1) the driver is impaired; (2) the driver gets distracted or is confused; or (3) the signage and markings are difficult to follow. The primary focus of this research was to determine the viability of existing detector systems to identify entry of wrong-way vehicles onto the highway system using five different technologies: microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors. The devices were installed on freeway exit ramps. Each device was tested in both a controlled environment and in the field under normal traffic operating conditions. During the controlled testing, staged events were conducted to determine whether the devices would accurately detect wrong-way vehicles. The study results of this proof of concept effort verify that wrong-way vehicles can be detected using easily deployable equipment that is currently available on the market. While each system tested over the trial period had missed or false calls, none of the systems were installed under the vendors' ideal conditions.

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ACRONYMS AND ABBREVIATIONS

ADOT	Arizona Department of Transportation
ALISS	Accident Location Identification Surveillance System
ATR	Alliance for Transportation Research
Caltrans	California Department of Transportation
DMS	dynamic message sign
DPS	Arizona Department of Public Safety
FARS	Fatality Analysis Reporting System
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GHz	gigahertz
I-10	Interstate 10
I-17	Interstate 17
ITS	Intelligent Transportation Systems
MUTCD	Manual of Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NMDOT	New Mexico Department of Transportation
PDO	property damage only
TAC	technical advisory committee
TOC	Traffic Operations Center
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

Intelligent Transportation System (ITS) field elements have traditionally been used in the role of traffic management. New and inventive ideas however, allow these same technologies to transform and enhance safety on some of our national highway systems. This project explores the safety enhancements that potentially could be used statewide by innovatively improving the current ability of the Arizona Department of Transportation (ADOT) to detect wrong-way drivers and reduce wrong-way crashes on the Arizona state highway system.

Using ITS technologies, the wrong-way detection system will detect and notify a driver of a wrong-way entry onto the highway system via lighted signs or sounds. Simultaneously, a call will alert the ADOT Traffic Operations Center (TOC) and the Arizona Department of Public Safety (DPS), allowing quicker response time to an errant driver. Eventually, using either sophisticated algorithms or human input, dynamic message signs (DMS) could display pertinent information that will notify oncoming traffic of the errant driver.

The wrong-way detection system is not expected to eliminate all wrong-way crashes. Notifying errant drivers of potentially fatal mistakes via visual or audible warnings may prompt drivers into corrective action. Should a driver continue onto the highway in the wrong direction, this system alerts authorities to the wrong-way driver and provides additional lead time to respond to an impending crash or incident. Additionally, the wrong-way vehicle can be observed through video monitoring at the entry point and along the mainline, allowing dispatchers to accurately share real time information with officers in the field. Furthermore, when used appropriately, DMS could effectively notify travelers of the wrong-way vehicle, allowing them the opportunity to move out of its path. Notifications to right-way mainline drivers of an oncoming vehicle pose their own potential concerns, however. Therefore, an in-depth review of this concept would require future research and collaboration with both ADOT and DPS managers and directors.

RESEARCH PURPOSE

The primary focus of this initial research is to determine the viability of existing detector systems to identify entry of wrong-way vehicles onto the highway system. This exploratory proof of concept uses available off-the-shelf vehicle detector equipment and applies complex data-processing algorithms to the output files to instantly detect a vehicle traversing in the wrong direction. Secondary focuses include: evaluating the capabilities of varying technologies, determining the effectiveness of the wrong-way detection system in real-world environments, and providing insight into the operational feasibility of wrong-way detection. Five different detection technologies were evaluated: microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors.

STUDY EFFORT

The Federal Highway Administration (FHWA), ADOT, and DPS created a wrong-way detection technical advisory committee (TAC). The TAC was instrumental in selecting detector vendors, guiding the evaluation criteria, overseeing testing procedure processes, and offering direction and feedback throughout the research effort.

DPS identified locations with a history of wrong-way entries, based on the volume of calls to the dispatch center regarding wrong-way drivers at specific locations. The locations also had to meet the following criteria: ease of equipment installation, available power supplies, and probabilities of wrong-way occurrences. These locations were given first priority for proof-of-concept field testing efforts. Ultimately, after careful consideration by both ADOT and DPS, the following six off-ramp locations — along Interstate 17 (I-17), Interstate 10 (I-10), and Loop 101 — were chosen for this pilot project:

- I-17 northbound off-ramp at Carefree Highway
- I-10 southbound off-ramp at Queen Creek Road
- I-10 northbound off-ramp at Ray Road
- I-10 northbound off-ramp at Wild Horse Pass
- Loop 101 northbound off-ramp at Thunderbird Road
- Loop 101 southbound off-ramp at Peoria Avenue

This operational research evaluation included a one-week field testing period and a controlled testing evaluation. Data from the field testing included primarily false calls, as missed calls were impossible to identify from the information gathered during the normal ramp operation period. The controlled testing procedure involved temporarily closing each ramp while a test vehicle simulated wrong-way incidents. Data from the controlled test was evaluated primarily on the basis of missed calls to the indication strobe at the end of the ramp. Additional measures included missed email notifications to the ADOT TOC.

It is important to note that the vendors volunteered their time and equipment for this project. Additionally, each vendor had its own specific intentions and performance measures. Some were steadfast about a low-cost solution as their measure of success, while others envisioned their systems to have dual functionality. Therefore, it is impossible to compare equipment and technology based on this research evaluation. This research effort summarizes equipment used, testing procedures and results based on the available supplies provided by the vendors, and existing infrastructure used to support the equipment. Therefore, ideal conditions and testing applications were not obtainable due to the limited budget and short-term scope of this project. The primary intent of this research was to push the limits of the typical vehicle detection applications and confidently reach a conclusion that detection systems installed for this application reliably detect wrong-way drivers.

CONCLUSIONS AND RECOMMENDATIONS

The study results of this proof-of-concept effort verify that wrong-way vehicles can be detected using non-intrusive, easily deployable equipment that is currently available on the market. While each system tested over the trial period had missed and false calls, none of the systems were installed under the vendor's ideal conditions. The recommended steps in this wrong-way detection research effort are to:

- Develop wrong-way detector specifications that ideally utilize detection equipment.
- Consider redundancy in the detector design.

- Prepare guidelines for wrong-way detectors that take into account their most applicable uses as well as their limitations. These limitations include, but are not restricted to: cones of detection, vehicle detection speeds, and placement of detectors.
- Research warning notification devices that have the highest success rates for righting errant drivers prior to freeway entry.
- Research the possibilities of integrating wrong-way detection with notification systems onto the mainline freeway system, such as dynamic message signs.
- Address maintenance issues and long term maintenance of the system.
- Consider training required on system operations.
- Research impacts due to weather (heat, dust, snow, glare).
- Address installation requirements and technical support of the system.
- Research and develop training guides for police on response and integration into enforcement efforts.

1.0 INTRODUCTION

Since the construction of the first highway system in the 1950s, entering the highway in the wrong direction has been a persistent traffic safety problem (Cooner, Cothron and Ranft 2004). Drivers making wrong-way entries onto the freeway system pose serious safety risks both to other motorists and to themselves. According to the National Traffic Safety Administration's Fatality Analysis Reporting System (FARS) on national average, there are 350 annual fatalities as a result of wrong-way crashes (Moler 2002). This figure includes fatalities on divided highways as well as those on freeway ramps. Arizona crash history shows that, on average, 11 people statewide are killed in wrong-way crashes annually. Typically, wrong-way drivers enter the highway system for one or more of the following reasons: the driver is impaired, the driver is distracted or confused, or the signage and pavement markings are difficult to follow. Despite decades of pavement delineation and innovative signing efforts to notify drivers of wrong-way entry from freeway off-ramps, wrong-way crashes continue to occur.

1.1 PROJECT NEED

FHWA is committed to reducing highway fatalities. In 2010, 32,885 people died in motor vehicle traffic crashes in the United States, the lowest number of deaths since 1949 (Federal Highway Administration 2012). Additionally, the number of people injured in motor vehicle crashes in 2010 declined for an 11^{th} straight year. Arizona has experienced a similar trend in crash reduction. Table 1 presents the total number of crashes on the Arizona highway system as well as injury, fatal, and property-damage-only crashes. To continue the progress of reducing crash rates, new technologies must be deployed in a systematic approach to improve the safety performance of the roadways.

Table 1. Arizona Crash Statistics

YEAR	INJURY	FATAL	PDO	TOTAL	% FATALS
2004	46,674	990	90,883	138,547	0.71%
2005	45,361	1038	92,866	139,265	0.75%
2006	44,458	1121	94,618	140,197	0.80%
2007	43,304	952	96,115	140,371	0.68%
2008	37,180	842	81,566	119,588	0.70%
2009	33,380	709	72,678	106,767	0.66%

Source: AZ Crash Facts, ADOT

Wrong-way crashes are a problem in Arizona as well as nationwide. According to the Texas Transportation Institute (TTI), while relatively infrequent, wrong-way collisions are more likely to produce serious injuries and fatalities when compared to other types of crashes (Cooner et. al 2004). Two recent wrong-way collisions, as reported in the online news site azcentral.com, resulted in fatal injuries, highlighting the hazards of errant drivers (Ringle and Strande 2012; Woodfill 2010). In 2009 alone, the National Highway Traffic Safety Administration (NHTSA) reported 1,772 national fatalities due to wrong-way collisions; 23 of these occurred in Arizona

(National Highway Traffic Safety Administration (NHTSA) 2010). Even as the overall fatal crash rate is declining, wrong-way collisions are becoming more common.

United Civil Group staff reviewed crash data queried from the Accident Location Identification Surveillance System (ALISS) database on freeways from 2004 through 2009. This investigation highlighted the frequency of wrong-way crashes in Arizona, and these crashes are presented in Table 2. Collisions that were considered for review included those on controlled-access freeways where the officer on the scene noted that the driver traveled in the opposing lane of traffic. These statistics alone show that 38 percent of all crashes caused by wrong-way drivers result in at least one fatality. Individual police reports were not collected or reviewed for this preliminary crash analysis effort.

Table 2. Wrong-Way Crashes in Arizona

YEAR	INJURY	FATAL	PDO	TOTAL
2004	13	13	5	31
2005	19	8	5	32
2006	16	9	0	25
2007	10	13	2	25
2008	9	9	1	19
2009	16	16	0	32
Average	14	11	2	27

Source: ALISS 2010

The percent of fatal wrong-way crashes versus total fatal crashes in Arizona was calculated to determine the trend in wrong-way crashes as shown in Table 3. Based on this simple comparison, wrong-way crashes appear to be increasing, as a percentage of total fatal crashes, even though the total fatal crashes in Arizona have decreased from 2006 to 2009.

Table 3. Wrong-Way Crash Percentages

YEAR	FATAL FROM WRONG-WAY COLLISION	TOTAL FATAL	PERCENT WRONG-WAY
2004	13	990	1.3%
2005	8	1038	0.8%
2006	9	1121	0.8%
2007	13	952	1.4%
2008	9	842	1.1%
2009	16	709	2.3%

As a result of the increase in percentage of fatalities due to wrong-way crashes, the facts that wrong-way crashes often result in death and that these types of collisions are highly publicized, ADOT suggested investigating non-intrusive, readily deployable technologies that can detect vehicles entering the highway from the wrong direction.

1.2 THE WRONG-WAY DETECTION SYSTEM

The concept of the wrong-way system is to detect a wrong-way vehicle immediately upon entering an off-ramp. The detection device then sends a signal to an illuminated sign, providing a message to the driver at the earliest decision point possible, clearly informing the motorist of the mistake. A signal is also transmitted to alert the TOC and DPS personnel of the errant driver. TOC operators can then view nearby cameras to either determine that the driver self-corrected the error or dispatch the nearest DPS officer to the location of the wrong-way vehicle. Ultimately, the system could be enhanced to notify oncoming motorists of a wrong-way driver through such communications as dynamic message signs (DMS).

1.3 WRONG-WAY VEHICLE DETECTION PROOF OF CONCEPT

This initial research effort addresses the proof of concept that vehicles can be detected using standard non-intrusive detection devices. By no means does this research effort constitute the design and recommendations for a total system; future research will be necessary to develop the overall wrong-way detection system. For this research, the standards set forth by the TAC for proof of concept that the detection device responds satisfactorily are as follows: the detection device must detect a vehicle traversing the wrong direction down the off-ramp; the detection device must instantaneously activate a strobe light at the end of the ramp; and the detection device must notify the TOC of the incident through email.

1.4 DETECTOR TECHNOLOGIES

Five detector technologies were evaluated as part of this study. The technologies tested included: microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors.

Microwave Sensors – The microwave sensor continually transmits a low-power microwave signal of constantly varying frequency in a fixed fan-shaped beam. The beam "paints" a long elliptical "footprint" on the road surface. Any non-background targets reflect the signal back to the sensor where the targets are detected and their range is measured. By processing the characteristics of the energy reflected from a vehicle within the target area, the detector is able to recognize the presence of a vehicle through the detection of motion.

Doppler Radar – Doppler radar detectors emit focused, high-frequency signals within a specified frequency band in the GHz region. A vehicle moving into or through the detection area reflects the signals back to the detector. From the Doppler shift between the emitted and received frequency, the direction and speed of a vehicle can be determined.

Video Imaging – Video imaging consists of a video camera coupled with video image processing. This technology captures and analyzes video images through sophisticated algorithms and dedicated hardware and software. The software is programmed to recognize wrong-way vehicle movements and trigger the sensors when detected. With video detection, the actual detector videos can be transmitted using available communication technologies.

Thermal Sensors – Thermal video sensors operate similarly to the video imaging sensors. However, they rely on heat instead of light. This system also uses an imaging processor with sophisticated algorithms to detect vehicles and determine the direction of the vehicles. Actual detector video from the thermal sensors can be transmitted using current communication technologies.

Magnetic Sensors – Battery-operated magnetic sensors are embedded in the pavement to detect vehicles. The vehicles are detected by measuring the change in the Earth’s magnetic field caused by the presence of a vehicle near the sensor. When a change in the magnetic field is detected, the sensors send their data via radio to an access point near the field sensors. The vehicles’ signature can be processed for speed, classification, and direction using sophisticated algorithms at the roadside controller.

2.0 LITERATURE REVIEW

Since the late 1960s, theory held that off-ramp sensors can detect wrong-way drivers. The California Department of Transportation (Caltrans) began monitoring ramp movements in 1967 using a Kodak Instamatic camera triggered by two tubes stretched across the roadway. The tubes detected wrong-way drivers by their sequence of air pulses. Right-way drivers crossing the tubes with the correct sequence were ignored. Wrong-way drivers triggered the camera, which captured an image of the roadway along with the wrong-way vehicle (Rinde 1978). By the mid-1970s Caltrans refined its system and incorporated 150 wrong-way detector systems for a 30-day evaluation period. These systems were used to monitor each of the approximately 4,000 off-ramps in the state. Caltrans determined that approximately 250 of the off-ramps monitored had a high number of wrong-way occurrences: five or more entries per month (Weaver 1971). With this information, Caltrans upgraded the ramp signing on the California freeway system. These signing improvements positively affected wrong-way occurrences and reduced wrong-way driver entrances onto the freeway system by approximately 90 percent (Parsonson and Marks 1979).

In the mid-1970s, the Georgia Department of Transportation (GDT) purchased 18 wrong-way detection cameras from Caltrans for the purpose of studying their freeway off-ramps. Georgia's strategy was a bit different than that of California. They monitored 44 ramps and focused on wrong-way drivers based on the type of exit ramp; e.g., diamond, diagonal, partial clover, and cloverleaf (Parsonson and Marks 1979). Georgia tested each location for a 30-day period and found that, at certain locations, drivers entered the freeway from the off-ramp approximately 14 times per month. Georgia then modified the locations of high wrong-way entrances with improved signing and ultimately reduced their wrong-way entries (Parsonson and Marks 1979).

GDT and Caltrans used temporary devices to first detect and quantify wrong-way drivers. Currently, more permanent installations are being researched and installed on a small scale. Based on an internet search, some of the research efforts and permanent wrong-way detection device installations include: the states of California, New Mexico, Washington, Florida, and Texas; the Transportation Institute (TTI); and the Harris County Toll Road Authority.

In 2004, TTI researchers discovered that Caltrans adopted in-pavement warning lights as a wrong-way driving countermeasure on exit ramps that were susceptible to wrong-way collisions. Caltrans currently utilizes an inductive loop detector that activates a series of warning lights embedded in the pavement to alert a vehicle when it enters an off-ramp or other restricted roadway (Cooner, Cothron and Ranft 2004). Data could not be found regarding before and after studies to note the success of the pavement lights.

The New Mexico Department of Transportation (NMDOT) adopted a wrong-way detection program in 1992, when a fatal wrong-way entry collision took the lives of four family members. NMDOT, in cooperation with the Alliance for Transportation Research (ATR) and New Mexico State University, developed a prototype directional traffic sensor system that has notified drivers of their wrong-way entries since 1998. The system uses loop detectors and standard interstate highway warning signs. When a wrong-way driver is detected, the system illuminates two sets of warning lights for one minute. A red set faces the wrong-way vehicle, warning it of imminent danger. A yellow set faces right-way traffic and warns the traffic flow of a possible off-ramp problem. Video recorders are not used in New Mexico to record the event. This system is in place at specific locations with a known history of frequent wrong-way entry occurrences (Lathrop, Dick and Nolte 2010).

In 2006, New Mexico briefly attempted to alter the power source for the directional traffic sensor system. A solar-power system would allow the installation of these sensors in remote locations. The solar-power system did not perform well enough to remain in use, however, because insufficiently maintained solar panels did not produce enough energy to illuminate the wrong-way signs when activated (Collins 2007).

NMDOT is currently researching additional measures and installation procedures for wrong-way detection devices, as wrong-way crashes account for nearly 7 percent of the interstate deaths in New Mexico. Researchers assessed data between 1990 and 2004 and found that 924 fatal crashes occurred on the New Mexico Interstate System, resulting in 1,197 lost lives. Of those, 79 people died in 49 wrong-way crash incidents (Lathrop, Dick and Nolte 2010).

In 2002, the Washington State Department of Transportation (WSDOT) initiated two wrong-way detection projects to monitor wrong-way driver behaviors, and had a third project pending. The first project consisted of induction loops and a digital video camera at two off-ramp locations to detect and record motorists traveling in the wrong direction. When a wrong-way driver was detected, the video log device entered a time stamp and saved that portion of the video from deletion. Over an eight-month period, the wrong-way detection system recorded 17 wrong-way incidents. Of those, 12 motorists turned around, while five continued forward and disappeared from the camera's view (Moler 2002).

WSDOT's second wrong-way project occurred in a rural area. This project used electromagnetic sensors embedded in the roadway to detect wrong-way drivers. This system performed two functions when a vehicle was detected: (1) two wrong-way signs mounted on both sides of the exit ramp flashed an alternating yellow-red "Wrong Way;" (2) video cameras recorded the incident to assist engineers in determining the cause of the wrong-way incident (Moler 2002). The third adopted the use of video to detect a wrong-way driver. With this system, a signal was transmitted to a message board, which flashed the wrong-way message to notify the driver. It also recorded the incident (Moler 2002).

After several wrong-way accidents on the four-lane divided highway on the three-mile-long Pensacola Bay Bridge, the Florida Department of Transportation (FDOT) installed a wrong-way notification system. The system used loop detectors to detect a vehicle traveling in the wrong direction. It warned oncoming drivers with flashing lights, and sent an alert to the local police station. This wrong-way system was destroyed by a hurricane in 2004. In March 2006, FDOT reinstalled a similar wrong-way system on the bridge. Chad Williams, District 3 ITS Engineer for FDOT, gave a presentation on the new system. This new wrong-way detection system utilizes non-intrusive, low-power, microwave technology to detect a vehicle traveling the wrong way as it approaches the bridge. The wrong-way signs, placed directly over the travel lanes near the bridge entrance, are visibly enhanced by flashing beacons when the wrong-way detector is activated. The system warns the wrong-way driver with flashing lights and wrong-way signs near the bridge entrance. This alerts the driver approximately 1,000 feet before the bridge, allowing approximately 15 seconds of reaction and decision time (Williams 2006).

More recently, in 2010, FDOT has been researching the viability of video for wrong-way detection on expressway off-ramps. They prepared simulated test runs for this study along with a 27-day trial *in situ*. During the trial period, they detected a number of false alarms. The false calls were generally due to movement of vehicles on the shoulder, dark shadows, and the reflection of headlights from the wet pavement. Additionally, during the controlled testing, there were five missed calls that were due primarily to insufficient minimum tracking distances. The study concluded that FDOT should consider performing additional testing based upon updated design recommendations for the equipment (Rose 2010).

The Texas Department of Transportation (TxDOT) and FHWA sponsored a research project conducted by TTI in 2002. This study identified effective wrong-way driving countermeasures. The research focused on gathering information on the causes and consequences of wrong-way movements on the freeways in Texas. TTI then developed guidelines and recommended practices for wrong-way countermeasures. The recommendations included both traditional and innovative methods of signing and pavement marking, e.g., installation of pavement arrows on exits and low-mounted warning signs; geometric modifications such as ramp and road design changes; and intelligent transportation system (ITS) applications through the development of a wrong-way crash monitoring system (Cooner, Cothron and Ranft 2004).

In 2007, after a wrong-way collision resulted in a triple fatality, the Harris County Toll Road Authority in Texas researched and installed a wrong-way detection system on 13.2 miles of the Westpark Toll Way (Transcore 2008). The wrong-way system consisted of radar sensors at 18 off-ramp locations that triggered an alert on a wrong-way detection map within the traffic operations center. An audible alarm notified dispatchers to call the closest police unit to the wrong-way driver. Additionally, a message on the changeable message sign advised motorists of the oncoming driver (ITS International 2010). In a January 2011 news interview, Calvin Harvey of the Harris County Toll Road Authority shared that there have been no fatalities since the new system installation and that 23 drivers have been stopped and turned around after entering the freeway in the wrong direction. Of the 23 drivers, nine were charged with driving under the influence of an impairing substance (Willey 2011). This system affords both officers and right-way drivers crucial reaction time to respond to a wrong-way vehicle.

Currently, the Harris County Wrong Way System is the largest of its kind. The installations of wrong-way detection systems have not been deployed widely as a preventative measure due to the unresolved challenges involved with information processing, system effectiveness, and system maintenance. Continued research regarding human factors in wrong-way driving incidents, as well as public education, must also be a part of the overall vision to create a viable statewide wrong-way detection system.

3.0 IDENTIFICATION OF STUDY SITES

Within the Phoenix metropolitan area, DPS identified 10 interchange locations on Interstate 10 (I-10) and Interstate 17 (I-17) as potential locations for frequent wrong-way driver activity. The initial locations were determined from reviewed dispatch calls of wrong-way drivers on a monthly basis. Captain Burly Copland of the DPS recommended these locations based on the high volume of wrong-way calls per month. The locations he selected had the highest number of calls in the Phoenix metropolitan area, with an average of 20 per month. Wrong Way/Do Not Enter signage was reviewed at each location to confirm that the signs were in accordance with the Manual of Uniform Traffic Control Devices (MUTCD) and thus did not contribute to driver error.

Equipment needs and interchange geometrics were considered next in the selection of the test locations. Based on equipment needs, each location required an easily obtainable power supply near the off-ramp. Additional geometric criteria included overhead sign structures to mount detectors, locations of poles to receivers and detector controllers, and adequate ramp length to perform the controlled testing procedures once the equipment was installed. Due to time and budget constraints, fiber optic communication would not be considered as a site selection factor. Rather, all detector vendors would relay their information back to the TOC through a modem and cellular service.

Finally, the ramps were reviewed for connectivity to arterials, the ease of access onto the off-ramp in the wrong direction, and possible motorist confusion due to the ramp geometry. Of the 10 off-ramps identified by DPS, all but one were standard diamond interchange configurations on which wrong-way entries tend to occur. The I-17 and Carefree Highway interchange consists of a half clover with a diamond off-ramp. Both DPS and ADOT noted this location for frequent driver confusion.

The six ramps ultimately selected for the initial wrong-way detection research effort were:

- I-17 northbound off-ramp at Carefree Highway
- I-10 southbound off-ramp at Queen Creek Road
- I-10 northbound off-ramp at Ray Road
- I-10 northbound off-ramp at Wild Horse Pass
- Loop 101 northbound off-ramp at Thunderbird Road
- Loop 101 southbound off-ramp at Peoria Avenue

4.0 THE DETECTION SYSTEMS

ADOT, DPS, and United Civil Group developed installation parameters for each vendor participating in the wrong-way vehicle detection research. First, the detector system needed to activate a strobe near the existing wrong-way sign on the freeway off-ramp. Next, the wrong-way detector needed to communicate with the TOC, throughout the duration of the testing period, by automatically sending an email notification when the alarm was triggered. Finally, a video log of the detector location, the detector system, and vehicle calls was created. The video recorded an event, allowing researchers to review video logs both after the controlled testing and throughout the normal evaluation period. This aided researchers in determining the accuracy of the detection system. For this test, the video logs were not required to be streamed back to the TOC.

ADOT, in collaboration with the detector vendors, installed six temporary wrong-way detection systems at the selected off-ramps. The vendors were given an opportunity to meet ADOT and United Civil Group staff at their selected site one month prior to the installation date. During these meetings, all were able to discuss details and develop a workable test plan for the device under evaluation. With the assistance of ADOT maintenance staff, each vendor had one day to oversee equipment installation. After installation, the vendors performed preliminary tests of their equipment to confirm that the systems were activated and in proper working order.

Each vendor had variations to the design that they felt would enhance the system, e.g., reduce costs, simplify the installation, or create dual functions. Additionally, there were varying levels of vendor commitment and ability to offer the most comprehensive and ideal systems; each vendor volunteered time and supplied equipment at no cost to ADOT or the research project. It was not possible to obtain ideal conditions or testing applications for this level of research due to the limited budget and short-term scope of the project.

4.1 MICROWAVE DETECTION SYSTEM

Researchers studied the microwave detection system on the northbound off-ramp at the I-10/Wild Horse Pass Boulevard interchange. This system consisted of a single microwave vehicle-motion sensor, satellite communications, two cameras, a data recorder, and the software necessary to run the system. The sensor was installed on the east column of the sign bridge at a vertical height of approximately 20 feet. It pointed up the ramp toward the interchange to detect vehicles as they crossed the stop bar in the wrong direction. Technicians programmed the microwave system for dual detection zones, incorporating newly developed algorithms to minimize false calls. This system was designed with satellite-based technology that sent emails to the TOC when the system detected a wrong-way vehicle. The vendor mounted the cameras on the overhead sign pole near the microwave sensor and placed the data recorder in the system cabinet. The system recorded a video file of approximately five seconds before and five seconds after a detection occurred. A strobe, mounted on the wrong-way sign, illuminated at the detection of a wrong-way vehicle. Figure 1 illustrates the equipment placement in the field for this system.

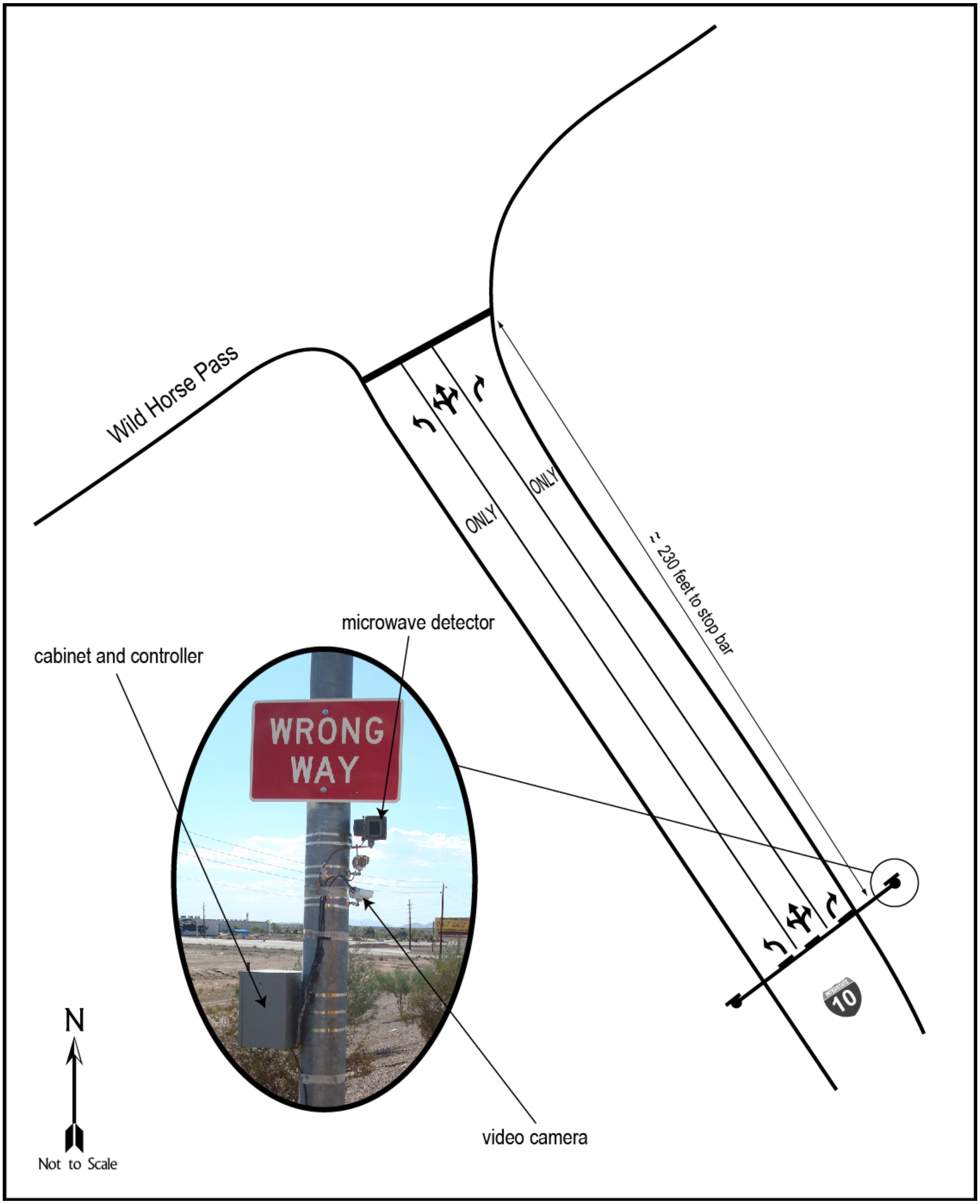

Figure 1. I-10/Wild Horse Pass – Microwave Detection System

Vendor Provided General Guidelines for System Consideration:

- Vendor believed in a low-cost system. Therefore, it purchased all field items, shelf-ready, from the Internet, for a total of approximately $600.
- Vendor believed in an easily installable system. It took ADOT maintenance crews approximately one hour to install all equipment from start to finish.
- System ran from a cabinet with a laptop computer
- Vendor developed its own wrong-way detection software for this project that would capture a 10-second video log, five seconds before and five seconds after detection of a wrong-way vehicle.

4.2 RADAR DETECTION SYSTEM

Two different radar detection systems were installed for testing. The first was located on the northbound off-ramp at the I-10/Ray Road interchange. This detection system consisted of three radar sensors located within a small cabinet on the east sign bridge column, plus the software necessary to run the system.

Technicians placed each sensor above a travel lane and aimed the sensors down the ramp toward the mainline. This allowed for the detection of vehicles traveling away from the sensor. They then individually calibrated each sensor to ensure accurate detection sensitivity and to minimize false detections. The first radar detector system was not equipped with any type of image-recording device or modem to record events or to receive email notifications of calls. Inside the cabinet, technicians mounted a strobe that illuminated when a wrong-way vehicle was detected. Figure 2 and Figure 3 illustrate the equipment placement in the field for these systems.

Vendor Provided General Guidelines for System Consideration:

- Vendor is a detector company and did not have the resources or staff to allocate to a video recording system. Vendor believed the video imaging could be done with a video detection camera to provide redundancy in the system.
- Vendor did not have cellular communication services easily available.
- Vendor installed radar detectors above each lane for complete coverage of the ramp.
- Vendor would prefer equipment to be located closer to the stop bar, because this equipment is triggered by the errant vehicle traveling away from the sensor. However, based on the current field conditions, the overhead sign structure was used toward the top of the ramp.

The second radar detection system was located on the southbound off-ramp at the I-10/ Queen Creek Road interchange. This system was composed of a single radar sensor, a modem, a server, and the software necessary to run the system. The modem and software were located within the system cabinet installed on the west sign bridge column. The single radar sensor was located on top of the sign bridge and pointed up the ramp toward the interchange, where it detected vehicles just as they crossed the stop bar. A modem was used to transmit data between the radar sensor and the server, which was then used to send an email to the TOC. This radar detection system was not equipped with video recording for detected events. A strobe was mounted on the wrong-way sign and illuminated when a wrong-way vehicle was detected.

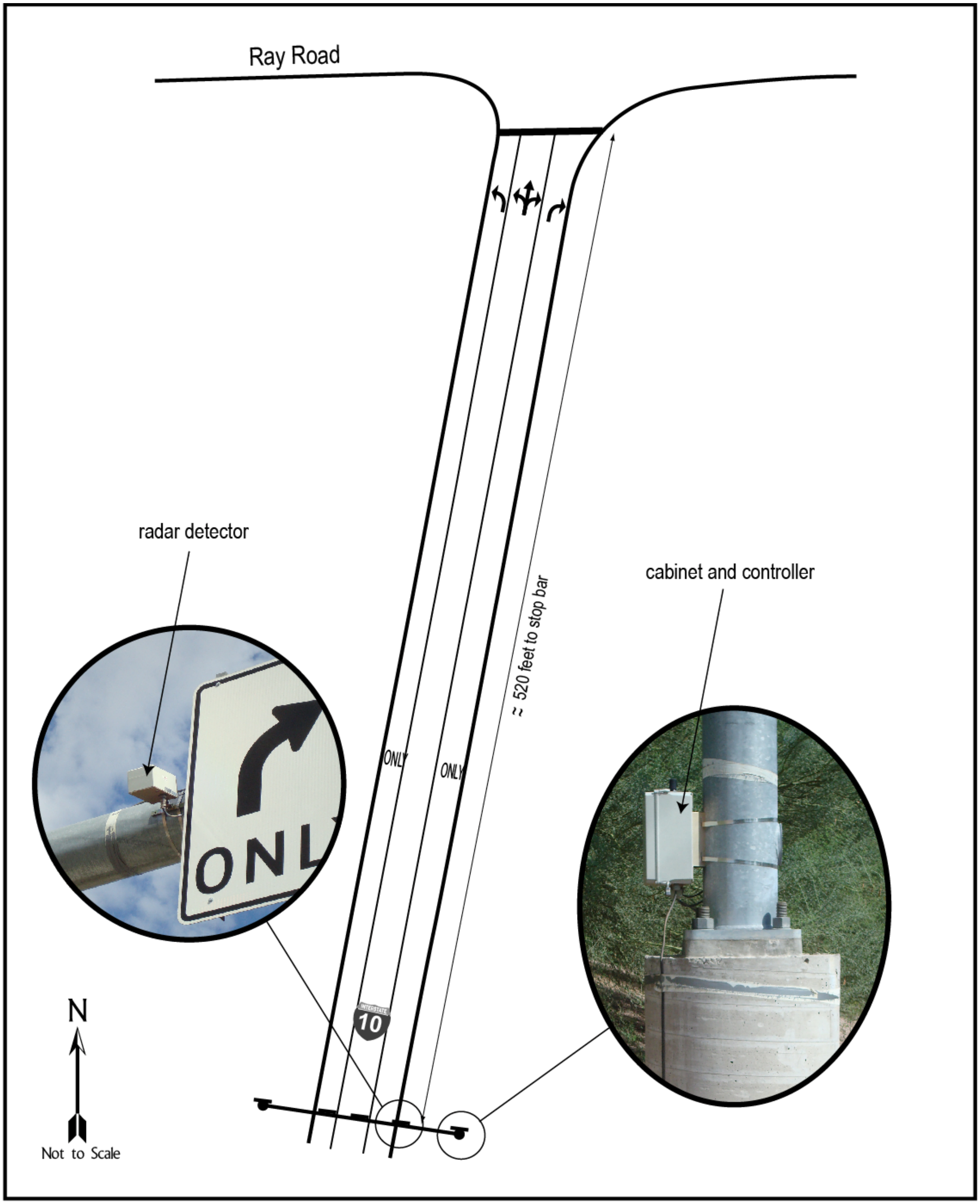

Figure 2. I-10/Ray Road – Radar Detection System I

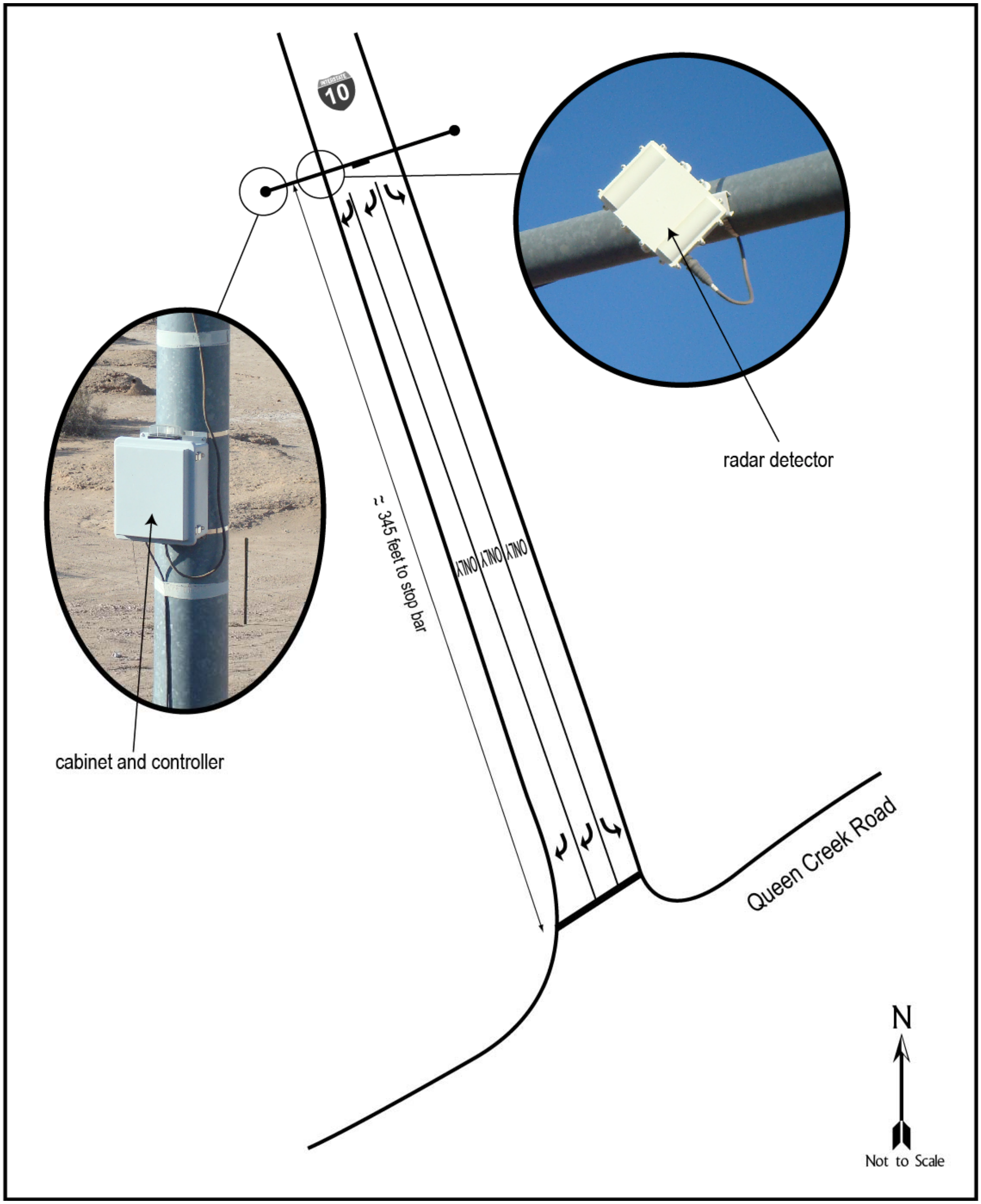

Figure 3. I-10/Queen Creek Road – Radar Detection System II

Vendor Provided General Guidelines for System Consideration:

- Vendor installed one radar detector to prove the system worked. However, vendor recommended two radar detection devices if installed for a permanent system.
- Vendor set system to trigger at the detection of a pedestrian moving down the ramp in the opposite flow of traffic.
- Vendor is a detector company and did not have the resources or staff to allocate to a video-recording system.

4.3 VIDEO DETECTION SYSTEM

The video detection system was located on the northbound off-ramp at the Loop 101/Thunderbird Road interchange. The video detection system consisted of a video camera and imaging processor, a modem, a data recorder, and the software necessary to run the system.

Technicians installed the video camera and imaging processor on the signal arm to the north of the exit ramp. They aimed the southbound-facing camera just south of the crosswalk. The system used dual detection zones along with the appropriate software to alleviate false calls. The system used a modem to communicate with the TOC once detection occurred. This previously installed system consisted of the data recorder and the software necessary to run the system. Both resided within the traffic signal cabinet, where they recorded a video file slightly before and slightly after a detected occurrence. The video detector at this location was already installed and is being used for vehicle detection and traffic control at the interchange. Therefore, only software modifications were made to detect wrong-way movements. Figure 4 illustrates the equipment placement in the field for this system.

Vendor Provided General Guidelines for System Consideration:

- Vendor demonstrated that the equipment performed multiple detection functions by detecting vehicles for the signalized intersection while also detecting wrong-way vehicles.
- Vendor did not install additional equipment for this project. All equipment was already in the field and in operation prior to this research effort.
- Vendor had the ability to use two detection zones to ensure correct identification of an errant vehicle traveling onto the freeway. The first zone signaled the wrong-way driver, and the second notified the TOC and DPS just prior to the wrong-way driver entrance to the freeway system.

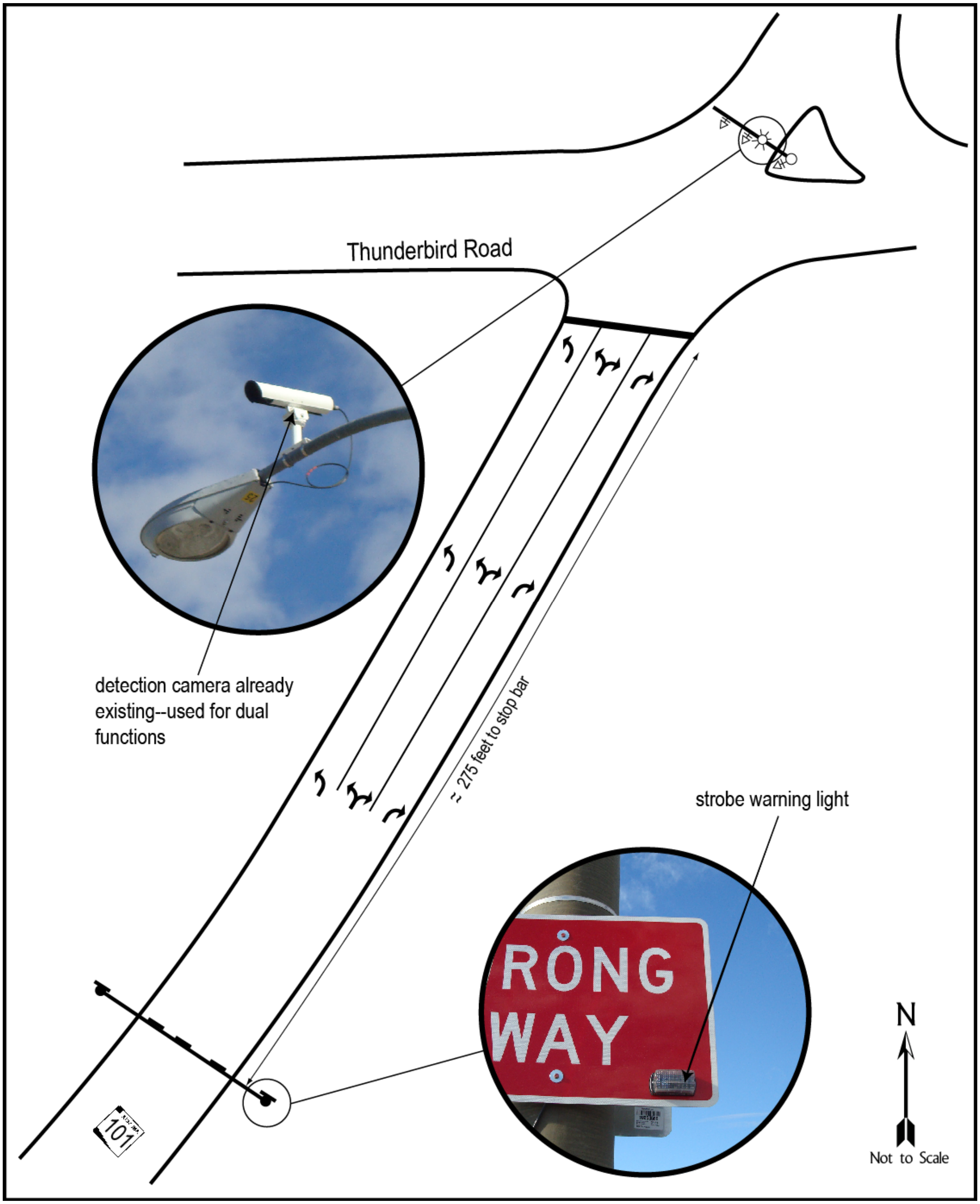

Figure 4. Loop 101/Thunderbird Road – Video Detection System

4.4 THERMAL VIDEO DETECTION SYSTEM

Technicians installed the thermal video-camera detection system on the southbound off-ramp at the Loop 101/ Peoria Avenue interchange. This system consisted of a single, long-range thermal video analytic camera sensor, a modem, a data recorder, and the software necessary to run the system. The camera, located on top of the sign bridge, pointed south toward the interchange. It detected vehicles immediately after they crossed the stop bar. The system cabinet was located on the west sign bridge column. This system used dual detection zones, along with the appropriate software, to minimize false calls. The data recorder, located within the cabinet, recorded a video file approximately three seconds before and three seconds after detection took place. Figure 5 illustrates the equipment placement in the field for this system.

Vendor Provided General Guidelines for System Consideration:

- Vendor demonstrated that the heat camera would be used under low light/no headlights and would still successfully record events.
- Vendor had dual detection zones to ensure that an errant vehicle was traveling onto the freeway. The first notified the wrong-way driver and the second notified TOC and DPS just prior to the wrong-way driver entrance onto the freeway system.

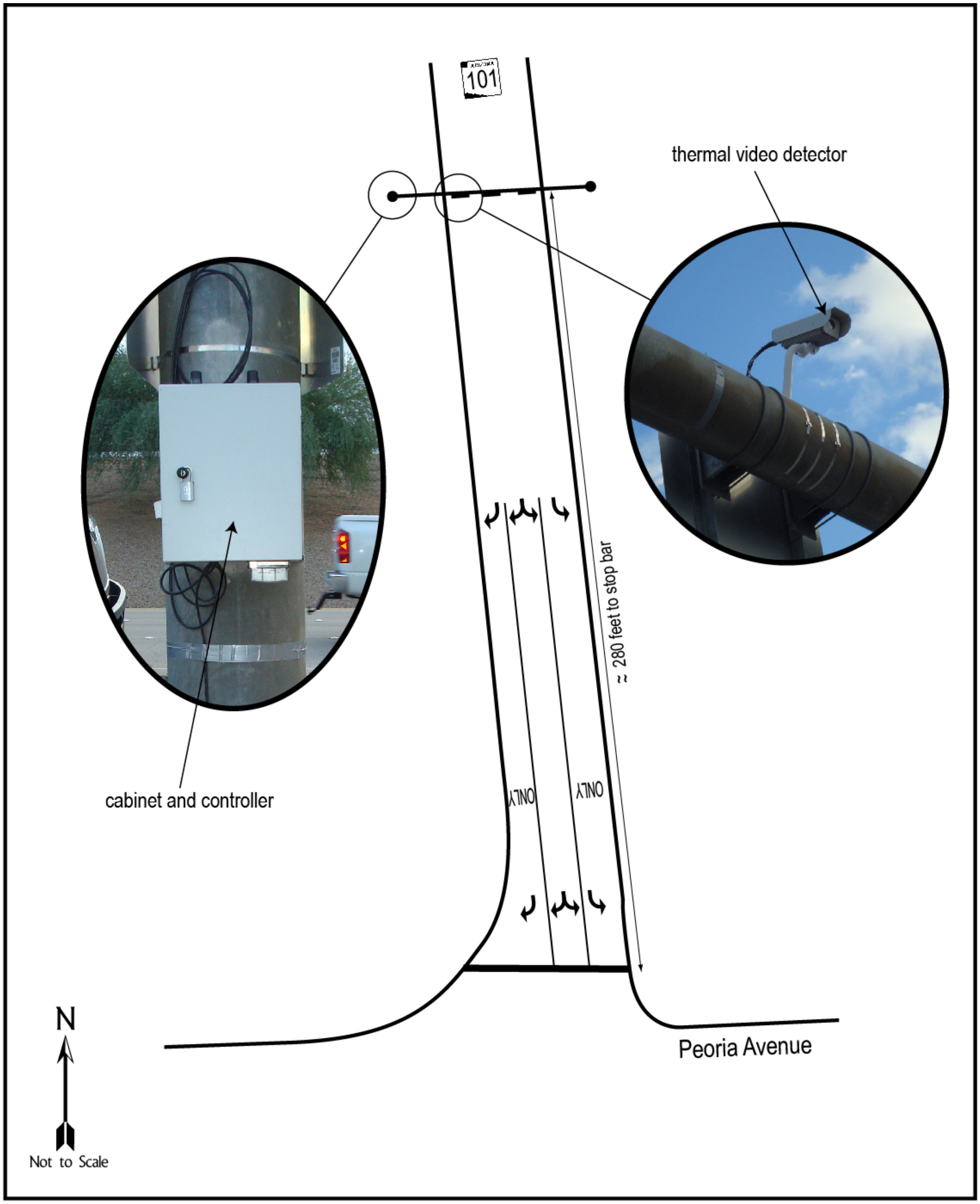

Figure 5. Loop 101/Peoria Avenue – Thermal Video Detection System

4.5 MAGNETIC DETECTION SYSTEM

Technicians installed the magnetic detection system within a small cabinet on the east sign bridge column on the northbound off-ramp (223A – East) at the I-17/Carefree Highway Interchange. The detection system consisted of 27 magneto-resistive sensors, a transmitter, a modem, a video camera, a data recorder, and all of the necessary software to run the system.

The 27 magneto-resistive sensors resided in the pavement approximately 70 feet from the crosswalk. The sensors, spaced approximately four feet apart, created a three feet deep by nine feet wide grid across all four off-ramp lanes. The system used the grid system of sensors along with the appropriate software to minimize false calls. The magnetic system used a radio transmitter to send detection alerts to the transmitter. The transmitter was located approximately 20 feet high on the signal pole on the southeast corner of the interchange. The system used a modem to communicate an occurrence to the TOC. When triggered, a video camera — installed just under the transmitter on the signal pole — recorded a video file of approximately five seconds before and five seconds after the received call. Figure 6 illustrates the equipment placement in the field for this system.

This vendor did not provide general guidelines for consideration with this system. This wrong-way detection system was based on the information and guidelines set forth by ADOT, DPS and United Civil Group.

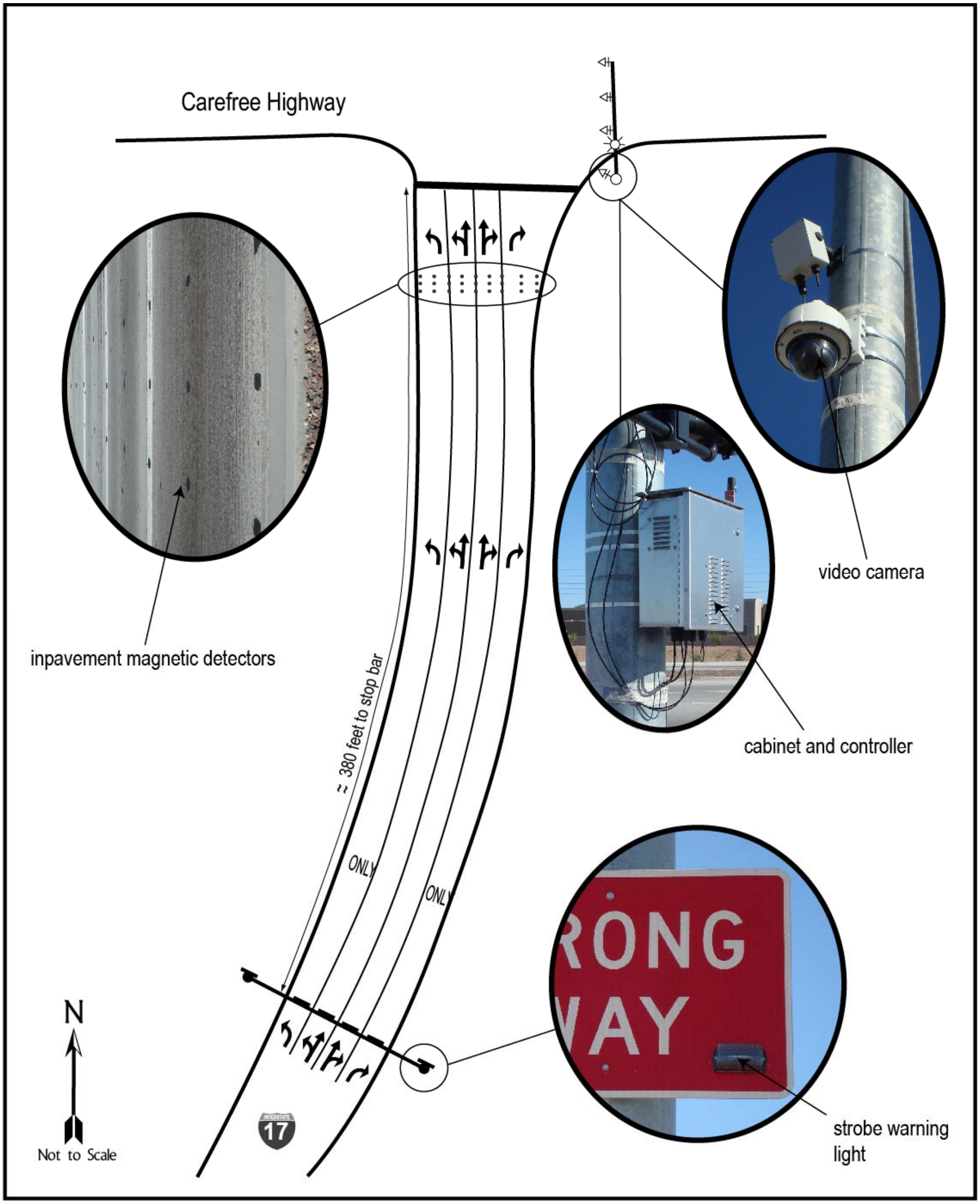

Figure 6. I-17/Carefree Highway – Magnetic Detection System

5.0 EVALUATION CRITERIA AND TESTING PROCEDURES

Upon the complete installation of all systems, United Civil Group staff, assisted by DPS and ADOT, conducted the first controlled testing procedure. Respective vendors were the sole recipients of the initial test results. This allowed each vendor the opportunity to adjust, modify, or enhance equipment and software as needed to obtain the most accurate results. Upon mutual agreement with the vendors, the researchers conducted the controlled testing approximately three months after the initial controlled testing occurred.

Researchers evaluated each detector on a stand-alone basis. They did not compare among detector systems. They developed the evaluation criteria with the assistance and oversight of the technical advisory committee (TAC). To maximize the objectives of this study, they developed measures of effectiveness to analyze the detection systems.

The TAC approved the following measures of effectiveness for this research:

- *Missed Calls* – The detector system needed to be accurate when determining wrong-way vehicles. Missed calls were counted when the system failed to detect a wrong-way vehicle. This measure was only quantified during the controlled testing as there was no way to determine missed calls during normal field conditions, without an extensive and thorough evaluation technique.

- *False Detection* – The detector system needed to be at least 90 percent accurate. A false call was recorded if a positive detection occurred without the presence of a wrong-way vehicle. If the detector system indicated a false detection more than 25 percent of the time over a week-long evaluation period, then the vendor was notified and allowed to recalibrate the respective system.

- *Notification* – Each system was tested for its ability to communicate via email and notify TOC of a wrong-way driver.
- *Additional Qualification Measures* – Evaluation measures included the ease of installation, ability to install the wrong-way device on a system-wide basis, and the cost of equipment.

5.1 FIELD TESTING

The objective of the field testing was to observe the system performance over a week-long period under normal conditions and collect information regarding false calls. Because some of the systems did not have video capabilities, the only indication of false calls was multiple calls within a 15-minute period. While possible, the probability of this occurring is extremely low. With systems that had operational videos, the email call alerts were cross-referenced to the video logs.

5.2 CONTROLLED TESTING

Researchers performed the wrong-way detection trials on the evenings of Monday and Tuesday, July 18 and 19, 2011. Testing started at approximately 10:00 p.m. and consisted of testing three to four detector systems each night.

A complete closure of the test site, including maintenance of traffic and the presence of an off-duty DPS officer, was required to conduct the testing. On-site lane widths, detection zone lengths, and trigger lengths were measured and recorded during the testing. United Civil Group personnel used a passenger car to simulate wrong-way incident scenarios at various speeds and entry points.

There were 14 test runs at each location. The test vehicle entered the ramp from the right and traveled in the lane denoted as 1 on Figure 7, then made runs in lanes 2 and 3. The first few tests involved the test vehicle traveling in the wrong direction in each lane at an approximate speed of 7 miles per hour. The speed was then increased to 20 miles per hour. Next, a series of test runs was conducted by straddling the lane lines and varying the speeds between 7 miles per hour and 20 miles per hour. Finally, the test vehicle swerved down the ramp beginning in the right lane, then beginning in the left lane at approximately 7 miles per hour. If a test failed, that test was run again to confirm the failure.

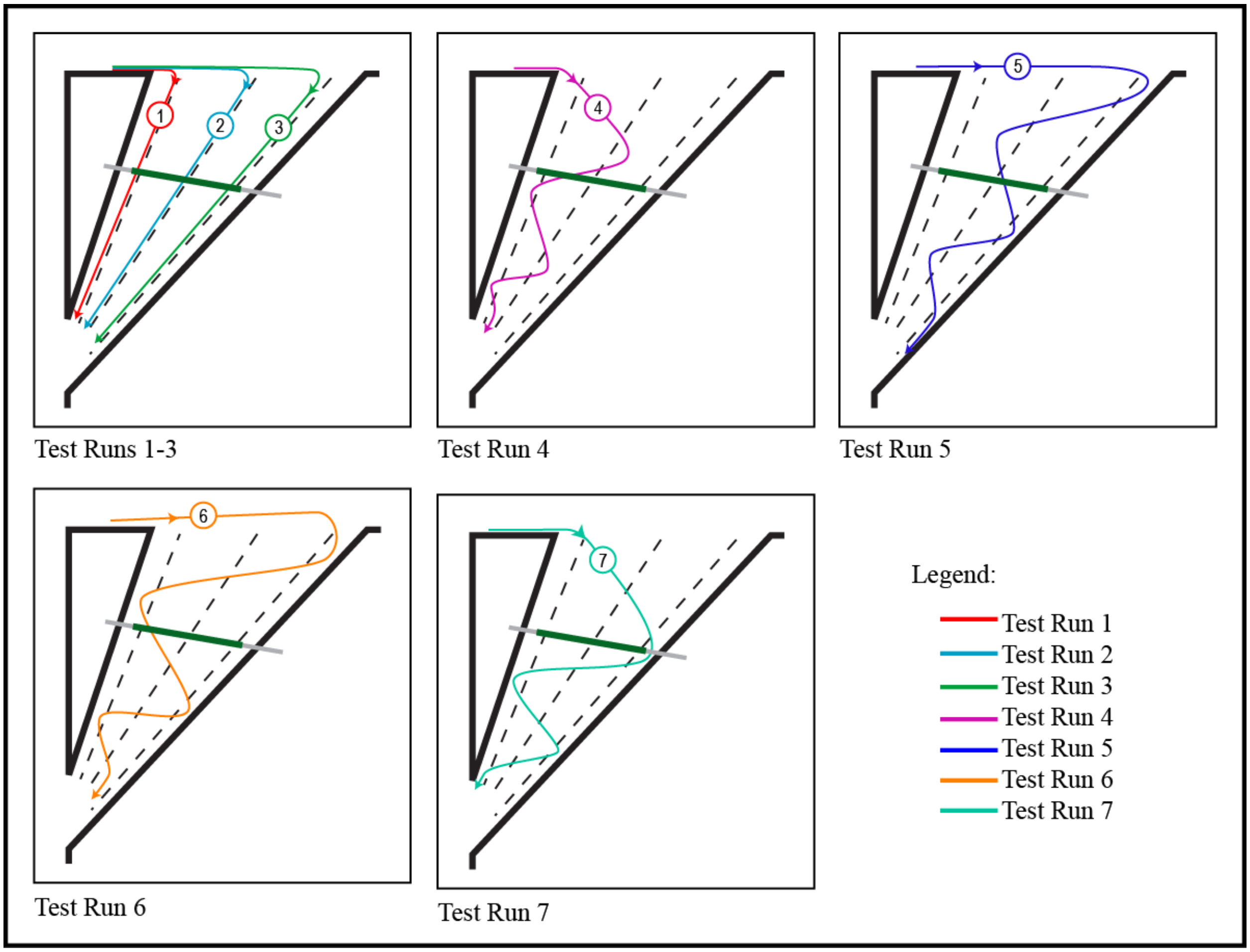

Figure 7. Test Plan

6.0 TECHNOLOGY EVALUATION AND TEST RESULTS

Currently, there are no standards for evaluating wrong-way detection devices. This research was a proof of concept to evaluate varying non-intrusive technologies. The wrong-way devices were installed on existing poles for ease of installation. They were not installed per vendor recommendations due to limited funding and the expedited nature of this project. Therefore, this evaluation does not compare technologies or recommend a final technology as superior to the others. The goal of this evaluation was to determine, with confidence, detector technologies that will detect wrong-way motorists, send email notification to the TOC, and send a signal to a device down the ramp that will alert drivers of their mistake.

6.1 FIELD TESTING

Researchers compiled the field test results for false calls during the week of July 18 through July 24, 2011. They compiled the following information from email notifications and comparisons with available video logs. Table 4 presents the number of recorded false calls for each type of detector technology during the weeklong field testing.

Table 4. False Calls

Detector Technology	False Calls During Week Recording Period
Microwave	3
Radar	no communication with TOC
Video	8
Thermal Sensor	no communication with TOC
Magnetic Sensor	0

6.2 CONTROLLED TESTING

Tables 4 through 9 present the findings for each detector technology. The tables exhibit the following information for each detector type.

Test # – test run number
Description – the off-ramp lane in which the vehicle was traveling
Start Time – the time the test started
Speed – the speed the vehicle was traveling over the detector for the given test run
Strobe Light – Yes/No indicating if the wrong-way vehicle tripped the strobe light
Email – Yes/No indicating if the wrong-way vehicle tripped the email notification
Time – time taken for the vehicle to traverse from the stop bar until the strobe flashed
Distance – distance measured from the stop bar to the location the vehicle would travel when the driver would receive notification from the strobe (dependent upon equipment placement in field)
False Call – Yes/No indicating if a false call was received while performing the controlled test

6.2.1 Microwave Detector System

United Civil Group staff conducted 14 controlled wrong-way test runs on the microwave detector system off-ramp. The system detected the test vehicle during all 14 tests. The system also communicated with TOC for all of the detections. The vendor supplied recorded video logs for each test run to United Civil Group for verification. Table 5 presents controlled test results for the system.

Table 5. Microwave Detector System Test Results

Test #	Description	Start Time	Speed	Strobe Light	Email	Time*	Distance*	False Call
1	Lane 1	10:07 PM	7 mph	Yes	Yes	12 s	178 ft.	No
2	Lane 2	10:10 PM	7 mph	Yes	Yes	12 s	185 ft.	No
3	Lane 3	10:11 PM	7 mph	Yes	Yes	12 s	194 ft.	No
4	Overlap Lane 1-2	10:13 PM	7 mph	Yes	Yes	12 s	182 ft.	No
5	Overlap Lane 2-3	10:14 PM	7 mph	Yes	Yes	12 s	188 ft.	No
6	Swerve-start from Lane 1	10:15 PM	7 mph	Yes	Yes	12 s	175 ft.	No
7	Swerve-start from Lane 3	10:17 PM	7 mph	Yes	Yes	11 s	175 ft.	No
8	Lane 1	10:18 PM	20 mph	Yes	Yes	7 s	178 ft.	No
9	Lane 2	10:19 PM	20 mph	Yes	Yes	7 s	180 ft.	No
10	Lane 3	10:20 PM	20 mph	Yes	Yes	7 s	180 ft.	No
11	Overlap Lane 1-2	10:21 PM	20 mph	Yes	Yes	6 s	179 ft.	No
12	Overlap Lane 2-3	10:23 PM	20 mph	Yes	Yes	7 s	182 ft.	No
13	Swerve-start from Lane 1	10:24 PM	15 mph	Yes	Yes	10 s	179 ft.	No
14	Swerve-start from Lane 3	10:25 PM	15 mph	Yes	Yes	10 s	179 ft.	No

* time and vehicle distance from stop bar to strobe indication

Technology Summary of the Microwave Detector System:

- The detection system detected the wrong-way vehicle successfully during all of the test runs.

- The detection system communicated successfully during all detected test runs.

6.2.2 Radar Detector Systems

United Civil Group staff conducted controlled wrong-way test runs on the two radar detector system off-ramps. The system detected the test vehicle during all 14 tests for the first system and on 14 of the 15 tests for the second system. The results for both systems are presented in Tables 6 and 7, respectively.

Table 6. Radar Detection System Results – System 1

Test #	Description	Start Time	Speed	Strobe Light	Email*	Time	Distance	False Call
1	Lane 1	11:09 PM	7 mph	Yes	N/A	12 s	146 ft.	No
2	Lane 2	11:10 PM	7 mph	Yes	N/A	12 s	172 ft.	No
3	Lane 3	11:12 PM	7 mph	Yes	N/A	13 s	195 ft.	No
4	Overlap Lane 1-2	11:18 PM	7 mph	Yes	N/A	12 s	142 ft.	No
5	Overlap Lane 2-3	11:19 PM	7 mph	Yes	N/A	9 s	131 ft.	No
6	Swerve-start from Lane 1	11:20 PM	7 mph	Yes	N/A	9 s	149 ft.	No
7	Swerve-start from Lane 3	11:21 PM	7 mph	Yes	N/A	8 s	110 ft.	No
8	Lane 1	11:22 PM	20 mph	Yes	N/A	6 s	145 ft.	No
9	Lane 2	11:23 PM	20 mph	Yes	N/A	6 s	150 ft.	No
10	Lane 3	11:23 PM	20 mph	Yes	N/A	6 s	147 ft.	No
11	Overlap Lane 1-2	11:24 PM	20 mph	Yes	N/A	6 s	145 ft.	No
12	Overlap Lane 2-3	11:25 PM	20 mph	Yes	N/A	7 s	153 ft.	No
13	Swerve-start from Lane 1	11:26 PM	15 mph	Yes	N/A	6 s	105 ft.	No
14	Swerve-start from Lane 3	11:27 PM	15 mph	Yes	N/A	6 s	135 ft.	No

* system does not have email notification

Technology Summary of the First Radar Detector System:

- The first radar detection system detected the wrong-way vehicle successfully during all of the test runs.

Table 7. Radar Detection System Results – System 2

Test #	Description	Start Time	Speed	Strobe Light	Email*	Time	Distance	False Call
1	Lane 1	11:54 PM	7 mph	Yes	No	12 s	182 ft.	No
2	Lane 2	12:00 AM	7 mph	Yes	No	2 s	20 ft.	No
3	Lane 3	12:02 AM	7 mph	Yes	No	2 s	25 ft.	No
4	Overlap Lane 1-2	12:04 AM	7 mph	Yes	No	1 s	25 ft.	No
5	Overlap Lane 2-3	12:06 AM	7 mph	Yes	No	9 s	130 ft.	No
6	Swerve-start from Lane 1	12:08 AM	7 mph	Yes	No	1 s	20 ft.	No
7	Swerve-start from Lane 3	12:10 AM	7 mph	Yes	No	1 s	20 ft.	No
8	Lane 1	12:12 AM	20 mph	No	No	-	-	No
9	Lane 2	12:13 AM	20 mph	Yes	No	1 s	20 ft.	No
10	Lane 3	12:15 AM	20 mph	Yes	No	1 s	20 ft.	No
11	Overlap Lane 1-2	12:17 AM	20 mph	Yes	No	1 s	20 ft.	No
12	Overlap Lane 2-3	12:19 AM	20 mph	Yes	No	1 s	20 ft.	No
13	Swerve-start from Lane 1	12:21 AM	15 mph	Yes	No	1 s	20 ft.	No
14	Swerve-start from Lane 3	12:23 AM	15 mph	Yes	No	1 s	20 ft.	No
15	Lane 1	12:25 AM	20 mph	Yes	No	1 s	20 ft.	No

* email notification not working

Technology Summary of the Second Radar Detector System:

- The radar detection system successfully detected the wrong-way vehicle for all but one of the tests. The missed detection was repeated with another test run and the system then successfully detected the test vehicle.

6.2.3 Video Detection System

Researchers tested the video detection system a total of 14 times. They used the test vehicle for all of the trials (11 with lights on, three with lights off). With the test vehicle's headlights turned on, the system detected the test vehicle during seven out of the 11 tests. With the headlights turned off, the system did not detect the test vehicle during any of the three tests at night. The system communicated with the TOC for all of the detections noted. Table 8 presents controlled test results for this system.

Table 8. Video Detection System Results

Test #	Description	Start Time	Speed	Strobe light	Email	Time	Distance	False Call
1	Lane 1	10:18 PM	12 mph	Yes	Yes	8 s	170 ft.	No
2	Lane 2	10:22 PM	7 mph	Yes	Yes	8 s	147 ft.	No
3	Lane 3	10:24 PM	7 mph	Yes	Yes	9 s	145 ft.	No
4	Overlap Lane 1-2	10:24 PM	7 mph	Yes	Yes	11 s	160 ft.	No
5	Overlap Lane 2-3	10:31 PM	7 mph	Yes	Yes	10 s	156 ft.	No
6	Swerve-start from Lane 1	10:34 PM	7 mph	No	-	-	-	No
7	Swerve-start from Lane 3	10:36 PM	7 mph	No	-	-	-	No
8	Lane 1	10:39 PM	7 mph	No	-	-	-	No
9	Lane 2	10:41 PM	7 mph	No	-	-	-	No
10	Lane 3	10:43 PM	7 mph	No	-	-	-	No
11	Swerve-start from Lane 1	10:48 PM	7 mph	No	-	-	-	No
12	Swerve-start from Lane 3	10:50 PM	7 mph	No	-	-	-	No
13	Overlap Lane 1-2	10:53 PM	20 mph	Yes	Yes	4 s	158 ft.	No
14	Overlap Lane 2-3	10:55 PM	20 mph	Yes	Yes	4 s	162 ft.	No

Technology Summary of the Video System:

- The system successfully detected the wrong-way vehicle when the headlights were on and the vehicle was traveling straight down the ramp.
- The system was unable to detect the test vehicle when the headlights were not on at night.
- The missed detections occurred when the test vehicle swerved in all three lanes, with the test vehicle traveling at 7 mph.
- The detection system communicated successfully during all detected test runs.

6.2.4 Thermal Video Detection System

United Civil Group staff conducted 14 runs on the off-ramp with the thermal video detection camera. The system detected the test vehicle during every run. Table 9 presents controlled test results for this system.

Table 9. Thermal Video Detector System Test Results

Test #	Description	Start Time	Speed	Strobe Light	Email	Time	Distance	False Call
1	Lane 1	1:32 AM	7 mph	Yes	N/A	17 s	239 ft.	No
2	Lane 2	1:34 AM	7 mph	Yes	N/A	17 s	243 ft.	No
3	Lane 3	1:36 AM	7 mph	Yes	N/A	17 s	237 ft.	No
4	Overlap Lane 1-2	1:37 AM	7 mph	Yes	N/A	17 s	249 ft.	No
5	Overlap Lane 2-3	1:39 AM	7 mph	Yes	N/A	17 s	239 ft.	No
6	Swerve-start from Lane 1	1:41 AM	7 mph	Yes	N/A	17 s	235 ft.	No
7	Swerve-start from Lane 3	1:43 AM	7 mph	Yes	N/A	17 s	235 ft.	No
8	Lane 1	1:44 AM	20 mph	Yes	N/A	11 s	249 ft.	No
9	Lane 2	1:46 AM	20 mph	Yes	N/A	11 s	265 ft.	No
10	Lane 3	1:47 AM	20 mph	Yes	N/A	9 s	260 ft.	No
11	Overlap Lane 1-2	1:49 AM	20 mph	Yes	N/A	9 s	260 ft.	No
12	Overlap Lane 2-3	1:50 AM	20 mph	Yes	N/A	11 s	260 ft.	No
13	Swerve-start from Lane 1	1:52 AM	15 mph	Yes	N/A	13 s	260 ft.	No
14	Swerve-start from Lane 3	1:54 AM	15 mph	Yes	N/A	13 s	260 ft.	No

Technology Summary of the Thermal Video System:

- The thermal video detection system detected the wrong-way vehicle successfully for all of the test runs.

6.2.5 Magnetic Detection System

Researchers tested the magnetic detection system a total of 20 times. The system sensed the test vehicle in 15 of the 20 runs. They completed several additional trials to replicate the missed detections. During the additional tests the vehicle was not detected. The system communicated with the TOC for all of the detections noted. Table 10 presents controlled test results for this system.

Table 10. Magnetic Detection System Test Results

Test #	Description	Start Time	Speed	Strobe Light	Email	Time	Distance	False Call
1	Lane 1	12:31 AM	7 mph	Yes	Yes	2 s	37 ft.	No
2	Lane 2	12:33 AM	7 mph	Yes	Yes	2 s	43 ft.	No
3	Lane 3	12:35 AM	7 mph	Yes	Yes	2 s	43 ft.	No
4	Lane 4	12:37 AM	7 mph	Yes	Yes	2 s	37 ft.	No
5	Overlap Lane 1-2	12:39 AM	7 mph	Yes	Yes	2 s	38 ft.	No
6	Overlap Lane 2-3	12:41 AM	7 mph	Yes	Yes	2 s	38 ft.	No
7	Overlap Lane 3-4	12:43 AM	7 mph	Yes	Yes	2 s	34 ft.	No
8	Swerve-start from Lane 1	12:45 AM	7 mph	Yes	Yes	2 s	29 ft.	No
9	Swerve-start from Lane 4	12:47 AM	7 mph	No	-	-	-	No
10	Lane 1	12:50 AM	20 mph	Yes	Yes	2 s	36 ft.	No
11	Lane 2	12:52 AM	20 mph	Yes	Yes	2 s	39 ft.	No
12	Lane 3	12:54 AM	20 mph	Yes	Yes	2 s	37 ft.	No
13	Lane 4	12:56 AM	20 mph	Yes	Yes	2 s	40 ft.	No
14	Overlap Lane 1-2	12:58 AM	20 mph	Yes	Yes	3 s	112 ft.	No
15	Overlap Lane 2-3	1:00 AM	20 mph	No	-	-	-	No
16	Overlap Lane 3-4	1:02 AM	20 mph	Yes	Yes	2 s	66 ft.	No
17	Swerve-start from Lane 1	1:04 AM	7 mph	Yes	Yes	2 s	33 ft.	No
18	Swerve-start from Lane 4	1:06 AM	7 mph	No	-	-	-	No
19	Overlap Lane 2-3	1:08 AM	20 mph	No	-	-	-	No
20	Swerve-start from Lane 4	1:10 AM	7 mph	No	-	-	-	No

Technology Summary of the Magnetic Detector System:

- The detection system successfully recognized the wrong-way vehicle when the test vehicle traveled straight down the ramp within the marked lanes.

- The detection system had difficulty detecting the test vehicle in the middle of the ramp when the vehicle overlapped lanes or swerved from one side to another.

- The detection system communicated successfully during all detected test runs.

6.3 TEST RESULTS

The wrong-way detection devices that were developed for this project are presented in the following matrix. Table 11 compares the types of devices to with measures of effectiveness developed by the TAC.

Table 11. Summary of Test Results for the Controlled Test Procedure

Device Type	**Detected Wrong-Way Vehicles**	**Response Time**	**Non-Intrusive**	**Minimal Maintenance**	**Night Operations**	**Communication**	**Ease of Installation**	**No Missed Calls**	**No False Calls**	**Dual Function**	**Low Cost**
Microwave	**x**	**x**	**x**		**x**	**x**	**x**	**x**			**x**
Radar	**x**	**x**	**x**	**x**	**x**		**x**		**N/A**		
Video	**x**	**x**	**x**			**x**	**x**			**x**	
Thermal Sensor	**x**	**x**	**x**		**x**		**x**	**x**	**N/A**		
Magnetic Detection	**x**	**x**		**x**	**x**	**x**			**x**	**x**	

Detected Wrong-way Vehicles – The detector devices detected the test vehicle.

Response Time – The detector sent a signal to the strobe light in time to notify drivers prior to their entry onto the highway system.

Non-Intrusive – The detector must be mounted on a structure or pole, and is not placed within the pavement on the ramp.

Minimal Maintenance – The equipment is durable and does not need to be maintained annually.

Night Operations – The detector can detect vehicles during the night, regardless of headlight illumination.

Communications with TOC – During the controlled testing, the device sent an email to the TOC when the detector was triggered.

Ease of Installation – The device and all corresponding equipment were installed in less than four hours.

No Missed Calls – The detector was triggered for each test run during the controlled procedure.

No False Calls – The detector did not record an event without the presence of a wrong-way vehicle.

Dual Function – Detector can operate in a dual function capacity. Example: daily ramp vehicle counts as well as detection of a wrong-way vehicle.

Low Cost – The wrong-way detection device was purchased for less than $1,500.

7.0 CONCLUSIONS AND RECOMMENDATIONS

ADOT, through its Research Center and Traffic Engineering Division, collaborated with United Civil Group and six national detector vendors to develop a proof of concept in detecting wrong-way vehicles. The aggressive testing schedule and limited funding of this project restricted the design of an "ideal" installation, but provided the opportunity to test the limits of each product and prove that wrong-way vehicle detection is viable under normal traffic operating conditions. Each vendor's ADOT-specified parameters involved:

- Detection of a wrong-way vehicle
- Video recording of the wrong-way event
- Illumination of a strobe at the end of the ramp
- Notification of the TOC

Vendors donated their equipment during the testing procedures and added variations to the parameters to best suit what they believed would enhance the system. Some of the additional parameters included a low-cost system, ease of installation, and minimal or zero maintenance throughout the life of the equipment. These different aspects are pertinent to the design and must be incorporated into the final selection process when determining which type of detection will work best for ADOT.

Some systems were not ideally located in the field due to convenience and simplicity of installation for the testing procedure. Cameras and detector devices were mounted to existing structures to minimize cost while providing reasonable detection coverage. Therefore, these conditions must be taken into consideration when assessing specific system applications. In the final design, equipment from various vendors may be used together at specific locations to create redundancy. Hence, it is imperative that specifications be created for this wrong-way detection device to provide standardization and consistency throughout the system.

This initial proof of concept provides insight into the operational feasibility of non-intrusive wrong-way detection devices; however, further study is required to develop driver notification signing and ultimately notify oncoming traffic of an errant driver traveling in their direction. Cost effectiveness of the system should also be studied to determine the feasibility. The total system cost should include design, construction, operations, and maintenance.

Recommended steps in this wrong-way detection research are to:

- Develop wrong-way detector specifications that ideally utilize detection equipment.
- Consider redundancy in the detector design.
- Prepare guidelines for wrong-way detectors that take into account their most applicable uses as well as their limitations. These limitations include, but are not limited to: cones of detection, vehicle detection speeds, and placement of detectors.
- Research warning notification devices that have the highest success rates for righting errant drivers prior to freeway entry.
- Research the possibilities of integrating wrong-way detection with notification systems, such as dynamic message signs, onto the mainline freeway system.

- Address maintenance issues and long-term maintenance of the system.
- Consider training required on system operations.
- Research impacts due to weather (heat, dust, snow, glare).
- Address installation requirements and technical support of the system.
- Research and develop training guides for police on response and integration into enforcement efforts.

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