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Detection and Warning Systems for Wrong-Way Driving

Arizona Department of Transportation Research Center

ADOT

Detection and Warning Systems for Wrong-Way Driving

SPR-741
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16. Abstract
Arizona's wrong-way crash data were compiled from 2004 through 2014 and show that 245 wrong-way crashes occurred with 91 fatalities over the 11-year period. Approximately 65 percent of the wrong-way drivers in the Arizona crashes were documented as impaired. Arizona's statistics align with the national average showing that approximately 60 percent of wrong-way drivers are impaired. Until impaired driving is significantly lessened, wrong-way driving will continue to occur. However, technology might provide a means to reduce wrong-way crashes by alerting authorities instantly of the errant driver's entry and tracking the errant vehicle's exact location on the highway system, giving law enforcement the knowledge needed to stop the vehicle before a crash occurs. This research developed a conceptual system to detect a wrong-way driver upon entry, inform the errant driver of their mistake, notify the ADOT Traffic Operations Center (TOC) and law enforcement instantly, track the wrong-way vehicle on the highway system, and warn right-way drivers in the vicinity of the oncoming vehicle. The proposed design would integrate readily available technologies with the existing freeway management system (FMS) infrastructure. To integrate these technologies and devices would require the development of customized software for wrong-way detection.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Contents

EXECUTIVE SUMMARY 1

CHAPTER 1. INTRODUCTION 3

CHAPTER 2. LITERATURE REVIEW 5

SUMMARIZING WRONG-WAY CRASHES ON A NATIONAL LEVEL 5

Driving Under the Influence 7

Age 7

Temporal Factors 7

WRONG-WAY COUNTERMEASURES IN THE UNITED STATES 7

National 7

Virginia 9

California 10

Arizona 10

Florida 11

Illinois 11

New Mexico 12

Texas 12

Wisconsin 14

INTERNATIONAL WRONG-WAY COUNTERMEASURES 14

Japan 14

Germany 14

Sweden 14

EMERGING TECHNOLOGY 14

In-Vehicle Applications 15

Roadside Applications 15

CHAPTER 3. ANALYSIS OF WRONG-WAY CRASHES IN ARIZONA 17

METHODOLOGY 17

CHARACTERISTICS OF WRONG-WAY CRASHES IN ARIZONA 19

Temporal Distribution 22

Crash Location 24

Wrong-Way Driver 26

SUMMARY 33
CHAPTER 4. EXAMINATION OF TECHNOLOGIES AND CONCEPTS 35
DETECTION ELEMENT 36
Loop Detectors 37
Radar Detectors 38
Microwave 38
Magnometers 39
Video 39
NOTIFICATION ELEMENT 40
Notification to ADOT Traffic Operations Center 40
Notification to Law Enforcement 41
The Notification Element Candidates for Evaluation 41
DRIVER INFORMATION ELEMENT 43
Warnings to the Wrong-Way Driver 43
Warnings to Right-Way Drivers 45
Emergency Notification Systems 45
CHAPTER 5. ASSESSING AND SELECTING THE SYSTEM ELEMENTS 47
PERFORMANCE MEASURES 47
SCORING 50
CHAPTER 6. PILOT DEPLOYMENT PLAN 55
THE PILOT DEPLOYMENT PLAN 55
DESCRIPTION OF THE PROPOSED SYSTEM 59
Software Modifications 59
Wrong-Way Detection Response 59
LONG TERM 59
CHAPTER 7. MONITORING PLAN 61
SUB-SYSTEM TESTING 61
Detection Element 61
Notification Element 62
Warning Element 63
ONGOING SYSTEM MONITORING 63
CHAPTER 8. CONCLUSIONS 67
REFERENCES 69

List of Figures

Figure 1. US Overall Fatal Crashes vs. Wrong-Way Fatal Crashes (Baratian-Ghorghi, Zhou and Shaw 2014) 6

Figure 2. Mercedes-Benz Sign Assistance System (Daimler 2015) 15

Figure 3. Australia's Water Curtain (Orlave 2013) 16

Figure 4. Flowchart to Confirm Wrong-Way Crashes Using Arizona's Safety Data Mart (SDM) Data 18

Figure 5. Confirmed Wrong-Way Crash Sites in Arizona – 2004 through 2014 19

Figure 6. Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014: Number of Fatal versus Non-Fatal Crashes 21

Figure 7. Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014: Percent of Fatal versus Non-Fatal Crashes 22

Figure 8. Wrong-Way Crashes on Arizona Divided Highways by Time of Day – 2004 through 2014 23

Figure 9. Wrong-Way Crashes on Arizona Divided Highways by Day of the Week – 2004 through 2014 23

Figure 10. Wrong-Way Crashes on Arizona Divided Highways by Month – 2004 through 2014 24

Figure 11. Arizona Wrong-Way Crashes per Mile on Urban Divided Highways – 2004 through 2014 25

Figure 12. Arizona Wrong-Way Crashes per Mile on Rural Divided Highways – 2004 through 2014 26

Figure 13. Impairment of Wrong-Way Drivers in Arizona Crashes on Divided Highways — 2004 through 2014 27

Figure 14. Reported Impairment Levels of Wrong-Way Drivers in Arizona Wrong-Way Crashes on Divided Highways — 2004 through 2014 28

Figure 15. Blood Alcohol Content of Drivers in Arizona Wrong-Way Crashes – 2004 through 2014 29

Figure 16. Ages of Drivers in Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014 31

Figure 17. Ages and Sex of Wrong-Way Drivers in Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014 32

Figure 18. Driver Licenses (by Issuing State) of All Wrong-Way Drivers Involved in Arizona Crashes – 2004 through 2014 33

Figure 19. Suggested Wrong-Way Detection, Notification, and Warning System 56

Figure 20. Suggested Plan for Pilot Deployment 58

List of Tables

Table 1. National Summary of Fatal Wrong-Way Crashes (Baratian-Ghorghi, Zhou and Shaw 2014) 6

Table 2. Summary of Emerging Countermeasures from 10 Case Studies (Pour-Rouholamin, et al. 2015) 9

Table 3. Arizona's General Crash Statistics 2004 through 2014 (Arizona Department of Transportation 2015) 20

Table 4. Percent per Year of Arizona Crashes Involving Alcohol: Total Crashes Compared to Wrong-Way Crashes (Arizona Department of Transportation 2015) 30

Table 5. Percent per Year of Arizona Fatal Crashes Involving Alcohol: Total Crashes Compared to Wrong-Way Crashes (Arizona Department of Transportation 2015) 30

Table 7. Notification Candidates for Evaluation 43

Table 8. Driver Information Candidates for Evaluation 46

Table 9. Performance Measures for the Detection Elements 51

Table 10. Performance Measures for the Notification Element 51

Table 11. Performance Measures for Warning Elements 52

List of Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADEM	Arizona Division of Emergency Management
ADOT	Arizona Department of Transportation
BAC	blood alcohol concentration
Caltrans	California Department of Transportation
CCTV	closed circuit television
DOT	department of transportation
DPS	Arizona Department of Public Safety
DMS	dynamic message sign
FARS	Fatality Analysis Reporting System
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FMS	freeway management system
IDOT	Illinois Department of Transportation
ITS	intelligent transportation system
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Association
NTSB	National Transportation Safety Board
NYSDOT	New York State Department of Transportation
SDM	Safety Data Mart
TOC	traffic operations center
TxDOT	Texas Department of Transportation
TTI	Texas A&M Transportation Institute
WWD	wrong-way driving
VDOT	Virginia Department of Transportation

EXECUTIVE SUMMARY

The Arizona Department of Transportation (ADOT) studied the feasibility of a pilot deployment of a wrong-way detection and warning system with current technology. The study is aimed at researching ways to detect a wrong-way driver and instantly inform them of their mistake. If the driver continues onto the highway, such a system would automatically notify the ADOT Traffic Operations Center (TOC) and Arizona Department of Public Safety (DPS) of the wrong-way entry, track and monitor the errant vehicle on the highway system, and warn oncoming drivers of the wrong-way vehicle.

A total of 91 people died and others were injured in 245 wrong-way crashes in Arizona from 2004 through 2014. On average, the crash data analysis revealed, 25 percent of all wrong-way crashes are fatal compared to 1 percent of crashes overall that occur on divided highways. Impaired drivers are the cause of 65 percent of all wrong-way crashes. The crash analysis also showed that wrong-way crashes occur most often after dark and predominately in the morning hours from 12 a.m. to 2 a.m.

Wrong-way crash locations were analyzed to determine if there are trends in entry point locations and if one highway was more susceptible to wrong-way driving than another. Based on the information provided in the police reports, it was impossible to determine how or where wrong-way drivers entered the highway. Crash locations were sorted by highway to determine wrong-way crash per mile ratios on rural and urban highways. The rate of wrong-way crashes per mile was used as a means to standardize and compare the highways since each highway varies in length. The urban highway with the greatest rate of wrong-way crashes per mile was a 39-mile segment of Interstate 17 (I-17) in metropolitan Phoenix. The rural highway with the greatest rate of wrong-way crashes per mile was approximately 14 miles of divided highway on State Route Alternate 89 (SR 89A) between Cottonwood and Sedona.

A literature review was prepared to identify the magnitude of wrong-way driving on a national level, determine current wrong-way warning system deployments, understand countermeasure practices throughout the nation, and research new emerging technological advances to reduce wrong-way driving. The literature review shows that Arizona is no different than other states with regard to wrong-way crashes. Nationally, approximately 60 percent of wrong-way crashes can be contributed to impaired drivers. This review also shows that countermeasures to minimize wrong-way driving have been developed since the 1960s which include enhanced signing, modified pavement markings, flashing signing, and the implementation of wrong-way detection systems. Not every experimental countermeasure proves to be effective. For example, a Texas engineering analysis showed that permanent spike strips — which have been mentioned by Arizona constituents — would be ineffective for numerous reasons (Texas Department of Transportation 2011).

Currently, wrong-way deployments within the United States consist of detection systems that simultaneously notify the wrong-way driver and traffic management of a wrong-way entry. While some states vary in the signing to notify the wrong-way driver of their mistake, the idea of the system is the same: inform the wrong-way driver of their mistake and notify law enforcement immediately when a wrong-way vehicle is detected. Eventually, technological advances in vehicle-to-vehicle and vehicle-to-infrastructure capabilities may reduce wrong-way driving, but none of these technologies are currently available to deploy.

In order to develop the wrong-way detection and warning system for Arizona, the components of the system were defined as three sub-categories: the detection element, the notification element and the warning element. Existing freeway management system (FMS) devices were incorporated into each element sub-category where feasible to leverage the existing ADOT infrastructure. Performance measures were then developed to assess the strategies and equipment in each element sub-category. A matrix was prepared that documents the scores given for each performance measure. Each device was ranked from one to five (five being the best) based on specified criteria. Because multiple strategies or devices could be used to obtain the same result, the research team recommended that multiple devices be installed in the initial deployment to determine if one application outperformed the others.

Law enforcement officers rely on 911 calls to determine the location of the wrong-way vehicle and then try to intercept and stop the vehicle before a crash occurs. Having an exact location of the wrong-way vehicle would increase the chances of their success. Therefore, tracking a wrong-way vehicle is a key characteristic of this wrong-way detection and warning concept.

The detection element consists of both wrong-way in-system detection (detection on the highway) and detection on the exit ramp. The highest ranked technologies were loop detectors and radar devices. The researchers suggest using loop detectors as the best means to detect a wrong-way vehicle on both exit ramps and the highway. The existing highway loop detectors, which currently collect traffic data, could be modified to detect a wrong-way vehicle. This may entail replacing the existing loop detector cards with ones that will perform both tasks at once. Currently, loop detectors do not exist on exit ramps, so additional detectors would need to be installed to pinpoint a wrong-way entry

The notification element includes notifying the TOC and DPS of the errant vehicle. The existing freeway management system (FMS) uses a fiber network, which could accommodate the wrong-way detection technology. Notification would include audible and visual signals for operators at the TOC. Notification also includes visual monitor screen indications and CCTV cameras with pre-positioned stops depending upon which detector is activated.

The final element includes warning both the wrong-way driver and the right-way driver. To notify the wrong-way driver, LED signing and in-pavement lights ranked highest. Notifying oncoming traffic includes using DMS with automated messages.

Wrong-way detection and warning systems that track a wrong-way vehicle on the highway are not yet deployed anywhere in the nation. If ADOT chooses to conduct a wrong-way pilot deployment, this will be the first of its kind to track, in real time, a wrong-way vehicle so that law enforcement can stop it.

CHAPTER 1. INTRODUCTION

Since the construction of the first interstate highways in the 1950s, wrong-way entries have been a persistent traffic safety problem. A majority of the wrong-way drivers correct their mistake before causing a crash. However, impaired, distracted, or confused drivers that continue onto the highway pose life threatening risks to themselves and oncoming motorists. The National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS) shows, from 2004 to 2011, an approximate average of 350 people died per year in an annual average of 270 fatal wrong-way crashes (American Traffic Safety Services Association 2014).

Wrong-way driving is a difficult problem with no single solution, and researching it present challenges. No national level effort exists to reduce wrong-way crashes, so research addressing wrong-way driving is compiled on a state level. In Arizona, it is difficult to define the magnitude of the problem using historical crash data, because until January 2015, no specific check box on the crash report form denoted a wrong-way driver. Therefore, the data must be queried then reviewed case by case to identify a crash as a result of a wrong-way driver.

Little or no data exists on exact wrong-way entry points, because the initial entry usually has no witnesses since the majority of wrong-way driving incidents occur in the early morning hours. Additionally, it is difficult to locate and track wrong-way drivers once they are on the highway. Arizona Department of Public Safety (DPS) officers must rely on 911 calls to locate and track wrong-way drivers prior to a collision.

Next, ITS elements for wrong-way driver detection are still in the experimental stages throughout the nation. There are no national standards or programs that address wrong-way driver behavior even though individual state departments of transportation have been researching wrong-way countermeasures for years. Since 2000, approximately 10 state departments of transportation (DOTs) have begun developing and deploying wrong-way detection systems on their highways using intelligent transportation system (ITS) technologies. While each state's technology is slightly different, the individual DOT's goal remains the similar: reducing wrong-way crashes through various strategies. As of 2015, the Federal Highway Administration (FHWA), American Association of State Highway and Transportation Officials (AASHTO,) and the Manual on Uniform Traffic Control Devices (MUTCD) have not made recommendations addressing the use of technology in wrong-way countermeasures.

The Arizona Department of Transportation (ADOT) began researching ways to reduce wrong-way crashes in 2010. In 2013, ADOT investigated the potential of detecting wrong-way vehicles using existing roadway detector systems and complex data processing algorithms (Simpson 2013). By 2014, ADOT installed two permanent wrong-way detection stations for continued testing, monitoring, and evaluation. These two systems use radar to detect a wrong-way driver and instantly notify the ADOT Traffic Operations Center (TOC) of the wrong-way entry. ADOT also began enhancing wrong-way signing with larger, lower signs and added innovative pavement markings as another countermeasure to advise drivers of their wrong-way entry. In early 2015, ADOT procured three new wrong-way LED warning systems that give wrong-way drivers a visible real-time indication prior to highway entry. When activated, the wrong-way signs flash with high intensity LEDs. As of 2015, ADOT was in the process of installing these three systems for evaluation (phone conversation, ADOT State Traffic Operations Engineer, June 30, 2015).

Through technology, more may be done to reduce wrong-way crashes by alerting authorities instantly of the errant driver's entry and providing updates of the errant driver's exact location on the highway system. ADOT initiated this research to explore ways of detecting, notifying and tracking a wrong-way driver, and providing timely warnings to the wrong-way driver, to relevant authorities, and to other motorists as an additional mitigation tool for select highway locations. This research effort also aimed to: better understand why wrong-way crashes occur throughout the nation and in Arizona; examine state-of-the-art technology that detects wrong-way vehicles; assess the viability of these detection, notification and warning systems; and develop a comprehensive pilot deployment and monitoring plan as an option for ADOT consideration.

CHAPTER 2. LITERATURE REVIEW

This literature review focused on summarizing national documented wrong-way crash statistics; evaluating recommended countermeasures to reduce wrong-way collisions; and exploring emerging ITS technologies under consideration or deployed internationally.

SUMMARIZING WRONG-WAY CRASHES ON A NATIONAL LEVEL

Three reports were found that describe wrong-way driving nationally. The first report, prepared in 2002, summarized an interview with a retired Federal Highway Administration (FHWA) traffic engineer who used FARS to estimate that approximately 350 people are killed each year nationwide in wrong-way freeway crashes (Moler 2002). In 2012, the National Transportation Safety Board (NTSB) undertook a study in an effort to define the problem of wrong way driving (NTSB 2012). This report characterized wrong-way driving on a national level, thoroughly investigated nine fatal wrong-way crashes, and concluded that a significant portion of wrong-way crashes are caused by impaired drivers. In 2014, a report examined eight years (2004 to 2014) of fatal wrong-way crash data extracted from FARS (Baratian-Ghorghi, Zhou and Shaw 2014). This report provided an overview of the general trend of wrong-way fatal crashes in the United States coupled with the significant contributing factors. On average, there are approximately 270 fatal crashes resulting in approximately 350 deaths annually across the United States (Baratian-Ghorghi, Zhou and Shaw 2014). Both NTSB (2012) and Baratian-Ghorghi, Zhou & Shaw (2014) present similar data on a national level.

When comparing wrong-way fatal crashes with overall fatal crashes across the United States, Baratian-Ghorghi, Zhou & Shaw (2014) concluded that the number of wrong-way crashes appeared to remain fairly constant over the analysis years while the total number of fatal crashes within the same time period declined substantially (approximately 22 percent). These trending differences may be explained by the fact that there have been no coordinated national campaigns to reduce wrong-way driving (Baratian-Ghorghi, Zhou and Shaw 2014). Figure 1 illustrates the overall reduction in fatal crashes nationwide compared to the steady trend in fatal wrong-way crashes from 2004 through 2011.

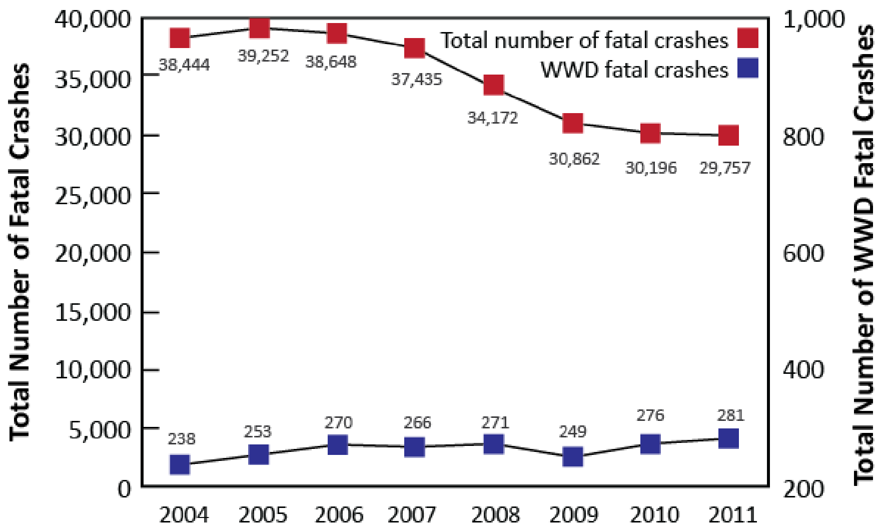


Figure 1. US Overall Fatal Crashes vs. Wrong-Way Fatal Crashes (Baratian-Ghorghi, Zhou and Shaw 2014)

The researchers further determined the characteristics of these fatal wrong-way crashes. A summary of the study findings is presented in Table 1 for the analysis period of 2004 through 2011.

Table 1. National Summary of Fatal Wrong-Way Crashes (Baratian-Ghorghi, Zhou and Shaw 2014)

Characteristics	National Average
Rural and Urban Areas	
Rural	44%
Urban	56%
Drivers Under the Influence	
DUI (BAC at or above 0. 08)	58%
No DUI Reported	42%
Gender	
Male Wrong-Way Driver	71%
Female Wrong-Way Driver	29%
Age	
Age < 24	18%
Age 24-65	67%
Age > 65	15%

The NTSB also extracted data from FARS (2004 – 2009) to investigate wrong-way crashes (NTSB 2012). They restricted their analysis to 1,566 fatal wrong-way crashes that occurred on entrance/exit ramps and controlled access highways. They found that, on average, 261 fatal wrong-way crashes led to 357 deaths nationally (NTSB 2012).

Driving Under the Influence

NTSB researchers reviewed alcohol involvement and documented blood alcohol concentration (BAC) of wrong-way drivers involved in fatal collisions to determine the extent of impairment (NTSB 2012). The alcohol involvement and BAC of right-way drivers involved in the same wrong-way crashes was also examined for comparison. NTSB found that 60 percent of the wrong-way drivers had some indication of alcohol involvement while only 6.5 percent of the right-way drivers had some indication of alcohol involvement. This study also noted that, of the total number of wrong-way drivers reported as being alcohol impaired, 69 percent of those drivers had a BAC of 0.08 or greater and 59 percent had a BAC greater than 0.15 (NTSB 2012). If a driver had a BAC of at least 0.08, it is presumed that the driver was under the influence of intoxicating liquor (Arizona Revised Statutes 28-1381 2015), and a BAC of 0.15 or greater indicates that the driver was under the extreme influence of intoxicating liquor (Arizona Revised Statutes 28-1382 2015).

Age

To see if age can be a factor in wrong-way driving, the NTSB compared the age of wrong-way drivers involved in crashes to right-way drivers involved in the same crashes. NTSB (2012) found that approximately 13 percent of the wrong-way drivers involved in the fatal collisions were 70 years old or greater. Within the same age range, only 3.5 percent of right-way drivers were involved in the same collisions analyzed.

Temporal Factors

The NTSB reviewed temporal factors to determine if wrong-way crashes were occurring more frequently after dark. NTSB (2012) found that approximately 78 percent of wrong-way crashes occurred between 6:00 pm and 6:00 am and a third of the wrong-way crashes occurred between midnight and 3:00 am. Additionally, 57 percent of the collisions occurred within the weekend, Friday through Sunday.

WRONG-WAY COUNTERMEASURES IN THE UNITED STATES

National level countermeasures that address wrong-way driving are just beginning to emerge. But, numerous studies have been conducted over the past 55 years to gain an understanding of the actions that lead to wrong-way driving on a state level. Because wrong-way crash statistics are difficult to obtain, state DOTs focus their efforts on available crash data within their regions. Therefore, many states have developed their own countermeasures to reduce wrong-way driving events. This section presents national level countermeasures suggested in a 2012 NTSB report and during the first National Wrong-Way Driving Summit, then presents countermeasures individual states are focusing on to reduce wrong-way crashes.

National

In the 2012 NTSB study, nine fatal wrong-way crashes across the United States were investigated to assist in developing national countermeasures to reduce wrong-way driving. Three of the NTSB wrong-way collisions that were selected involved passenger cars that struck buses. Based on this review, the study proposed countermeasures for three specific areas: (1) the errant driver, (2) highway traffic control devices and infrastructure, and (3) vehicle safety systems (NTSB 2012).

Area one proposed countermeasures that addressed the wrong-way driver. Because seven of the nine wrong-way drivers investigated had a blood alcohol level (BAC) of 0.15 or higher, NTSB recognized that driver intoxication is still a major factor nationally. Area one countermeasures focus on alcohol ignition interlock devices and new in-vehicle alcohol detection technologies. In addition, NTSB's (2012) analysis using FARS determined that the older driver population is the second highest driver characteristic involved in wrong-way crashes. Therefore, countermeasures also focus on older driver safety. NTSB recommends that each state develop a comprehensive highway safety program for older drivers that incorporates National Highway Traffic Safety Association (NHTSA) elements from their older driver guide, which includes driver licensing and medical review of at-risk drivers, working in collaboration with social services and transportation service providers (NHTSA 2014) . The third wrong-way driver characteristic recognized by NTSB (2012) was drug impairment. However, the report does not directly associate drug involvement in wrong-way collisions because data is neither clear nor available. The report does state that alcohol impaired drivers and older drivers have a higher likelihood of drug use than the general population and therefore, drug impairment was associated with the two primary driver characteristics, intoxication and older age.

Area two proposed countermeasures to combat wrong-way driving by improving the highway conditions. Factors that may influence wrong-way driving included poor visibility due to road geometrics, inadequate traffic control, lack of positive signing, and absence of lighting. The report suggested reduced sign heights, adding red reflective tape to vertical posts, and using over-sized wrong-way signs for improved visibility. Illuminating wrong-way signs which flash when a wrong-way vehicle is detected, and installation of a second set of wrong-way signs at the exit ramp farther upstream from the cross road were additional options. The report also recommended using channelized striping to guide drivers from the cross road onto the on-ramp in an effort to keep motorists from inadvertently entering an exit ramp. Geometric modifications to exit ramps was also listed as a wrong-way entry countermeasure; however, NTSB (2012) noted that these redesigns require engineering analyses and are at times difficult to accomplish.

Area three considered wrong-way navigation alerts on vehicles and emerging technology. In 2011, Toyota tested an on-screen warning and voice alert when a vehicle traveled against the flow of traffic and indicated that it will offer the system in the future to the United States (NTSB 2012). Nissan also developed a wrong-way in-vehicle alert system. However, no recent information was found from Toyota or Nissan that suggests these systems are available in the United States. As technology advances, in-vehicle systems could inform drivers of a wrong-way maneuver. However, additional research is necessary to develop national user interface standards that are intuitively understood by all drivers (NTSB 2012).

In 2013, the first National Wrong-Way Driving Summit gave a platform for both practitioners and researchers to exchange ideas, evaluate current countermeasures, and develop the best practices to reduce wrong-way crashes (Pour-Rouholamin, et al. 2015). At the summit, a survey was distributed, with

16 states responding. The survey inquired if wrong-way driving was a severe problem and 70 percent of the respondents said it was. Sixty-three percent of the respondents had implemented countermeasures to combat wrong-way driving, while 31 percent had developed a monitoring program designed to obtain data on the location, severity, and time of day of wrong-way collisions. Pour-Rouholamin (2015) also examined 10 national case studies where state agencies installed wrong-way driving countermeasures. Specific countermeasures from the case studies are presented in Table 2.

Table 2. Summary of Emerging Countermeasures from 10 Case Studies (Pour-Rouholamin, et al. 2015)

Emerging Countermeasures	Location	Performance	Reference
Low-mounted DO NOT ENTER and WRONG WAY signs	various locations - California	Reduced frequency of WWD from 50-60 per month to 2-6 per month at problematic locations	(Kaminski Leduc 2008)
Flashing LED border WRONG WAY signs	San Antonio, Texas	30% reduction in WWD	(American Traffic Safety Services Association 2014)
Red reflective stripes and reflective raised pavement markers	various locations - Texas	No statistical analysis of performance	
Access management near interchange ramps	Dallas, Texas	Reduced incidents from an average of 9/year to an average of 2. 5/year	(Ouyang 2014)
Raised and vertical longitudinal channelization	Detroit, Michigan	No data showing the effect of the system	
ITS detection system	Houston, Texas	2008-2012 law enforcement successfully stopped 19 WWD motorists and there were 0 WWD crashes	(Harris County Toll Road Authority (HCTRA) 2012)
Wrong-way entry ITS warning system	Buffalo, New York	No data showing the effect of the system	
Enhanced DO NOT ENTER and WRONG WAY signing	various locations - Illinois, Texas	No statistical analysis of performance	
Enhanced pavement marking and improved lane use arrows	various locations – Illinois	40% reduction in WWD	(American Traffic Safety Services Association 2014)
Countermeasure package for partial cloverleaf interchanges	various locations - Michigan	Originating point of 10 wrong-way crashes, reduced to 0 after improvement	(Morena and Ault 2014)

Virginia

A two-year Virginia survey showed that 70 percent of divided highway wrong-way entries occurred in the darkness by intoxicated drivers and that most of the wrong-way entries occurred at partial interchanges of the diamond type (Vaswani 1973). The proposed strategies to mitigate these types of crashes included channelizing the left turn lane of the exit ramp, making entry ramps conspicuous and the exit ramps inconspicuous, locating signs to improve readability, adding intersection geometry signing, illuminating entry points onto the highway system, and bringing stop lines closer to the pavement edge lines.

California

In 1967, California Department of Transportation (Caltrans) was the first to use technology to detect wrong-way drivers by installing a Kodak Instamatic camera triggered by two tubes stretched across the roadway. When wrong-way drivers triggered the camera, it captured an image of the roadway and the wrong-way vehicle. These images were used to identify off-ramps with high wrong-way entries (Rinde 1978). In the early 1970s, Caltrans lowered the mounting height of wrong-way signing based on their research efforts. After the signs were lowered, Caltrans found wrong-way entries had dropped from an average of 55 entries per month to four entries per month on 90 percent of their problem off-ramps (Kaminski Leduc 2008). In 1989, a Caltrans study suggested adding a second set of wrong-way signs to give errant drivers a second chance to correct their error prior to entering the freeway in the wrong direction (Copelan 1989).

In 2004, researchers noted in a study that Caltrans had adopted in-pavement warning lights as a wrong-way driving countermeasure on exit ramps that were susceptible to wrong-way collisions (Cooner, Cothron and Ranft 2004). Caltrans utilized an inductive loop detector to activate 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). No before-and-after data was offered regarding the success of the pavement lights.

Arizona

Arizona Department of Transportation (ADOT) began researching strategies to combat wrong-way driving in 2010. Their primary focus was to determine the viability of existing detector systems to identify entry of wrong-way vehicles on to the highway system using different technologies: microwave, Doppler radar, video imaging, thermal sensors and magnetic sensors (Simpson 2013). ADOT installed the systems on the highway and performed field testing and controlled testing to verify their feasibility. The results of this proof of concept confirm that wrong-way vehicles can be detected using easily deployable equipment.

In 2014, ADOT took steps to enhance wrong-way signing and pavement markings. The agency installed over-sized, low-mounted wrong-way signing at exit ramps and added large arrows with reflectors to the pavement that point the right way at six test sites (Arizona Department of Transportation 2014).Approximately six months after the initial test installations, ADOT expanded the program to 50 locations in both the rural and urban areas. Additionally, ADOT introduced using the enhanced wrong-way signing in every future design project.

Specifically the engineering countermeasures are as follows to increase visibility of exit ramps:

- Installed over-sized wrong-way signage
- Lowered wrong-way signage height (better illumination from headlights at night)
- Installed red reflective striping on sign posts
- Installed white pavement arrows in direction of exit ramp traffic
- Installed red raised pavement markers on white pavement arrows
- Added left turn pavement marking guides to assist drivers entering an on-ramp

ADOT deployed two sites with active wrong-way detection technology in 2014 based on the results the Simpson (2013) report. These sites both use radar detection and have capture cameras that photograph an errant driver's entry when the detector is activated. Notification is sent to the TOC immediately upon activation, and DPS is informed of the wrong-way entry. These systems are currently under evaluation and testing.

In August 2015, ADOT installed three new wrong-way LED warning systems that give wrong-way drivers a visible real-time indication prior to highway entry. When activated, the wrong-way signs flash with high intensity LEDs. ADOT will test and evaluate these three systems (phone conversation, ADOT State Traffic Operations Engineer, August 13, 2015).

Florida

In 2010, the Florida Department of Transportation (FDOT) studied the viability of video for wrong-way detection on expressway off-ramps (Rose 2011). The study simulated test runs for this study and a 27-day field trial. During the trial period, FDOT detected a number of false alarms, generally due to movement of vehicles on the shoulder, dark shadows, or the reflection of headlights from the wet pavement. The study concluded that FDOT should consider performing additional testing based upon updated design recommendations for the equipment.

In October 2014, FDOT installed wrong-way detection devices on 10 off-ramps in Miami-Dade County and five off-ramps in Broward County as part of a statewide wrong-way pilot project (Florida Department of Transportation 2014). When activated, LED enhanced signs illuminate and a signal notifies law enforcement and authorities of the wrong-way entry. Other districts within FDOT are testing different types of technology to determine which will be the best to implement statewide (phone conversation, FDOT Regional TMC Manager, July 23, 2015). No results have been published on FDOT's pilot project; however, an FDOT manager said that a university was preparing a before-and-after study that would provide data on the viability of their wrong-way pilot deployment in 2017.

Illinois

The Illinois Department of Transportation (IDOT) studied the magnitude of wrong-way driving in the state and developed countermeasures to mitigate such crashes (Zhou, et al. 2012). At the 12 highest ranked wrong-way entry locations, researchers recommended combinations of countermeasures ranging from signing adjustments, to pavement markings, geometric design, and traffic signal arrow modifications. Implementation was recommended in two phases; the first phase would focus on short term, low cost countermeasures, while phase two would be a long-term systematic approach using engineering, education, enforcement, and emergency response. The Illinois study suggested future research on advanced signing and wrong-way detection/warning systems (Zhou, et al. 2012).

New Mexico

The New Mexico Department of Transportation (NMDOT) decided to pursue wrong-way detection strategies in 1992, after a fatal wrong-way collision (Moler 2002). NMDOT, in cooperation with the Alliance for Transportation Research (ATR) and New Mexico State University, developed a prototype directional traffic sensor to notify drivers of their wrong-way entries. NMDOT installed the sensor in the Albuquerque area and two sensors remain operational. When a wrong-way driver is detected, two sets of warning lights illuminate to warn the wrong-way driver of their error and to alert right-way traffic. No data could be found that shows before-and-after statistics on the success of these devices. In 2006, NMDOT experimented with solar panels to power the wrong-way detector, but the warning lights did not function properly when the solar panels were dirty (Kaminski Leduc 2008).

Texas

The Texas Department of Transportation (TxDOT) and the Texas counties have been studying wrong-way detection systems over the last 20 years. TxDOT and FHWA sponsored a research project in 2002 (Cooner, Cothron and Ranft 2004). The research gathered information on the causes and consequences of wrong-way movements on Texas freeways and recommended guidelines and practices for wrong-way countermeasures. Some of the guidelines included:

- Installing reflectorized wrong-way pavement arrows on left-side freeway exit ramps
- Revising typical standard freeway pavement marking standards to include raised pavement markers
- Installing and maintaining wrong-way pavement arrows and making their maintenance a priority, particularly in the urban areas
- Lowering wrong-way signing
- Installing inductive loops or other detectors on exit ramps in future construction projects

In 2007, after a wrong-way collision resulted in a triple fatality, the Harris County Toll Road Authority in Texas installed a wrong-way detection system on 13.2 miles of toll roads (TransCore 2008). The system consisted of radar sensors at 18 off-ramp locations that triggered an alert on a wrong-way detection map within the TOC. An audible alarm notified dispatchers to call the closest police unit to the wrong-way vehicle. Additionally, a message on the changeable message sign advised motorists of the oncoming driver (ITS International 2010). In a January 2011 news interview, an official with the Harris County Toll Road Authority stated that there had been no fatalities since the system's installation and 23 wrong-way drivers had been stopped or turned around. Of the 23 drivers, nine were charged with driving under the influence (DUI) of an impairing substance (Willey 2011). Currently, the Harris County wrong-way system is the largest of its kind.

In 2011, TxDOT conducted a research analysis to determine if spike strips could be used to stop a wrong-way vehicle (TxDOT 2011). TxDOT does not consider the installation of spike strips for some of the following reasons:

- Tire spike strips are designed for very low speeds. Manufacturers' literature specifies installation at locations where speeds do not exceed 5 mph.
- During testing, the spikes did not cause the tires to deflate quickly enough to prevent a vehicle from entering the freeway.
- During testing, the spikes broke leaving stubs that damaged the tires of right-way vehicles.
- Right-way drivers perceived the spikes as a hazard and hit their brakes creating a hazardous situation.
- Over time, dirt and debris build-up within the devices, impeding the ability for the device to fully fold down as intended.
- The devices are a hazard for motorcycles and small cars exiting in the correct direction.
- The cost to pursue permanent installation spikes for speeds greater than 5 mph would be extremely high.
- If they were designed and installed, any failure of the system would result in damage to right-way vehicles, so maintenance technicians would have to be immediately dispatched 24/7 to address any issues that are detected with the system.
- All traffic control devices must comply with Manual of Uniform Traffic Control Devices (MUTCD). Federal approval is required for compliance.

In 2012, TxDOT installed wrong-way signs and radar devices as a pilot project at 16 highway locations to combat wrong-way driving in the San Antonio area (Fariello 2012). Data from the test corridor suggested that wrong-way signing with flashing LEDs around the border is visible at a greater distance than without LEDs. After the 30-month pilot period, a study was conducted that showed a reduction of 28 percent in the average rate of wrong-way driving events according to the TOC logs and a reduction of 31 percent in the average rate of wrong-way driving events in the law enforcement 911 logs (Gianotti 2015).

In 2014, TxDOT assessed the effectiveness of wrong-way driving countermeasures including LEDs around wrong-way signing activated by a wrong-way driver (Finley 2014). Through a series of two experimental closed-course tests, researchers found that intoxicated drivers tend to look toward the pavement area in front of them and not left or right. They also confirmed that drivers with higher BAC levels took longer to locate signs on the side of the roadway. the controlled impaired drivers had to be closer to the signs with LEDs flashing around the border before they could read the legend compared to signs without flashing LEDs. Lowering the height of signing did not improve the ability of the controlled alcohol impaired drivers to locate signs, identify the background color or read the legend (Finley 2014). Making the sign larger, adding red reflective sheeting to the sign support or adding flashing red LEDs around the border of the sign also did not improve the time that the impaired driver located wrong-way signing. However, the participants felt that these three countermeasures made it easier to find the sign and believed that these measures caught their attention easier than traditional wrong-way signing.

Wisconsin

Milwaukee County and the Wisconsin Department of Transportation installed nine wireless alert notification systems in 2012. When a sensor is triggered, notifications are sent instantly to the State TOC and the Sheriff's Office so that dispatchers can alert authorities to respond. At two locations LED warning signs were installed to alert the wrong-way driver of their error (Rich 2012). No research has been published on the effectiveness of this system.

INTERNATIONAL WRONG-WAY COUNTERMEASURES

Japan

From 1997 through 2000, on average Japan had approximately 31 wrong-way crashes per year (ITARDA 2002). The companies in charge of expressway construction and maintenance have been replacing conventional reflecting signposts with larger internally illuminated signposts to improve nighttime visibility coupled with a traffic sign similar to the "do not enter" sign used in the United States (ITARDA 2002). No research could be found that shows if the larger illuminated signposts are effective in reducing wrong-way driving. As of May 2010, the West Nippon Expressway Company installed 8 wrong-way sensors with wrong-way warning signing and was planning to install an additional 420 units (Adachi 2010). No additional research could be found that indicates if the additional units were installed or analyzed for their effectiveness.

Germany

The Institute for StraBenwesen Aachen (ISAC) and Rwthaachen University have been researching low-cost ways to reduce unintentional wrong-way entries onto Germany's freeway system, specifically focusing on using radio tomography technology (Oeser, et al. 2015). The researchers generated a radio field by placing radio antennas along with a radio module and energy source inside existing roadside delineators. An algorithm was then developed to detect a wrong-way vehicle as it crossed the radio field. If a wrong-way vehicle was detected, information was sent to the control station via a mobile radio module. The control center then distributed the information to radio stations and navigation devices. A mobile app was in production so that eventually the warning could also be sent to mobile devices. This research included a driving simulator to determine the applicability of navigation and audible signals.

Sweden

Sweden's Oresund Bridge, comprising of a bridge and a tunnel, is a vital link between Sweden and Denmark. Sweden has faced wrong-way driving on the bridge and has developed a system to deal with it (Ghost Hunters 2014). If a wrong-way entry occurs, the lane management signs will display a double cross to warn the wrong-way driver of their mistake. The lane management signs warn right-way drivers to stay to the right and indicate the left lane is blocked. Additionally, stop barriers in front of the tunnel lower automatically so that drivers are not faced with the wrong-way driver. When the wrong-way driver reaches the tunnel end, they are blocked by two steel barriers and the Swedish police .

EMERGING TECHNOLOGY

Emerging technologies which connect vehicles to the roadway and their surroundings could reduce wrong-way driving collisions. The potential exists to alert errant drivers when their vehicles are headed the wrong way, and to warn right-way drivers of an oncoming threat.

In-Vehicle Applications

In Japan, researchers are working toward a method of detecting wrong-way travel on highways and a method to warn drivers of an oncoming vehicle by using the car navigation systems (Takahera, et al. 2012). This method uses highly accurate location and communication based map update technologies on the car navigation system. Audible and visible displays in the navigation system warn the errant driver of their mistake and right-way drivers of the oncoming wrong-way vehicle. No further research on the applicability of these systems or additional research was found.

Mercedes-Benz is developing a sign recognition system that will help eliminate unintentionally driving in the wrong direction (Daimler 2015). This system will be designed to identify no-entry signs and send the information it receives to the computer processor. If the system detects that the vehicle is about to drive past the prohibition signs and enter the off-ramp, the system warns the driver by emitting low warning signals and flashing a red no entry symbol on the display to alert the driver of their error.

Figure 2. Mercedes-Benz Sign Assistance System (Daimler 2015)

Roadside Applications

Sydney, Australia, has had problems with oversized trucks entering tunnels that are too low. The city now uses height sensors that will activate a water curtain and project an image of a stop sign if an oversized vehicle tries to continue into the tunnel (Orlave 2013). This system has effectively reduced oversized truck crashes in tunnels. Hence, modifying this technology to deter wrong-way drivers could be a likely countermeasure. Assuming directional sensors could detect a wrong-way driver approaching; the emergency water curtain and stop sign images would then deploy and conceivably stop the errant driver.

Figure 3. Australia's Water Curtain (Orlave 2013)

SUMMARY

New technologies, such as LED wrong-way signing that warns the wrong-way drivers of their mistake, are in the early stages of development or pilot deployment, and the data is not yet available to assess their effectiveness. While there are many possible countermeasures available to deter wrong-way driving, there is no single solution to this international problem.

Connected vehicle systems use onboard sensors, such as radar, to identify crash threats and warn drivers to take corrective actions. However, these systems are still under testing and will not be available for some time.

Based on the literature review, it does not appear that tracking a wrong-way vehicle throughout the roadway system has been explored. The majority of new research in the United States focuses on deploying off-ramp wrong-way systems. Tracking the wrong-way vehicle through the system would allow authorities to share real time information on the wrong-way driver's location, and alert oncoming traffic to the threat of the wrong-way vehicle.

CHAPTER 3. ANALYSIS OF WRONG-WAY CRASHES IN ARIZONA

In order to reduce wrong-way crashes, it is important to understand why these crashes occur by analyzing crash history records, summarizing the data, and determining if there are potential wrong-way crash patterns in driver characteristics or known highway entry points. As a portion of this research effort, wrong-way crashes in Arizona were identified, confirmed, and analyzed for an 11 year period from 2004 through 2014. Normally, crash data is reviewed for the most current five-year period; however, because wrong-way crashes are infrequent, it was important to gain a better understanding by looking at a larger sample size to identify any indications of crash patterns because generally, wrong-way crashes appear to be random events.

Wrong-way driving is defined by ADOT as:

> *… any situation in which a driver is operating a vehicle in the wrong direction on a one-way road or the wrong direction on a divided traffic way. It is not improper passing or failing to keep in the proper lane*.

A wrong-way crash is defined as a crash that results from wrong-way driving.

The ADOT Safety Data Mart (SDM) is continually updated to include later reports, so total crash values change as new information is reported to ADOT. The data in this report was current as of February 2015. Hence, crash data presented in older studies cannot be compared to the crash data presented herein because that data is obsolete. For example, yearly wrong-way crash data quoted in Simpson (2013) varies from this report. The data obtained for Simpson (2013) was queried differently and are slightly greater because crash reports were not reviewed to confirm an actual wrong-way event.

The ADOT SDM, Highway Condition Reporting System (HCRS) data, DPS's list of the Top 40 Wrong-Way Locations based on 911 calls, combined with a thorough review of numerous Arizona Crash Reports, were used to identify and confirm wrong-way crashes from year 2004 through year 2014. Only confirmed wrong-way crashes were used in this analysis. Because there is no way of determining wrong-way crashes specifically from the ADOT SDM or the Arizona Crash Reports form, it is impossible to guarantee that all wrong-way collisions were accounted for in this research effort because wrong-way driving is only documented within the individual police investigation summaries.

METHODOLOGY

The ADOT Traffic Engineering Group provided SDM data in three sub-databases for analysis of all crashes that occurred from 2004 through 2013. The three sub-databases were Incident, Unit, and Person. The Incident sub-database was queried first to find all crashes on divided highways. That data was further filtered by collision manner (head-on, sideswipe opposite direction, other, unknown.) From these queries, a list of possible wrong-way crashes was generated. The next step was to determine the direction of travel for the vehicles involved in the crash. The incident number was used to reference the Unit database and verify that the crash vehicles were indeed traveling in opposing directions. The latitude and longitude information from the crash records was used to geocode the crash location; map and satellite images were derived from Google Earth to check whether the crash occurred on a divided highway, at a highway on-ramp, or at a highway off-ramp.

Using the possible wrong-way crash list and the known location of crashes on divided highways, the Arizona Crash Reports were reviewed. If confirmed by the report as a wrong-way crash, the incident number was noted. Altogether, a total of 245 crashes were confirmed as wrong-way crashes over the 11-year period. Because the sub-databases are linked using the incident number, the Person sub-database was utilized to determine driver characteristics such as blood alcohol content (BAC), age, and driver's license origins. Figure 4 illustrates the flowchart used to determine wrong-way crashes.

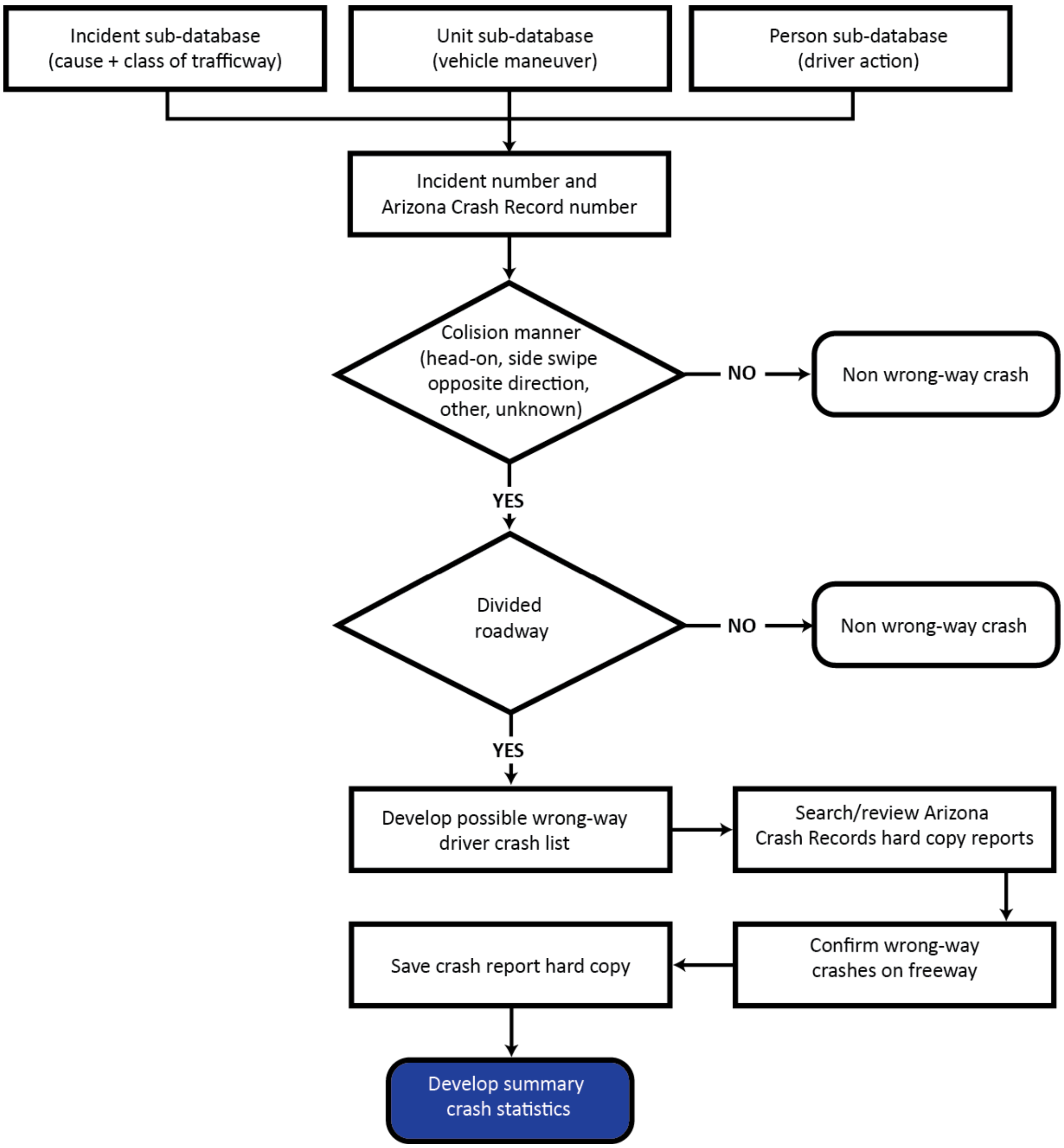


Figure 4. Flowchart to Confirm Wrong-Way Crashes Using Arizona's Safety Data Mart (SDM) Data

CHARACTERISTICS OF WRONG-WAY CRASHES IN ARIZONA

Figure 5 shows all wrong-way crash sites from 2004 through 2014. The red dots mark fatal crashes.

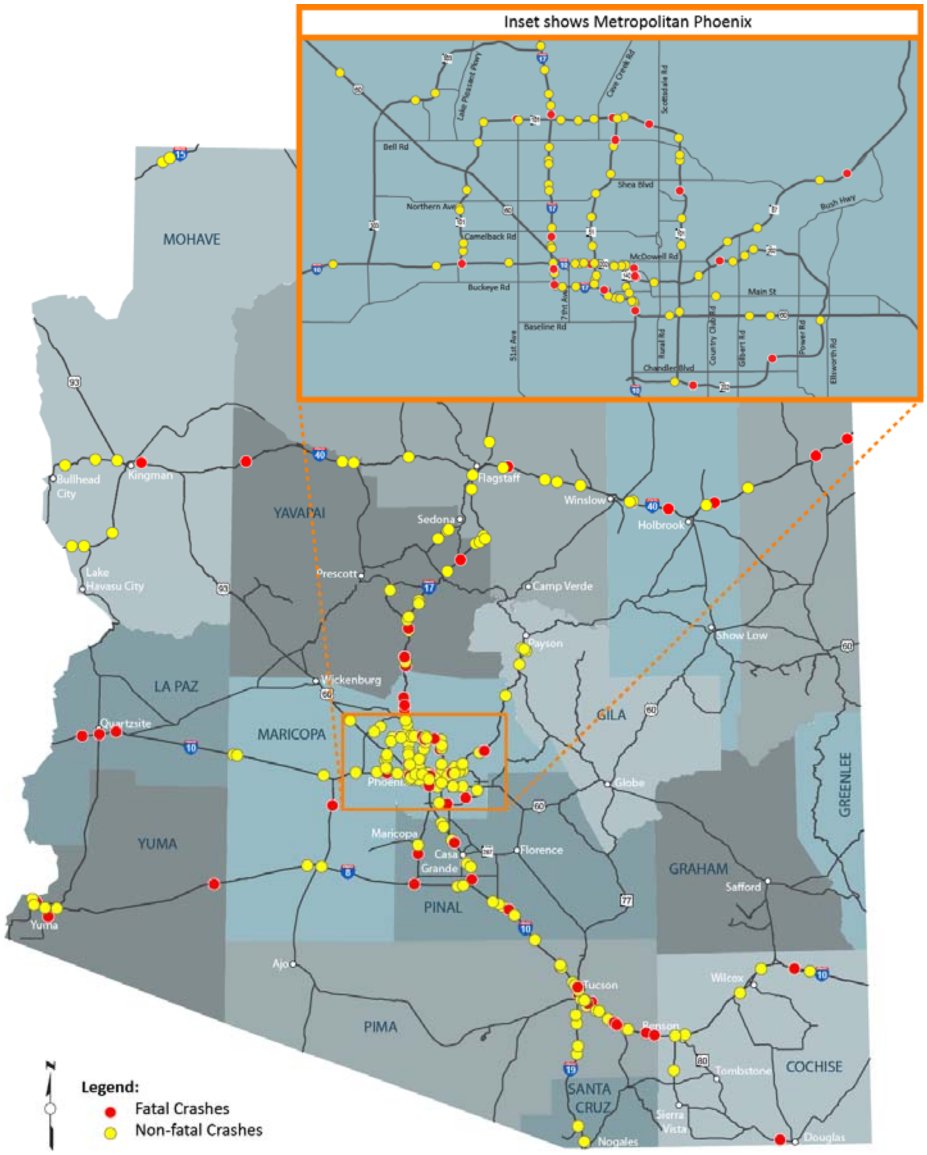


Figure 5. Confirmed Wrong-Way Crash Sites in Arizona – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

Table 3 compares the total number of Arizona highway crashes and fatalities to wrong-way crashes and fatalities in the state. When all crashes on divided highways were combined for 2004 through 2014, only 1 percent of the total crashes were fatal. However, 25 percent (62 crashes) of the wrong-way crashes were fatal. In an average fatal Arizona highway crash for that period, 1.1 persons died compared to the 1.5 persons who died in the average fatal wrong-way crash.

Table 3. Arizona's General Crash Statistics 2004 through 2014 (Arizona Department of Transportation 2015)

Category	Year											Average
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Total Crashes	138,547	139,265	140,197	140,371	119,588	106,767	106,177	103,423	103,637	107,348	109,554	**119534**
Total Crashes on Divided Highways	25,777	24,921	25,707	28,155	24,166	18,760	20,271	21,076	20,647	22,072	*Not yet reported*	***23,155***
Total Fatal Crashes	990	1,038	1,121	952	842	709	698	754	738	777	708	**848**
Total Fatalities	1,151	1,179	1,296	1,071	937	806	762	825	821	844	774	**951**
Total Fatal Crashes on Divided Highways	349	385	351	292	267	220	184	224	222	210	*Not yet reported*	***270***
Confirmed Wrong-Way Crashes	29	17	24	27	14	21	20	33	13	30	17	**22**
Confirmed Wrong-Way Fatal Crashes	9	6	4	6	4	6	7	5	4	6	5	**6**
Confirmed Wrong-Way Fatalities	11	7	9	7	7	9	9	9	5	9	9	**8**
% Wrong-Way Crashes Compared to Total Crashes	0. 02%	0. 01%	0. 02%	0. 02%	0. 01%	0. 02%	0. 02%	0. 03%	0. 01%	0. 03%	0. 02%	**0.02%**
% Fatal Wrong-Way Crashes Compared to Fatal Crashes	0. 91%	0. 68%	0. 36%	0. 63%	0. 48%	0. 85%	1. 0%	0. 66%	0. 54%	0. 77%	0. 71%	**0.70%**
% Wrong-Way Crashes Compared to Divided Highway Crashes	0. 11%	0. 07%	0. 09%	0. 09%	0. 06%	0. 11%	0. 10%	0. 15%	0. 06%	0. 12%	*Not yet reported*	**0.09%**
% Fatal Wrong-Way Crashes Compared to Fatal Divided Highway Crashes	2. 58%	1. 56%	1. 14%	2. 05%	1. 50%	2. 27%	3. 80%	2. 23%	1. 80%	2. 38%	*Not yet reported*	**2.22%**

Figure 6 presents the annual number of Arizona wrong-way crashes, defined as fatal versus non-fatal crashes, for the years 2004 through 2014. The comparison shows that for each year reported, the number of wrong-way crashes that resulted in fatalities were fewer than the crashes without fatalities.

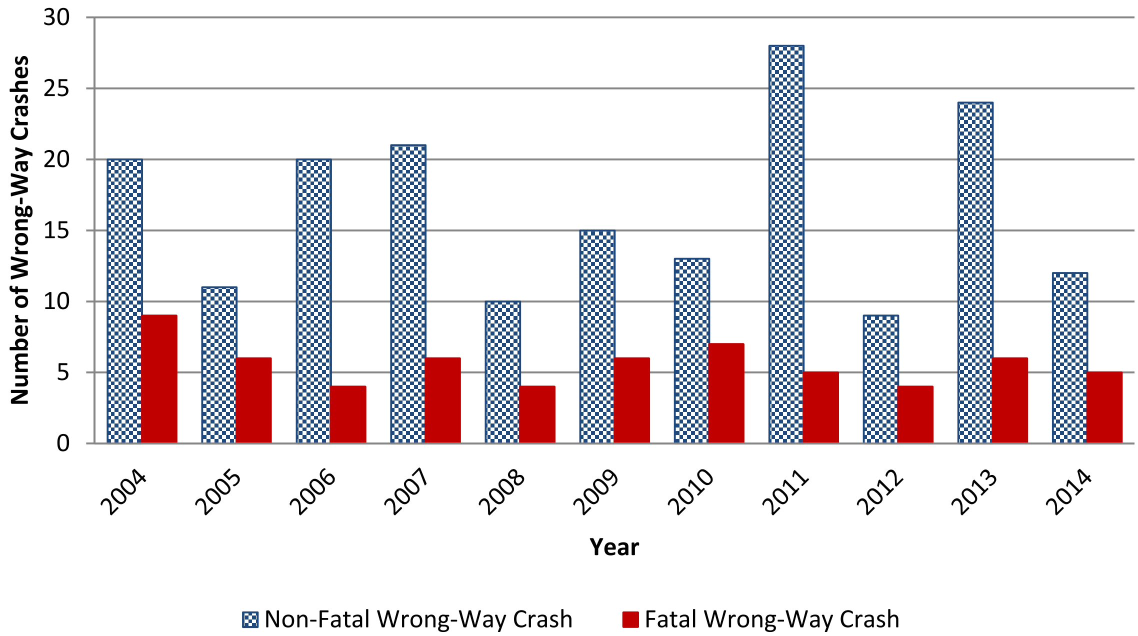


Figure 6. Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014: Number of Fatal versus Non-Fatal Crashes
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

The same information for wrong-way crashes on Arizona divided highways is presented in Figure 7 in terms of the percentage of fatal wrong-way crashes versus non-fatal wrong-way crashes. This crash information is for the years from 2004 through 2014.

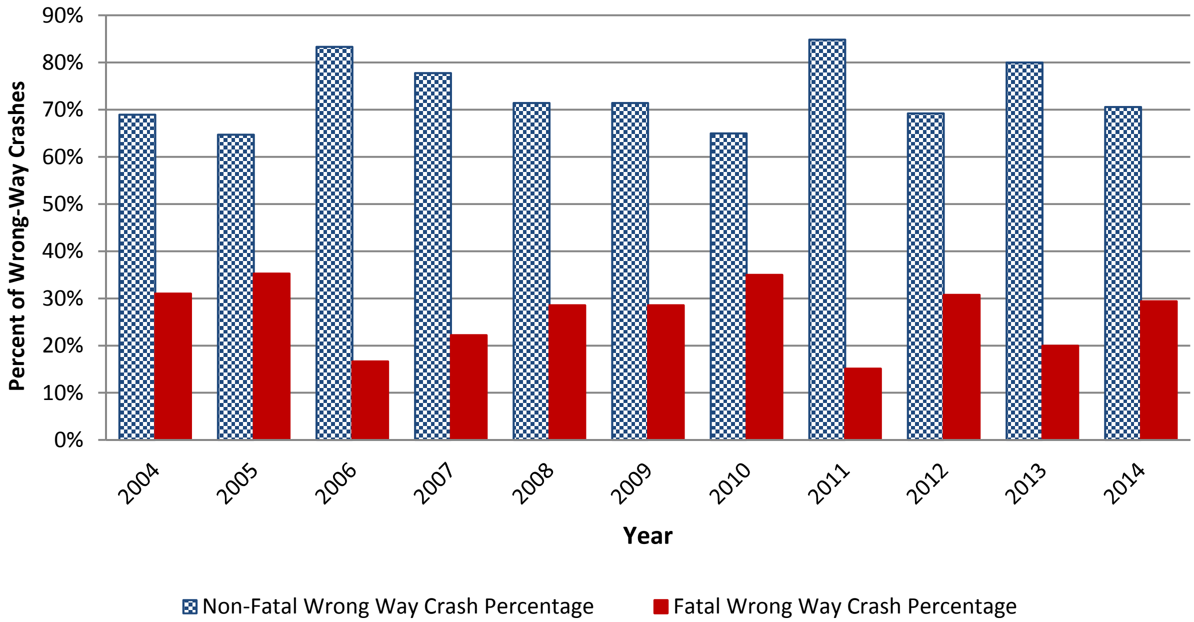


Figure 7. Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014: Percent of Fatal versus Non-Fatal Crashes

(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

According to the data analyzed over the 11 years, 75 percent of the total wrong-way crashes in Arizona were non-fatal.

Temporal Distribution

All 245 Arizona wrong-way crashes (the total number of wrong-way crashes on Arizona divided highways for 11 years) were analyzed to generate Figures 8 through 10. Distinct trends were indicated. First, regarding time of day, the data showed that wrong-way crashes were more prevalent after dark. Over half (56 percent) of all Arizona wrong-way crashes occurred between the hours of 10 p.m. and 4 a.m., with the peak hour being 2 a.m. Figure 8 shows all Arizona wrong-way highway crashes by time of day.

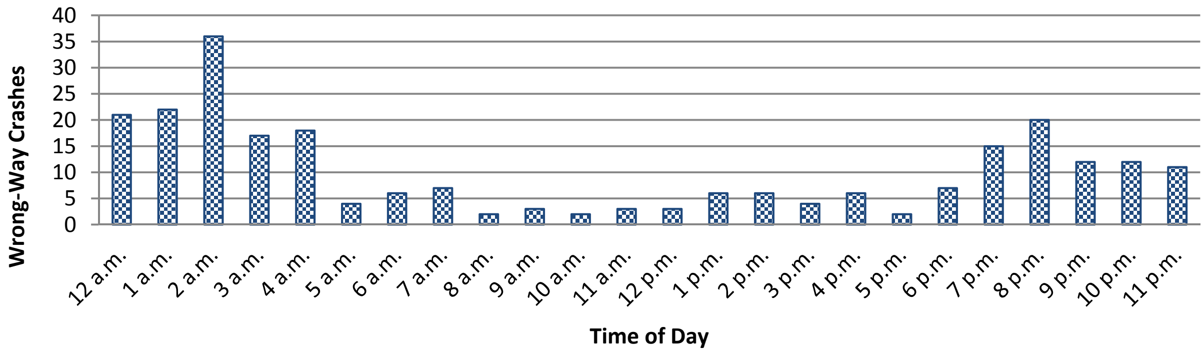


Figure 8. Wrong-Way Crashes on Arizona Divided Highways by Time of Day – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

Crash data for the daylight hours between 8 a.m. and 12 p.m. indicate lower occurrences of wrong-way driving crashes at those times.

Figure 9 shows wrong-way crashes by day of the week, with a higher frequency of crashes occurring during the weekends.

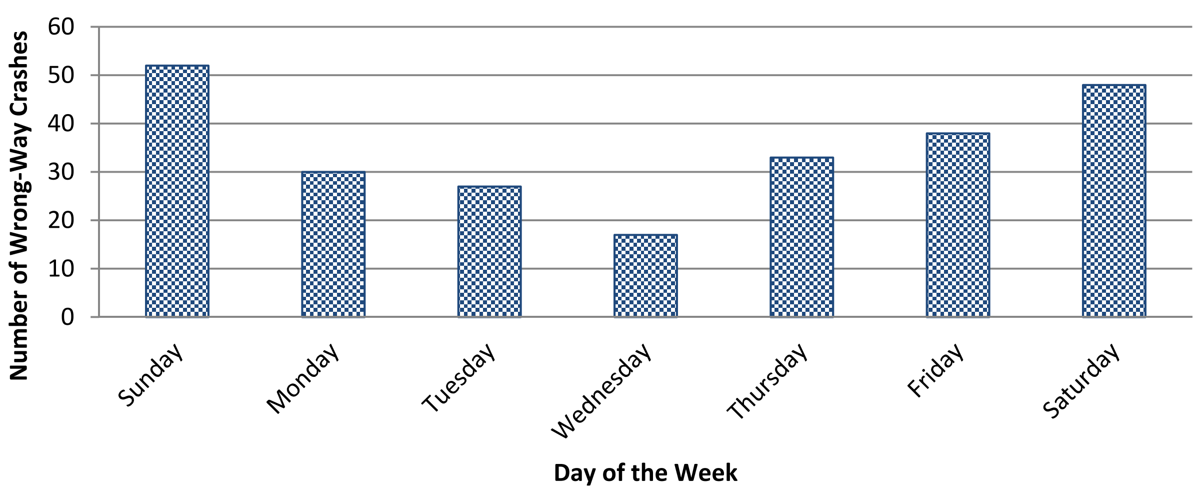


Figure 9. Wrong-Way Crashes on Arizona Divided Highways by Day of the Week – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

While noting that Sundays have more crashes than Saturdays, it should be remembered that the early morning hours of Sunday would reflect behaviors most likely initiated on Saturdays.

The monthly distribution of Arizona wrong-way crashes is shown on Figure 10. The summer months in Arizona appear to have the highest percentage of wrong-way drivers.

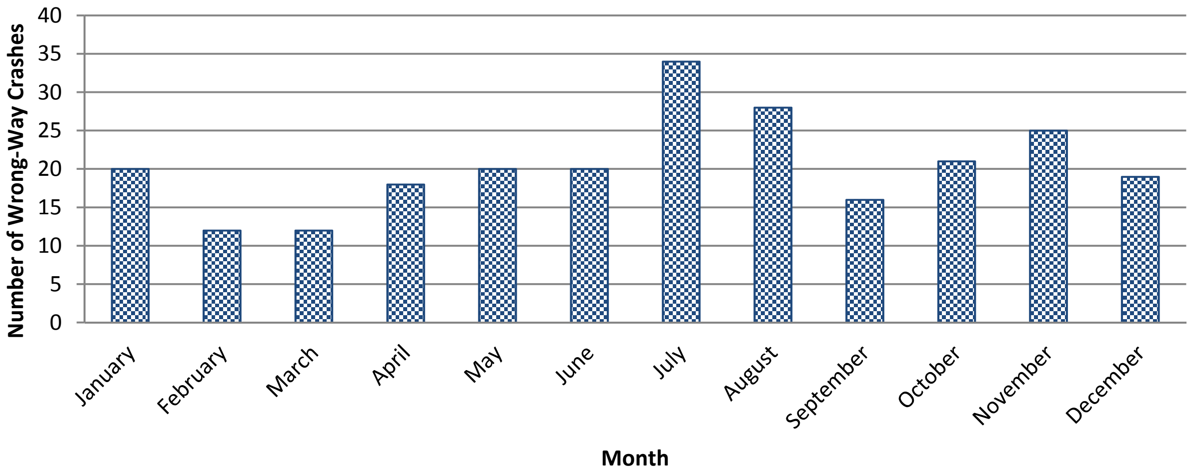


Figure 10. Wrong-Way Crashes on Arizona Divided Highways by Month – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

The occurrence of wrong-way crashes on Arizona highways is shown to peak in July. The month of August ranks second highest, with November following as third highest for the 11 years analyzed.

Crash Location

This research found that Arizona wrong-way crash sites were relatively evenly distributed along urban highways and rural highways. Approximately 53 percent of the Arizona wrong-way crashes occurred on urban divided highways and 47 percent occurred on rural divided highways.

The wrong-way crashes were plotted on Google Earth by longitude and latitude to determine wrong-way crashes per mile for both urban and rural divided highways. The length of each corridor, for the urban and rural conditions, was determined using engineering judgement. Figures 11 and 12 illustrate crashes per mile along urban highways and rural highways, respectively.

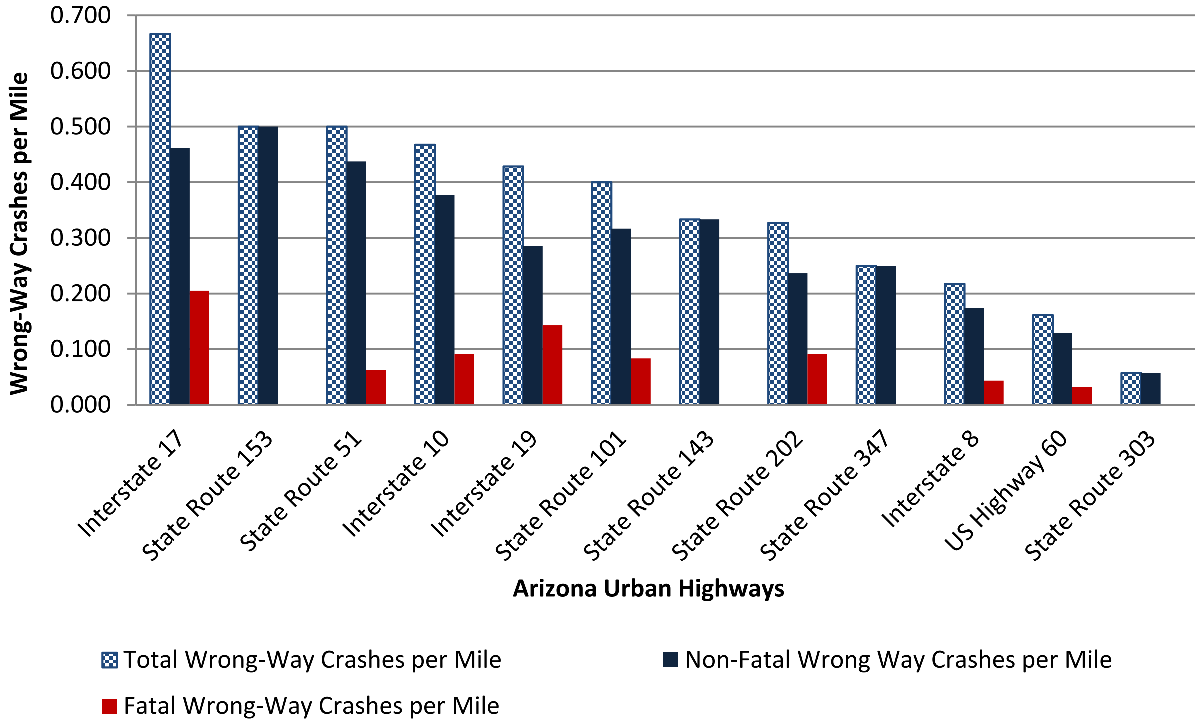


Figure 11. Arizona Wrong-Way Crashes per Mile on Urban Divided Highways – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

A total of 26 wrong-way crashes occurred on the urban section of Interstate 17 (39-mile segment) over the 11 years analyzed. Therefore, this highway has the highest rate of confirmed wrong-way crashes per mile of 0.667 on urban divided highways in Arizona. In addition, Interstate 17 also has the highest confirmed urban fatal wrong-way crash per mile rate of 0.205, with eight confirmed fatal wrong-way crashes within the 11 year analysis period.

State Route 153 and State Route 51 both have a crash per mile ratio of 0.5. However, State Route 153 had one wrong-way crash over a two mile stretch while State Route 51 had 8 wrong-way way crashes over the 16 mile stretch including a fatality.

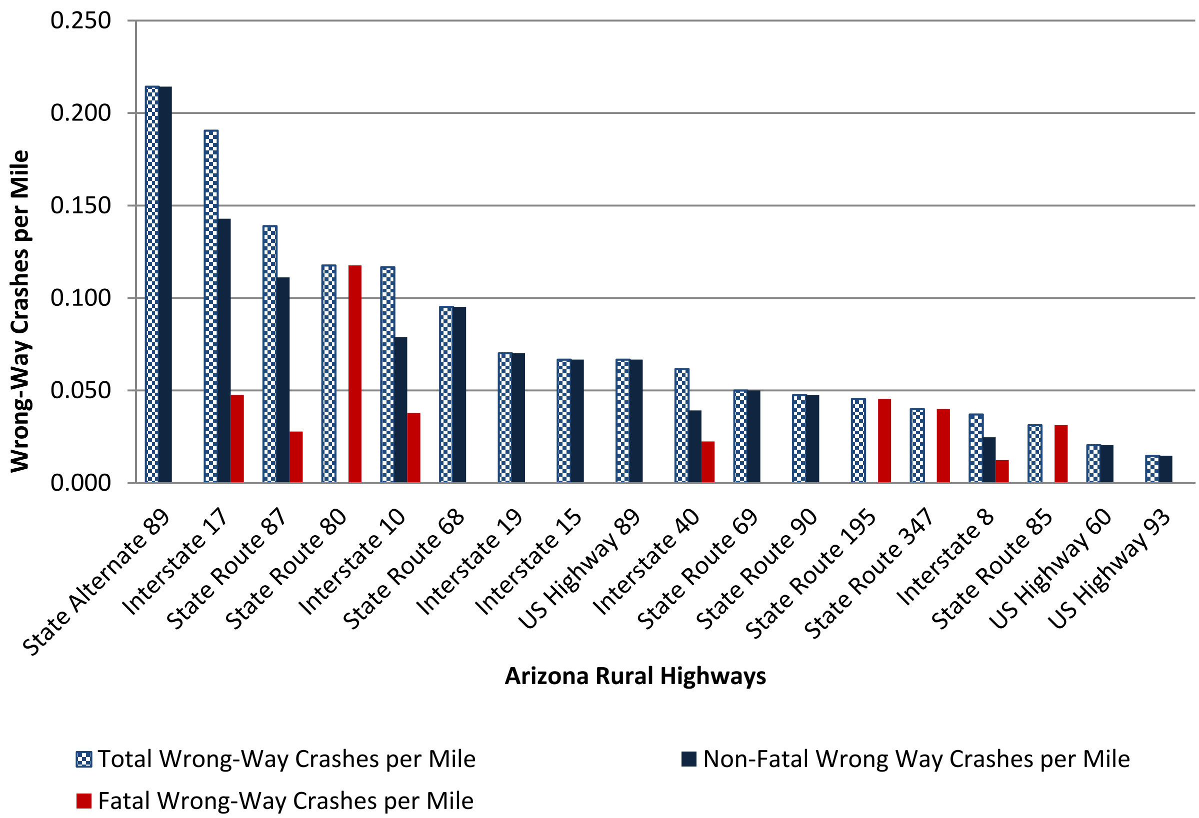


Figure 12. Arizona Wrong-Way Crashes per Mile on Rural Divided Highways – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

State Route 89A had the highest rural wrong-way crash per mile rate of 0.214 with three confirmed wrong-way crashes over 14 miles of SR 89A. Two of the wrong-way crashes on SR 89A were located within one mile of the Red Rock Road intersection. State Route 80 near the Douglas area had the highest fatal confirmed wrong-way crash per mile rate with one confirmed fatal wrong-way crash in 8.5 miles of SR 80. On I-10 near Quartzite, Arizona, three fatal wrong-way collisions occurred within 16 miles of each other over the 11 year analysis period.

Wrong-Way Driver

Wrong-way driver characteristics such as driver impairment and age were analyzed to determine possible trends in driver behavior. Such information might be useful in the future development of wrong-way driving countermeasures.

Impairment

A significant number of wrong-way crashes on Arizona divided highways were the result of drivers impaired by alcohol and/or drugs. The analysis shows that in Arizona, 65 percent of all wrong-way drivers were somehow impaired; 42 percent were legally impaired by alcohol and 6 percent were impaired by drugs, either prescription or illegal. Note that this Arizona data aligns with a national analysis (NTSB 2012) that showed approximately 60 percent of wrong-way drivers were impaired by alcohol or drugs. Figure 13 presents an overview of impairment of wrong-way drivers in Arizona from 2004 through 2014.

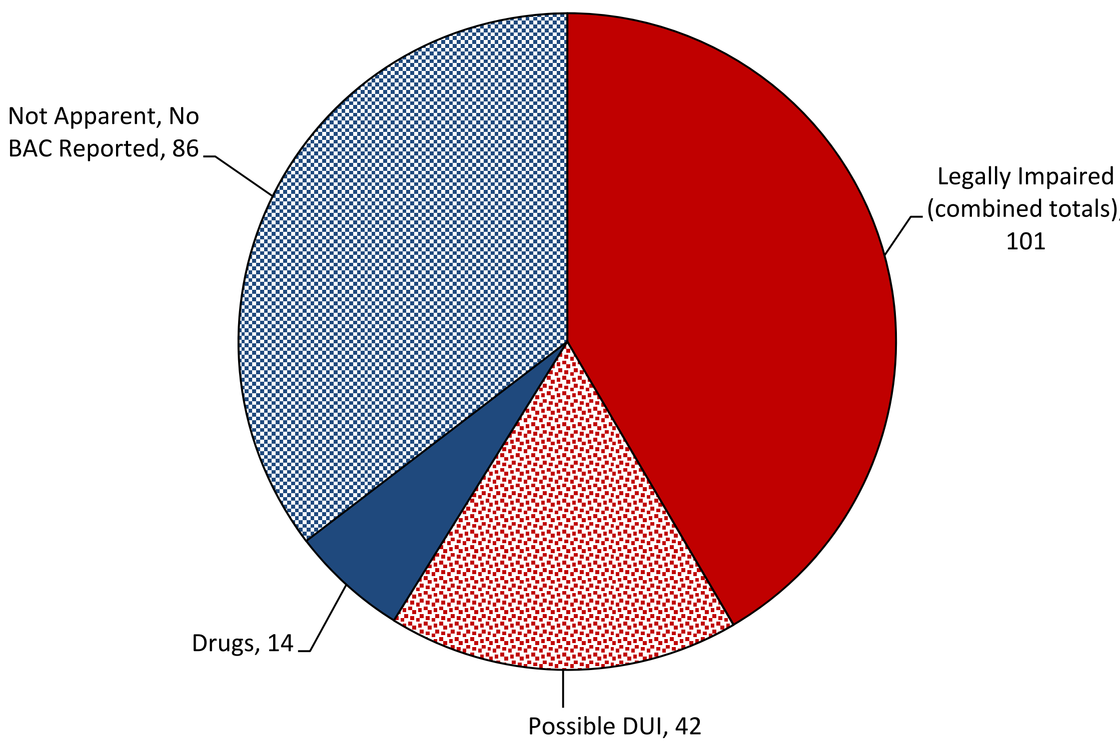


Figure 13. Impairment of Wrong-Way Drivers in Arizona Crashes on Divided Highways — 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

Figure 14 presents wrong-way drivers' blood alcohol content (BAC) levels. As can be seen, 67 of 245 wrong-way drivers had a BAC greater than 0.15, indicating that the driver was under the extreme influence of alcohol. In addition, 14 of the wrong-way drivers had a BAC over 0.08, but less than 0.15, which still presumes the driver was under the influence of alcohol. Law enforcement did not report the use of drugs or alcohol for 86 wrong-way drivers. However, some wrong-way drivers refused the BAC test, or were tested but the results were not attached to the crash records, or alcohol impairment was not documented on the crash report. Therefore, the actual percentage of impaired wrong-way drivers could be higher than what is reported in Figures 13 through 15. Untested wrong-way drivers were included in the Not Apparent, No BAC Reported category.

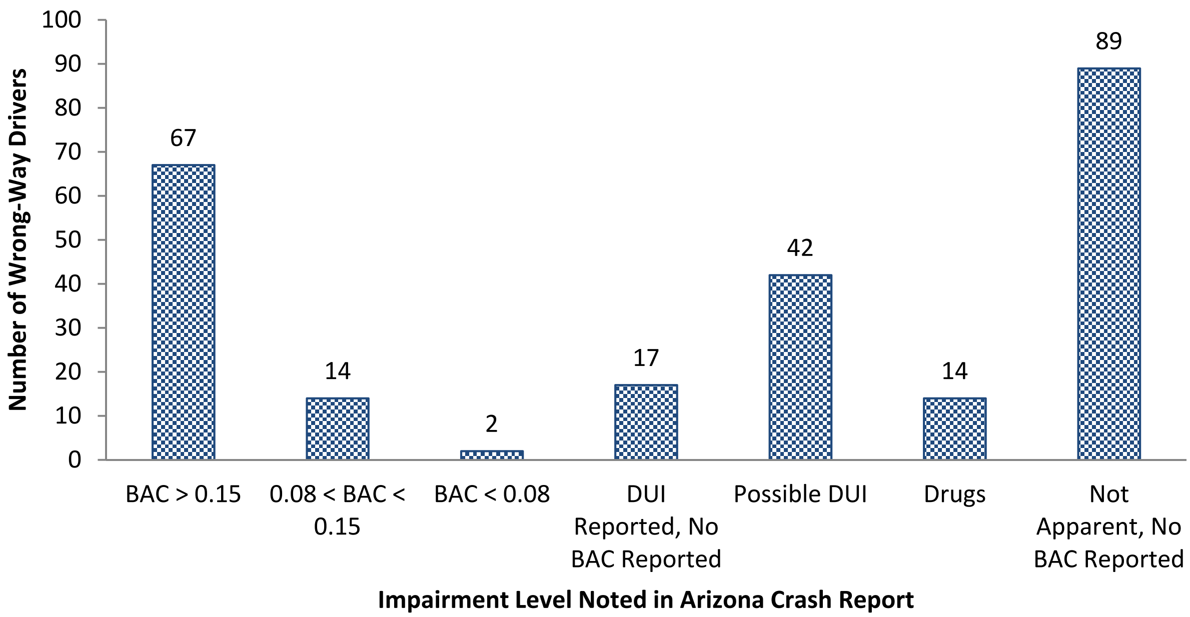


Figure 14. Reported Impairment Levels of Wrong-Way Drivers in Arizona Wrong-Way Crashes on Divided Highways — 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

Figure 15 compares BAC levels of wrong-way drivers with right-way drivers involved in wrong-way crashes. The analysis shows that no right-way drivers had a BAC of greater than 0.15, and only one right-way driver had a BAC above .08 but below 0.15. In contrast, 81 wrong-way drivers had a BAC greater than .08, and 67 of those drivers had a BAC greater than 0.15.

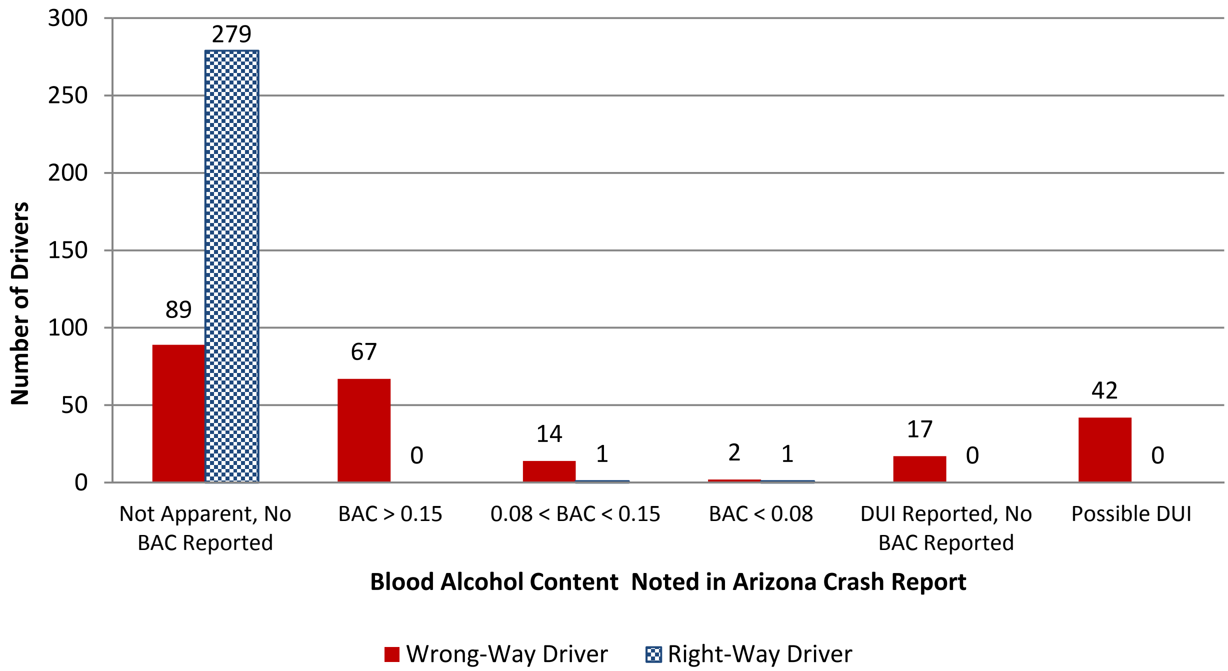


Figure 15. Blood Alcohol Content of Drivers in Arizona Wrong-Way Crashes – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

Alcohol impairment percentages for all crashes in Arizona are shown in Table 4 and compared to alcohol impairment percentages of wrong-way crashes, over the 11 years analyzed. On average, statewide, crashes involving alcohol account for approximately 5 percent of the total crashes. However, 65 percent of wrong-way crashes involved alcohol.

Table 4. Percent per Year of Arizona Crashes Involving Alcohol: Total Crashes Compared to Wrong-Way Crashes (Arizona Department of Transportation 2015)

Year	Percentage of Total Crashes Involving Alcohol	Percentage of Confirmed Wrong-Way Crashes Involving Alcohol
2004	5. 8% (8,005)	75. 9% (22)
2005	5. 5% (7,651)	64. 7% (11)
2006	5. 5% (7,693)	50. 0% (12)
2007	5. 6% (7,889)	66. 6% (18)
2008	5. 6% (6,757)	71. 4% (10)
2009	5. 4% (5,854)	66. 6% (14)
2010	5. 2% (5,489)	50. 0% (12)
2011	5. 3% (5,537)	75. 8% (22)
2012	5. 2% (5,444)	61. 5% (8)
2013	4. 8% (5,190)	75. 8% (22)
2014	4. 4% (4,887)	44. 4% (8)
Average	**5. 4% (70,396)**	**64. 9% (159)**

During the 11 years that were analyzed, the average percentage of overall Arizona fatal crashes with drivers impaired by alcohol was 29.2 percent. Alcohol-impaired drivers in wrong-way crashes during the same period are significantly overrepresented, with 66.1 percent being alcohol impaired. The percentage of all fatal crashes involving alcohol is compared to the percentage of wrong-way fatal crashes involving alcohol by year in Table 5.

Table 5. Percent per Year of Arizona Fatal Crashes Involving Alcohol: Total Crashes Compared to Wrong-Way Crashes (Arizona Department of Transportation 2015)

Year	Percentage of Fatal Crashes Involving Alcohol	Percentage of Wrong-Way Fatal Crashes Involving Alcohol
2004	22. 5% (223)	77. 8% (7)
2005	20. 4% (212)	66. 7% (4)
2006	23. 7% (266)	25. 0% (1)
2007	37. 4% (356)	83. 3% (5)
2008	34. 9% (294)	75. 0% (3)
2009	34. 4% (244)	50. 0% (3)
2010	30. 1% (210)	57. 1% (4)
2011	31. 3% (236)	100. 0% (5)
2012	34. 0% (251)	50. 0% (2)
2013	31. 5% (245)	83. 3% (5)
2014	33. 6% (238)	40. 0% (2)
Average	**29. 2% (2,775)**	**66. 1% (41)**

Because wrong-way crashes are infrequent, the yearly percentages of confirmed wrong-way crashes involving alcohol and the yearly percentages of wrong-way fatal crashes involving alcohol fluctuate. However, when the 11 year average is calculated, these percentages fall within the national average percentiles of wrong-way crashes involving alcohol as reported by NTSB (2012). Due to reporting procedures, the BAC and alcohol impairment are not always captured in the initial police reports of wrong-way drivers. Therefore, these results could be underreported. Consequently, these percentages may be higher than what is disclosed in Tables 4 and 5.

Age

An analysis of the crash data examined the age of the wrong-way driver compared to that of the right-way driver. As shown on Figure 16, the majority of wrong-way drivers were aged 16 to 35. However, in wrong-way crashes involving older drivers, drivers aged 76 and older were far more likely to be the wrong-way driver than the right-way driver.

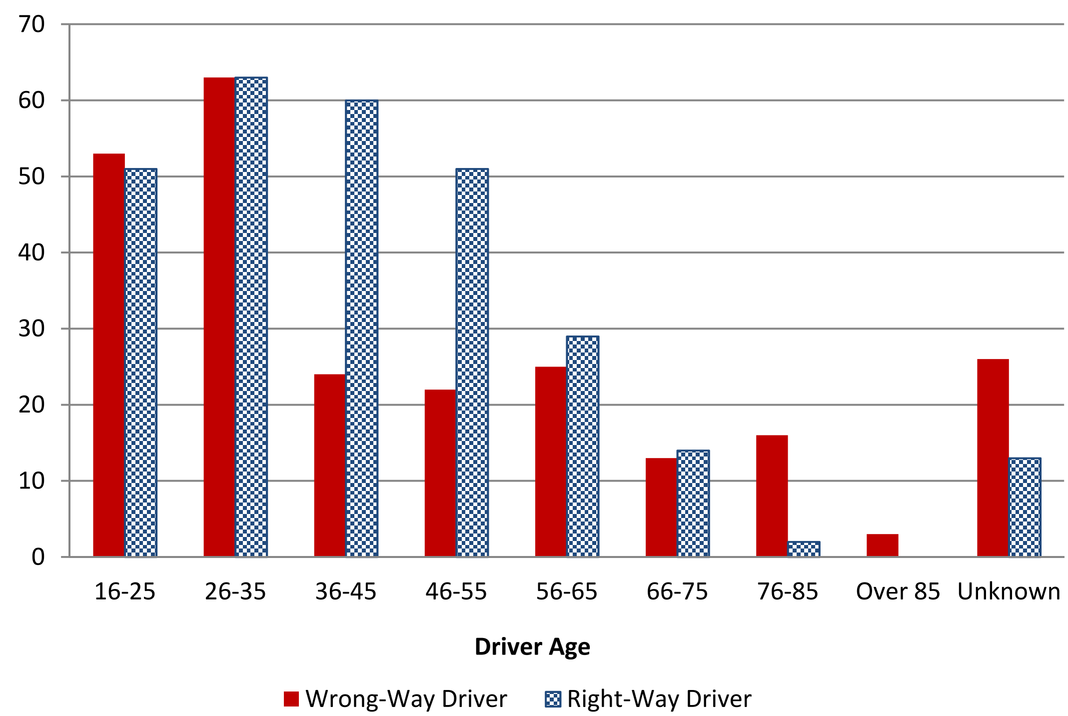


Figure 16. Ages of Drivers in Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

The Arizona data on older wrong-way drivers aligns with other research in the United States. The NTSB (2012) found that drivers over the age of 70 accounted for about 15 percent of the wrong-way crashes nationwide. Arizona's crash data analysis shows wrong-way drivers over the age of 70 were involved in 10 percent of the wrong-way crashes over the 11 year analysis period. Cooner (2004) and Braam (2006) reviewed age of wrong-way drivers in Texas and North Carolina, respectively, which shows that those states also have similar research results. Cooner (2004) found that between 1997 and 2000 drivers over the age of 65 accounted for 13 percent of the wrong-way crashes in Texas. Similarly, in North Carolina, Braam (2006) showed that drivers over the age of 65 accounted for 17 percent of the wrong-way crashes over the review period from 2000 through 2005.

Sex

With respect to sex, Arizona data analyzed from 2004 through 2014 indicated that the majority of wrong-way drivers were male, 65 percent. Females made up 25 percent of the wrong-way drivers, and 10 percent were documented as unknown sex. Figure 17 illustrates that males between the ages of 16 and 35 represent the largest portion of wrong-way drivers in Arizona (35 percent).

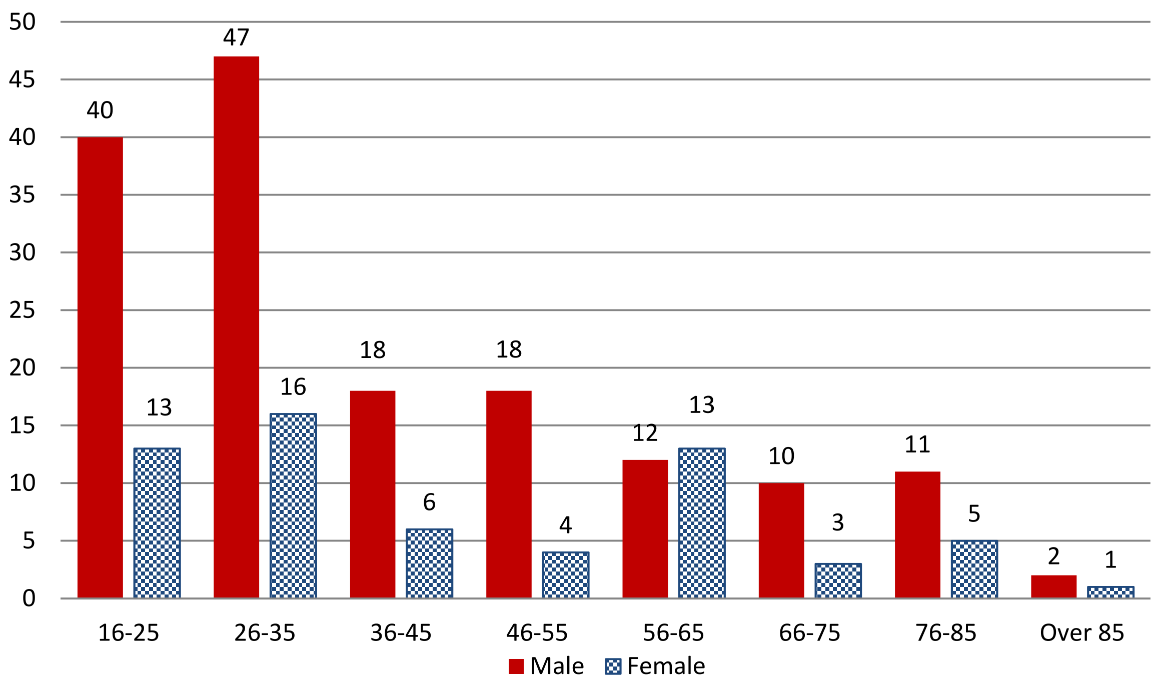


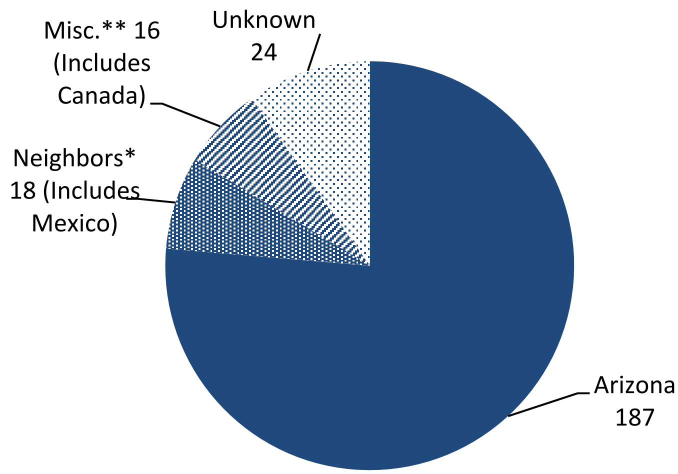
Figure 17. Ages and Sex of Wrong-Way Drivers in Arizona Wrong-Way Crashes on Divided Highways – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

Other Contributing Factors to Wrong-way Entries

Confusion, suicidal intentions, and evading police were additional factors that were documented in the crash summaries. Understanding these factors might assist in developing wrong-way driving countermeasures. The crash summaries noted that 15 wrong-way drivers were confused. Of those drivers, the average age was 72, with ages ranging from 58 to 92. Only two of the wrong-way drivers were noted as being suicidal and that they had deliberately chosen to drive the wrong way on the exit ramp. Four of the wrong-way drivers were evading police when they made a wrong-way entry onto the highway system; the evasive drivers were all males under the age of 31.

Driver License Origin

Based on the analysis of wrong-way crash data in Arizona, the majority of the wrong-way drivers (approximately 75 percent) had Arizona driver licenses, as shown in Figure 18.



* California, 5; New Mexico, 5; Nevada, 2; Utah, 2; Mexico, 4.
** Arkansas, 1; Florida, 2; Georgia, 1; Idaho, 1; Kansas, 1; Michigan, 1; Mississippi, 1;Ohio, 2; South Carolina, 1; Texas, 3; Virginia, 1; Canada, 1.

Figure 18. Driver Licenses (by Issuing State) of All Wrong-Way Drivers Involved in Arizona Crashes – 2004 through 2014
(source: Arizona Department of Transportation Safety Data Mart, current as of February 2015)

SUMMARY

The main function of analyzing wrong-way crash reports in Arizona was to investigate driver behaviors and characteristics, determine if there were high frequency wrong-way crash locations, and consider temporal information – all in an attempt to identify factors or patterns that would assist in the development of countermeasures. Based on this analysis, Arizona's wrong-way crash statistics show no significant difference from national data or other states studying wrong-way crashes. On average, 23 wrong-way crashes and six fatal wrong-way crashes occur in Arizona, annually.

After analyzing the data on driver behaviors and characteristics, the researchers determined that alcohol impairment plays a significant role in wrong-way driving, both on a national level and in Arizona. While the majority of wrong-way drivers were between the ages of 16 and 35, it may also be noted that drivers over the age of 76 were more likely to be the wrong-way driver than the right-way driver when involved in a wrong-way crash. Confusion was established as a contributing factor in wrong-way driving on 15 crash summaries in Arizona, which might be linked to age since the average age of the confused drivers was 72.

Crash locations on both urban and rural highways were reviewed to determine the rate of wrong-way crashes per mile. For Arizona's urban highways, I-17 had the highest crash per mile rate of 0.667 over the 11 year period analyzed from 2004 through 2014. A total of 26 wrong-way crashes occurred on 39 miles of I-17. With eight confirmed fatal wrong-way crashes during the 11 years, I-17 also had the highest confirmed fatal wrong-way crash per mile rate of 0.205.

For Arizona's rural divided highways, SR 89A had the highest rural wrong-way crash per mile rate of 0.214 with three confirmed wrong-way crashes over 14 miles of SR 89A. Two of the wrong-way crashes on SR 89A were located within one mile of the Red Rock Road intersection. SR 80 near Douglas had the highest fatal wrong-way crash per mile rate with one confirmed fatal wrong-way crash in 8.5 miles of divided highway. On I-10 near Quartzite, Arizona, wrong-way driving resulted in three fatal collisions that occurred within 16 miles of each other over the 11-year analysis period.

Temporal analyses showed that wrong-way crashes occur predominately during the weekend in the early morning hours from midnight to 4 a.m. Additionally, July appears to have the highest number of wrong-way crashes when reviewed over the 11-year period from 2004 through 2014.

CHAPTER 4. EXAMINATION OF TECHNOLOGIES AND CONCEPTS

This chapter focuses on developing equipment requirements and concepts that could be implemented as a system to reduce crashes from wrong-way driving. While some of the equipment and concepts presented may feature similarities to each other, this research effort investigated the gamut of options that were readily available. The criteria chosen for the proposed system were that the interacting concepts and equipment must:

- detect a wrong-way vehicle;
- simultaneously alert the errant driver to the mistake;
- instantly notify the ADOT TOC and DPS of the vehicle's entry location;
- track and monitor the errant vehicle on the highway; and
- warn oncoming traffic in the vehicle's general path.

The 2013 Arizona research (Simpson 2013) field tested technologies to detect a wrong-way vehicle, illuminate a warning light on the ramp, and transmit a message to the TOC (Simpson 2013). That study examined the feasibility of non-intrusive technologies (ones not inserted in the roadway's asphalt) — radar, microwave, video, thermal and magnetic detection — and found all could perform the task of wrong-way vehicle detection to various levels of efficiency and reliability without any particular technology outperforming the others.

While Chapter 2 detailed various past and ongoing research efforts, no state or national transportation agency has proven a type of technology or system to the extent that ADOT could immediately implement it. Whatever prototype system might be deployed for field testing, the researchers determined that it would incorporate, whenever possible, ADOT's existing investment in FMS devices, infrastructure, and traffic management tools. ADOT maintains an ITS system comprised of existing communications infrastructure, detection technologies, dynamic message signs (DMS), closed circuit TV (CCTV) cameras, and the TOC facilities employing traffic and law enforcement staff.

ADOT has an extensive FMS fiber infrastructure that links many of the highways within the Phoenix Metropolitan Area. The fiber network currently relays traffic information from detector stations in the pavement to the TOC. The data transmitted includes traffic volume, average vehicle speed, and lane occupancy (how long a vehicle sits in one spot). The data goes to the TOC, where it is logged every 20 seconds. The existing fiber communication network could be used to relay information from the wrong-way detector stations to the TOC and back to impacted notification devices along urban roadways. However, intercommunications with a wrong-way detection subsystem present many challenges. The software now in use would need to be supplemented or replaced in order to relay a wrong-way detection signal back to the TOC for operator notification. The software capabilities would be an issue regardless of whichever detection device or system is eventually selected.

Software also will have to be developed that sends automated commands back to existing field devices giving drivers pertinent information. For example, if a wrong-way vehicle is detected entering the highway, a predetermined automated command could be set that instantly places a message on the nearest DMS alerting right-way drivers of the oncoming vehicle. By automating this command and removing delay caused by human input, this step could inform right-way drivers immediately of an impending danger. While sending automated DMS messages may not be a difficult task, sending ramp meters notifications will be much more difficult due to existing limitations in the ramp meter firmware. Therefore, communications capabilities will need to be phased depending upon ADOT's existing software limitations and their future proposed upgrades to TOC hardware and software.

In order to develop viable concepts and technologies, the system was categorized as consisting of three types of elements:

- Detection Element
- Notification and Monitoring Element
- Driver Information Element

DETECTION ELEMENT

The purpose of the detection element is to discern and verify that a wrong-way vehicle is present on the highway. Ideally, detection should be at two levels (1) fixed: entry point detection, or where the wrong-way vehicle entered the highway system; and (2) moving: the continuing path of the wrong-way vehicle, or in-system detection. Entry point detection identifies the wrong-way vehicle as it enters the highway system, alerts the errant driver of their mistake to enable possible self-correction, and notifies traffic management and law enforcement. In-system detection tracks a wrong-way vehicle's location and speed, serves as secondary confirmation of a wrong-way event, and triggers multiple field devices to warn oncoming traffic of the errant vehicle.

In addition to the two types of detection, the wrong-way detection system would also:

- validate wrong-way events by identifying false calls and
- identify all wrong-way detection events.

The highest priority of the detection element is to accurately detect wrong-way events. Therefore, the focus of the detection element is to properly match detection devices with their logic execution processes, verification processes, and event announcements for further action. Current traffic detectors in the pavement already have some of the critical components that could be modified to detect a wrong-way vehicle and send information to the TOC. However, the existing devices and processes would need to be enhanced specifically for wrong-way detection.

Highway exit ramps do not have in-pavement traffic detectors that register vehicles exiting the highway, because ordinary traffic detection is not necessary at those points for routine operations. To enable wrong-way vehicle detection, vehicle sensors would need to be added to the exit ramps. Installation and deployment must take manufacturer recommendations into consideration to maximize system performance and obtain full system reliability. Wrong-way detection will require a mixture of the existing infrastructure technologies enhanced with new systems and technologies.

Viable detection elements that may be considered for possible pilot deployment on both the highway and exit ramps are loop detectors, radar, microwave, magnometers, and video. GPS technology is anticipated to hold promise further in the future, but it is not yet developed enough to be an available component for ADOT's needs.

Loop Detectors

Inductive loop detectors have been used for decades to detect vehicles at traffic signals and count vehicles on roadways. Loop detectors provide a mature technology and support the traditional "wire in pavement" concept. Loop detectors are called an intrusive technology because they are installed by cutting a slot in the pavement and then coiling wire inside for inductance. Loop detectors require a power source and a means to communicate information back to a controller for processing the data they collect.

ADOT uses loop detectors in Phoenix and Tucson for highway traffic detection, ramp metering, and queue detection for on-ramps. Existing loop detectors on the state highways are usually installed within each lane and typically near the on-ramp gore. With modifications, the existing in-system detection may be able to track a wrong-way vehicle on the highway.

The complication with loop detectors is that they only detect at a single fixed point, and unless those point actuations are correlated with a processor, they are simply "blips" indicating passage of a vehicle over a point in the roadway, with no association of travel direction. If a pair of loops in a single highway lane are processed under the assumption that the upstream loop is loop "A" and the downstream loop is loop "B," the typical assumption is that activation of “A” prior to “B” indicates traffic flowing in the expected direction; likewise, activation of “B” prior to “A” indicates an anomaly — a wrong-way vehicle. This concept requires logic checks for time elapsed between A/B activations establishing a range of speeds for which the A/B and B/A observations are valid. Traffic at very low speeds could be misinterpreted by the loop detection system, resulting in no actuation on the A loop, actuation of the B loop, then interpretation of a closely spaced vehicle that is activating the A loop as a wrong-way vehicle. Consideration of wrong-way vehicle speeds suggests that an errant vehicle is not traveling at extremely slow speeds, making the B/A logic evaluation a possibility and worthy of consideration.

Existing freeway loop sets are currently linked to a roadside processor that evaluates impulses from the loops and performs tasks associated with monitoring traffic speeds, gaps, and ramp metering releases for an on-ramp. Therefore, the existing loop software would require an additional routine to test for B/A actuations above a threshold speed parameter to identify a wrong-way vehicle. An advantage of this strategy is that the existing in-system loops are currently monitored on a per lane basis and linked to the TOC; this current structure would allow for immediate communication of wrong-way actuation. Further enhancements could be made to the loop software that would calculate the wrong-way vehicle's speed and convey the data to the TOC.

Loop detection at off-ramps offers a different set of challenges. First, no existing detection systems are in place on the freeway exit ramps, which are usually the suspected entry point of wrong-way drivers. More loops could be installed on exit ramps to detect wrong-way vehicles. In order to obtain directional detection, two or more loops located in the off-ramp lane would be required. Installing a third loop on the off-ramp would offer a more robust confirmation through expanded logic tests. Next, communications from the loops to field devices and the TOC are necessary. This can be addressed in two ways: 1) a new cabinet and controller could be installed to process wrong-way loop detector information, or 2) assuming that the interchange is signalized, a traffic signal control cabinet would be in proximity to the off-ramp. However, not all existing interchange traffic signal cabinets utilize loop detection, as some alternative forms such as video detection or radar are present at some locations.

Operations of the off-ramp wrong-way loop detectors would require a processing platform (similar to the B/A logic steps described for the in-system freeway detection) to minimize false notifications. If existing traffic signal cabinets were selected for a pilot deployment, the wrong-way loop detectors would need to be isolated from the traffic signal detection. Wrong-way notifications then would be routed through a separate processor designed to perform the minimum speed and B/A tests.

Radar Detectors

Radar detectors are non-intrusive devices (not implanted in the pavement) mounted above-ground on poles and require wiring for power and communications. Radar devices are sensitive to mounting location, so the manufacturer's guidelines should be followed to properly select the mounting location. One sensor could cover multiple lanes depending upon placement, meaning one detector on an exit ramp may be sufficient. Other factors to consider for radar include nearby structures and freeway noise walls, mounting height, mounting offset, and cable lengths (device to cabinet).

Currently, ADOT uses radar detection as a supplement to loop detectors to collect average speed, traffic volume and lane occupancy at locations where loop installations are not feasible, such as bridges. Therefore, ADOT has the ability to bring radar information back to the TOC. However, using radar to identify wrong-way vehicles requires specific software modifications to the communications equipment that ADOT does not currently provide.

In 2012, Simpson (2013) tested radar as a possible wrong-way driving detection device. Simpson found that the radar system detected wrong-way vehicles successfully during the controlled test runs and that the detector communicated successfully by illuminating a strobe. During the controlled and field testing procedures, email notifications were not activated for the radar devices. Therefore, false calls could not be documented or evaluated based on the trial installation.

In late 2014, ADOT installed two wrong-way radar devices for testing and evaluation. No results of this effort are available, yet. However, the system was designed to test email notifications based on wrong-way vehicle detection.

Overall, radar detection is a viable option for wrong-way detection on both the highway and the exit ramps. If radar is installed, a processing platform will be required to send notifications to the TOC and DPS when a wrong-way vehicle is detected.

Microwave

Microwave is another type of non-intrusive device that could be used to detect a wrong-way vehicle. Microwave is similar to radar in that it is mounted on a pole near the highway and faces perpendicular to the traffic lanes. Microwave sensors are programed for the number of lanes and can detect traffic up to 120 feet away from the sensor. Microwave may have an advantage over radar because microwaves can diffract around counters to detect vehicle that are hidden by other vehicles.

Microwave is not currently used by ADOT in any capacity. However, in 2012 Simpson (2013) tested microwave technologies for wrong-way detection. The microwave detector successfully detected all wrong-way vehicles during the controlled testing runs at varying speeds and activated the strobe in conjunction with an email notification. During the field testing period, three confirmed false calls were recorded.

Magnometers

Magnometers are in-pavement wireless vehicle detectors that transmit real-time data for a variety of traffic applications. These small devices are placed in each lane under the pavement and collect average speed, traffic volume, and occupancy. ADOT currently uses magnometers in the Tucson area for their FMS detector stations.

If these devices are installed in an array, algorithms could be developed to detect wrong-way vehicles. In 2012, Simpson (2013) tested magnometers as a technology to detect wrong-way vehicles. During the field testing, the magnometers did not produce any false calls. Additionally, the magnometer detection system successfully recognized the wrong-way test vehicle when it traveled straight down the ramp within the marked lanes. During the controlled testing event, magnometers had difficulty detecting the test vehicle in the middle of the ramp if it overlapped lanes. However, after the controlled testing procedure concluded, it was noted that a programming error was responsible for the middle lane issues. The magnometers were re-programmed and the system ran for an additional 6 months in the field with no false calls or detector errors. Images from the magnometer detection system were sent to the TOC for testing and evaluation purposes when wrong-way vehicles were detected.

Magnometors are a viable option for wrong-way detection on both the highway and exit ramps. This system was tested for an extended 6 month period and demonstrated that it may be a successful detection technology for ADOT’s consideration.

Video

Video detection has been used by ADOT for many years at freeway interchange signals. Video detection offers the additional capability of transmitting the video image to a TOC without requiring an additional capture camera. Video detection operates on the principal of a processor evaluating movements in a user-defined zone, within a fixed field of view. Depending on processor capabilities and user programmable parameters, video detection "looks for" movements in the defined zone and subsequently reports that movement to a traffic signal controller in a format the recipient processor understands (typically "presence" or "pulse") for use in operating some form of traffic management tool, such as a traffic signal operations, vehicle counts, or actuating pedestrian or bicycle movements.

Since video detection is fixed view, the user must consider the optimum aspects of camera placement in order for the video detection to operate to its highest capability. Such factors as angle of view, visual occlusion, lighting, direction of sun angle, height and directionality to the intended target are factors that must be addressed. Some manufacturers offer the ability to distinguish movement in a predefined direction, or movement in a direction opposing the defined direction, a potential detection trigger for wrong-way vehicles. The typical configuration of video detection, as arranged at an interchange serving off-ramps does not view distances beyond 100 feet from the stop line.

In the Proof of Concept demonstration, video detection was found to be sensitive to mounting location relative to the event being monitored (Simpson 2013). Given that traffic signal detection is typically conducted by a camera located on the far side of the approach, use of the existing video detection is not an optimum set-up for detecting a wrong-way vehicle. Therefore, additional video detection cameras and cabling would be required to achieve optimum placement for wrong-way detection.

If video detection is chosen as an option for wrong-way detection, it tends to be more efficient at angles closer to perpendicular movement. Therefore, wrong-way video detection should be located closer to, and above the spot to be detected. Possible locations include an existing traffic signal or highway lighting pole, if the pole position is favorable to video view aspects.

NOTIFICATION ELEMENT

This element includes notifying the TOC and law enforcement of a wrong-way vehicle's location and speed if the errant driver continues onto the highway system. The notification element relays a verified wrong-way vehicle detection event to systems and staff capable of initiating warning, interception and enforcement. The notification element assumes that the detection element included a communications media and strategy to transmit a notification message to a predetermined destination. The notification element is used to track the wrong-way vehicle through the highway system. Therefore, this element feeds adjustments to the warning element during the wrong-way event.

Because the notification element consists of several different communication devices, multiple notification element strategies could be developed for the proposed pilot deployment.

Notification to ADOT Traffic Operations Center

The notification from a wrong-way detector must be sent to the ADOT TOC, where it is received, interpreted, visually verified by CCTV cameras, and reacted to through automated pre-determined plans or trained staff. The initial stage of deployment should consider a notification strategy that would automatically trigger multiple simultaneous signals both visually and audibly, such as:

- Workstation text messages emphasized by special font size and style (visual)
- Video wall messages that preempt routine wall displays to allow simultaneous mass notification (visual)
- Emergency audio alerts, emphasized by tone and volume, sounding simultaneously at workstations and in the control room (audible)

Upon system notification of a wrong-way event, the TOC control room operators would immediately execute a set of procedures, coordinated with law enforcement and TOC management, to locate, confirm, react to, and monitor the wrong-way event through to its completion. These procedural steps would include a predetermined hierarchy of which individuals perform particular tasks and decisions, disseminate critical information, perform reliable confirmation processes, log wrong-way events and outcomes, and develop a process to review the strategies to determine if the wrong-way event history suggests an adjustment in the process.

Ideally, when a wrong-way notification would trigger audible and visual alerts at the TOC, the programmed CCTV camera would automatically aim upstream of the activated wrong-way detector location. The camera would allow the operators to visually confirm the wrong-way event, to identify the vehicle, and to then describe the vehicle to law enforcement. As the wrong-way event continues, additional CCTV cameras would activate along the vehicle's potential path and provide upstream images, thus providing remote visual tracking of the wrong-way vehicle. Operators would have the capability to manually assume CCTV camera control in case the wrong-way vehicle appears to stop moving or change course. Additional notification may be desirable by automated e-mail or text message to other management and support personnel.

Notification to Law Enforcement

Currently, DPS relies on 911 callers to locate wrong-way vehicles. Law enforcement then must intercept the wrong-way vehicle by estimating its direction and location, until the next 911 caller provides an update. A more effective strategy is to immediately locate a wrong-way vehicle using a wrong-way detection and continually update law enforcement of their location, direction, speed and vehicle description, automatically. During periods where law enforcement personnel are present at the TOC, the automatic notification triggers will initiate their involvement in the wrong-way event and they will be able to join the assessment and confirmation process with the control room operators, reacting suitably with other DPS staff.

During periods where law enforcement personnel are not present at the TOC, a formal procedure would be established to address the message relay process. Statistics show that most wrong-way events tend to occur during the early morning non-peak traffic periods. Law enforcement may consider the merits of staff dedication to hours of highest historical wrong-way event occurrence as an additional support measure. Alternatives may include a remote monitoring capability by a designated staff from a location other than the TOC, if suitable support systems for video, data and communications are provided.

General or mass notifications to parties beyond trained traffic and law enforcement professionals would not be productive in terms of the ability to evaluate, confirm, and react to wrong-way vehicle triggers.

The Notification Element Candidates for Evaluation

Notification is the backbone of the wrong-way detection system. It joins the detection element to the warning element. Therefore, the following six candidates are potential elements that could be used in notification. While similar, these six elements have different capabilities in notification and could be used individually or more effectively together, each bringing a unique element to the wrong-way detection system.

Capture Cameras – The purpose of a capture camera is to take a video or series of photographs of the wrong-way vehicle upon activation of the wrong-way detector. The images are immediately sent to the TOC operators for confirmation of a wrong-way entry. Capture cameras can be programmed to recall the event a set number of seconds before and after the wrong-way detector is activated. During pilot deployment monitoring and analysis, capture cameras are critical in diagnosing false calls and should be installed near all wrong-way detectors.

TOC/DPS Visual Prompt – A visual prompt should immediately display on all operators' monitors when a wrong-way event is activated. This visual prompt could include a red flashing border around the monitor with the capture camera images, or another obvious signal that a wrong-way event is in progress. No software currently exists to run this visual prompt. Therefore, software will need to be developed as required for the suggested system is deployed on a pilot basis.

TOC/DPS Audible Prompt – An audible prompt that notifies the TOC of a wrong-way vehicle entry and its location is another notification candidate for evaluation. The tone would alert operators of the wrong-way entry and the announcement would then tell the operators which wrong-way detector was activated.

CCTV Cameras – Currently, the TOC uses CCTV cameras to monitor traffic conditions. However, when a wrong-way event takes place, the cameras could be programmed with automated stops to immediately pan to the pre-determined location, allowing operators to monitor the wrong-way vehicle without manually trying to find its location. These pre-set stops would assist operators in locating the wrong-way vehicle, instantly. As the wrong-way vehicle traverses on the highway and triggers the next detector, the previous CCTV camera would hand off the image to the next camera to continually track and monitor the wrong-way vehicle.

Email Notification – Email notification could be used to instantly alert TOC operators of an activated wrong-way detector. The email notification could activate other notification devices. Email notification is already a function at the TOC and could be programmed more easily than other notification elements.

Logging System – A logging system is important to archive wrong-way events. The logging system should be a database type application and include fields such as time of day, date, entry location, detectors activated during call, images or video obtained from the capture camera, and other pertinent information about the wrong-way incident.

Table 7 summarizes the notification candidates for evaluation.

Table 7. Notification Candidates for Evaluation

Technology Option	Current Use	Potential Use
Capture Cameras	N/A	Used for confirmation of a wrong-way driver
TOC/DPS Visual Prompt	N/A	Used to notify an operator of a wrong-way event
TOC/DPS Audible Prompt	N/A	Used to notify an operator of a wrong-way event
CCTV Cameras	Used to monitor traffic conditions	Used to monitor the wrong-way event. Could be programmed with pre-determined camera stops.
Email Notification	Currently under ADOT evaluation and testing.	Used for others outside the TOC that have an interest in wrong-way events
Logging System	N/A	System that logs wrong-way events, triggered detectors

DRIVER INFORMATION ELEMENT

The purpose of the driver information element is to inform drivers so they can react to the wrong-way event. The driver information element would alert both the errant driver and any right-way driver near the activated wrong-way detector.

Warnings to the Wrong-Way Driver

The success of a warning system, intended to correct the errant driver, is subject to the mental condition and capacity of the errant driver. If the errant driver is impaired, the driver's capacity to make an appropriate decision is reduced. Likewise, drivers impaired by medical or age-related issues may be less likely to successfully react to and correct a wrong-way event on their own. However, some wrong-way situations are driver errors, correctable by drivers who have the capacity to apply logic and decision processes to successfully and safely correct a wrong-way situation without harming others or continuing onto the highway.

The first layer of driver information targeting the errant driver should be a warning at the entry point. Recent initiatives by ADOT and other states have emphasized with success the use of larger and more prominently displayed wrong-way signage, enhanced pavement markings, and raised pavement markers showing a red color to drivers travelling in the wrong direction. These forms of information are static and rely on the driver to be cognizant enough to see, interpret, and react on their own.

A second layer of driver information is a dynamic form of information that attracts the driver's attention by visual, audible, or tactile stimulus. Such devices could offer flashing lights, audible signals (horns, tones or sirens), or some form of movement or vibration to attract the driver's attention. Some highway signs have illumination elements in or around the sign panel that activate only upon wrong-way vehicle detection. Such systems are readily available from multiple vendors to perform the local detection and flashing light tasks, making them an immediate deployment option. Some have integral communications and camera capabilities. These signing techniques can also be developed specifically for ADOT using the loop detector option. Research in Texas suggests that impaired drivers have to be closer to signs with flashing red LEDs around the border before they can read the legend compared to signs without flashing LEDs (Finley 2014). Supplementing illumination with some form of audible tone may increase the opportunity for driver attention, but may be discouraged in areas with nearby conflicting land uses that may not be amenable to audible warnings.

Another visual concept may be the use of traditional sized (8 inch or 12 inch) red LED signal sections attached to the left and right side of an oversized WRONG WAY sign, activated by wrong-way detection, to assure a driver's attention during the bright daylight hours as well as night environments. Additional yellow warning flashers could be positioned at the diverge area of the off-ramp and/or adjacent to the highway shoulder with a special sign to warn of an oncoming wrong-way driver. LED blank-out signs that illuminate only upon actuation by the detection element may be deployed along the ramp or mainline as attention-getting devices with or without flashing elements.

The concept of an overhead sign and flasher assembly attached to an existing overhead sign structure or overpass bridge may be considered. Such device could be remotely activated by the detection element or contain its own detection element to activate 12" red LED signal section flashers next to a large WRONG WAY sign. At increased cost, the static wrong-way sign could be replaced with a sign implementing dynamic elements or characters that illuminate and/or produce audible stimuli.

Because impaired wrong-way drivers tend to look more at the pavement in front of their vehicle and search the forward driving scene less than non-impaired drivers, in-pavement countermeasures may have some merit in research and review (Finley 2014). This system could include flashing pavement markers that are activated upon a wrong-way entry.

There are other stimulation techniques that may work to correct an errant driver. Recent systems in Australia successfully utilize a wall of water as a means of attracting driver attention by combining a physical impact upon the vehicle with visual stimuli to attract driver attention. This is not a viable candidate for Arizona's freeway ramp layout. Another form of physical attention-getting may have merit is some mechanism by which the vehicle experiences vibration to a level that attracts driver attention without causing panic. The research team is currently investigating whether a directional rumble strip has been developed by any agency that is "neutral" to traffic traveling in one direction but produces noticeable vibration for vehicles traveling in an opposing direction.

The use of tire spikes or other similar destructive forms of disabling a wrong-way vehicle cannot be considered by ADOT because they pose significant risk to drivers traveling in the correct direction on exit ramps. A vehicle disabled "safely" within the confines of the travel way becomes a fixed object for other drivers and presents an undesirable hazard. A variation of this concept is the usage of extendable stop strips that can be deployed and retracted quickly. For similar safety reasons, these approaches are undesirable and confined to use by law enforcement, under the most extreme conditions.

The ideal wrong-way driver information system should combine static, visual, audible and vibration stimuli. However, because no acceptable vibration system has been identified, initial deployment is limited to the static, visible and audible warnings. An initial deployment of static/visual and static/visual/audible stimuli at select locations where the audible aspects will not impact adjacent land uses should be considered at off-ramps as a means of initial entry point warning.

Warnings to Right-Way Drivers

An unfortunate consequence of wrong-way driving is collisions with right-way drivers traveling lawfully in the correct direction. Therefore, these drivers should be warned of the oncoming potential danger and given an opportunity to react to that notification. Studies in Germany found that when given an alert of an oncoming vehicle, the right-way driver was more apt to avoid the head-on collision than without the notification (Oeser, et al. 2015).

The existing FMS in Phoenix and Tucson have the ability to post messages on existing DMS warning about a potential oncoming vehicle. The success of this approach is highly dependent upon quick reaction of TOC operators posting messages upstream to the wrong-way vehicle. This process is intended to be refined with deployment of a wrong-way detection system capable of detecting and notifying operators so they have the tools to post warning messages, and ultimately automatically post DMS messages based on reliable detection, confirmation and tracking of the wrong-way vehicle.

Because DMS are typically spaced approximately three miles apart in the urban areas, and much further apart in rural areas, gaps in potential warning areas exist. One potential solution to this gap issue is to mount additional signs with yellow 12 inch LED signals sections adjacent to the signs or dynamic blank-out signs that illuminate and display their message only upon activation by a TOC operator or automated wrong-way detection system.

Upstream ramp meters could be automatically set to solid red when a wrong-way driver triggers a detector. This would minimize exposure to the right-way drivers by disallowing additional traffic to enter the highway. Education would be essential to inform the public that a solid red ramp meter should be obeyed, especially during weekend travel in the early morning hours.

Emergency Notification Systems

Other forms of notification may be useful to right-way drivers and other target audiences, such as work crews who are active on the highway but may not encounter a DMS message. A possible example would be coordinating with the Arizona Division of Emergency Management (ADEM) to implement an emergency alert, similar to an Amber Alert, that would send a tone and text message to cellular phones warning of a potential wrong-way event. This wrong-way alert — if approved by ADEM — would be most effective if it were limited to cell towers in the vicinity of wrong-way detection or downstream from predicted areas covered by additional cell towers so as not be dismissed as irrelevant by unaffected drivers. The message format could convey the location and direction of the wrong-way vehicle to ensure that right-way drivers make a judgment as to applicability to their driving situation. Cellular phone users currently have the ability to block any non-presidential alerts.

Table 8 presents a summary of the driver information candidates for evaluation.

Table 8. Driver Information Candidates for Evaluation

Technology Option	Current Use	Potential Use
	Wrong-Way Driver	
Illuminated sign at off ramp	N/A	Sign triggered by the wrong-way driver giving them information that they are traveling in the wrong direction
Audible Signal	N/A	Triggered by wrong-way driver
In-Pavement Lights	N/A	Triggered by the wrong-way driver
	Right-way Driver	
Lights along mainline	N/A	Lights along the mainline to warn right way drivers when wrong-way driver is detected in rural applications
Ramp Meter	Currently used to adjust traffic flow onto the freeways, was in the vicinity	Set to solid red when a downstream detector is triggered. This would stop freeway entries when a wrong-way driver is in the vicinity
DMS	Currently used to provide traveler information and notification of a wrong-way driver in the vicinity	Could be programmed to automatically display a predetermined message if a detector senses a wrong-way vehicle in the vicinity of the DMS
Emergency Alert System	N/A	Could be used to broadcast the location and direction of a wrong-way vehicle

CHAPTER 5. ASSESSING AND SELECTING THE SYSTEM ELEMENTS

Assessing viable field equipment that best detects a wrong-way vehicle, notifies officials, and warns both types of driver (wrong-way and right-way) was a key task in this research effort. Only systems that meet the minimum requirements set by the performance criteria will be considered for potential deployment. No equipment was tested in the field during this research. Performance measures are solely based on previous research and ongoing ADOT testing. Testing of the preferred equipment would occur during a pilot deployment.

This effort centers on developing a viable pilot system to deploy using available technologies that are compatible with ADOT's existing FMS. The candidates can be combined in a variety of ways to create a wrong-way detection, warning, and notification system specific to ADOT's needs. The suggested system consists of the following elements:

Detection Element

- Entry point detection
- In-system detection

Notification Element

- Warnings within the TOC and DPS, triggered automatically by wrong-way detection

Warning Element

- Warning for wrong-way driver on off-ramp
- Warning for right-way drivers on mainline

PERFORMANCE MEASURES

The goal of this task is to combine all of the input from the technical advisory committee, decision makers and the literature review to establish performance measures for the wrong-way detection system leading to a viable pilot system. Not all performance measures are applicable for every element. Therefore, the score was determined as the average for the element. Each performance measure is followed by a short description along with guidance on how to score a five. Assigning the actual score within the range required engineering judgement and knowledge of each element.

<u>Constructible</u>

Detection Element — Equipment that is more easily installed in the field scored higher. Additionally, impacts to existing traffic during construction were considered. In order to receive a five, the detection technology must be non-intrusive and not installed within or over the traffic lanes.

Warning Element – An assessment of the temporary impacts to the public during construction related to traffic disruptions, detours and delays. Additional considerations include construction noise, dust and ease of installation.

Reliable

Detection Element — The technology that is selected to detect a wrong-way vehicle must be reliable. The technology must function during all weather conditions, and specifically in hot dry climates. In order to receive a five, the equipment must have been tested by ADOT or in use through ADOT's FMS system.

Notification Element — Systems that automatically perform their task without manual input will be ranked higher than systems which require manual input from a TOC operator.

Warning Element – Technology that has been tested by ADOT and performs when a detector is triggered will be ranked higher than technologies that have not been tested.

Accurate

Detection Element — This performance measure includes the technology's ability to pick up all wrong-way vehicles without missed calls or false detection. A missed call is defined when the detector fails to detect a wrong-way vehicle. A false detection is defined as a positive detection without the presence of a wrong-way vehicle. A numbering system from one to five will be used to represent reliability, with one being the least reliable and five being the most reliable.

Notification Element – Automatically sending a workstation notification to TOC operators of an errant vehicle, consistent with a set standard protocol, will rank higher than notification through tracking manually.

Warning Element – The device must correctly and immediately respond to a trigger from the detection element. The warning message must accurately deliver information to the right-way or wrong-way driver.

Cost

All Elements — The element costs are weighted according to their lifecycle cost that takes into account the longevity of the technology. For this technology, 20 years is considered outdated and the equipment would need to be upgraded. If ADOT currently owns and maintains the equipment, a five was received. The costs were ranked as follows:

Five - $5,000 or less equipment cost and $1,000 or less yearly maintenance cost.
Four - $10,000 or less equipment cost and $1,000 or less yearly maintenance cost.
Three - $15,000 or less equipment cost and $2,000 or less yearly maintenance cost.
Two - $20,000 or less equipment cost and $3,000 or less yearly maintenance cost.
One - over $25,000 equipment cost

Maintenance

Detector Element — The system may require built-in measures to make sure the detectors are fully operational at all times. This performance measure gives more weight to a detector that is easier to maintain. The more often a system requires maintenance, the lower the number given from one to five. If ADOT currently maintains an element, then that element received a five.

Notification Element – Maintenance considerations include longevity, ease of maintenance, and software modifications/upgrades. If ADOT currently maintains an element, then that element received a five.

Warning Element – Items that will require more care and field checks were given a lower number. Elements with flashing lights require more care than elements without. If ADOT currently maintains an element, then that element received a five.

<u>Integration with ADOT System</u>

Detector Element — Detection devices that have been used by ADOT in the past and are known to operate within the existing FMS system are weighted greater than newly proposed detection equipment.

Notification Element — The ability to integrate the system into the existing FMS is viewed more highly than a separate system. This will benefit operators, dispatchers and others that will be required to use the system. Therefore, a higher value, from one to five, is given if the notification system integrates into the ADOT FMS system. A five is given if the element is already integrated into the ADOT FMS system.

Warning Element – Items that will easily integrate into the existing FMS system were weighted higher than elements that will require a new system.

<u>Adaptable to Future Changes</u>

All Elements — Because technology and protocols change rapidly in this industry, the system should be adaptable. Systems that are known to be flexible and work with various software packages will be ranked higher than those that do not.

<u>Resistance to Vandalism</u>

All Elements — Vandalism is an issue with ITS technologies. Equipment that is placed lower than 12 feet in the field and is easily accessible to vandals will be ranked lower than equipment that is embedded in the pavement or mounted where it is difficult to reach.

<u>Redundancy</u>

Notification Element — If the device provides or can provide back-up in wrong-way notification, a higher value is given to the element.

Note: Any detection or warning element can provide redundancy if combined with another device, so this is not used as a performance measure for the detection or warning elements.

Dual Functionality

All Elements — Some equipment can perform two tasks at once. If the equipment is able to perform its normal operation and detect a wrong-way vehicle, it will be ranked higher than equipment which only serves one purpose.

Response Time

All Elements — The quickest response times will be rated with the highest value from one to five.

Data Logging

Notification Element — Using the system to capture data about a wrong-way crash is viewed as desirable. When a detector is triggered and signals the TOC, the data can be automatically logged into a database. This data could be used to enhance the system in the future. If logging capabilities are available, the element receives a score of five.

Safety

Warning Element — An errant driver is notified of a wrong-way entry through lights and/or audible sounds triggered by the detector. A higher score is placed on warning elements that have performance documentation.

Tested by ADOT

All Elements — In order to receive a five, the equipment must have been tested by ADOT or in use through ADOT's FMS system and perform well.

SCORING

All performance measures were given equal statistical weight because of unknowns prior to the pilot deployment. This may be subject to change after the pilot deployment with experience, modifications to the system, and data to evaluate after the wrong-way pilot is deployed.

Table 9 presents the scoring for each detection element evaluated. With these technologies, the equipment could be selected to stand alone, or to be coupled with other types of detectors, depending upon such installation factors as location, difficulty of installation, and equipment constraints. The technologies that scored the highest in the detection element category were loop detectors with an average score of 4.45, followed by radar with an average score of 4.18. These two technologies would be the best potential candidates to explore as possible wrong-way detection devices through the pilot deployment testing and evaluation period.

Table 9. Performance Measures for the Detection Elements

Candidate Alternatives for the Detection Elements		Constructible	Reliable	Accurate	Cost	Maintenance	Integration with the ADOT System	Adaptable to Future Changes	Resistance to Vandalism	Dual Functionality	Response Time	Tested by ADOT	Total Points Awarded	SCORE
Detection	Loop Detectors	3	4	5	5	4	5	5	5	5	5	3	49	4. 45
	Radar Detectors	5	4	4	4	5	4	5	3	2	5	5	46	4. 18
	Magnometers	4	3	5	2	3	5	5	5	5	5	2	44	4. 00
	Video/Thermal Video Detectors	5	4	4	3	2	4	5	3	3	3	2	38	3. 45
	Microwave Detectors	5	3	5	4	3	3	3	3	1	5	2	37	3. 36

(Performance Measures: Constructible through Tested by ADOT)

While all candidate alternatives from Table 10 could be operated individually to notify TOC operators or law enforcement of a wrong-way entry, the highest ranked elements combined together, create a more cohesive notification system that forms the backbone communications structure from the field conditions to the TOC. Therefore, while these candidate alternatives were scored individually it is understood that multiple notification elements will be chosen for the pilot deployment, because each element has a slightly different function even though they all notify in one way or another.

Table 10. Performance Measures for the Notification Element

Candidate Alternatives for the Notification Element		Reliable	Accurate	Cost	Maintenance	Integration with the ADOT System	Adaptable to Future Changes	Resistance to Vandalism	Redundancy	Dual Functionality	Response Time	Data Logging	Tested by ADOT	Total Points Awarded	SCORE
Notification and Monitoring	Email Notification	5	5	5	4	5	5	5	5	1	4	5	3	52	4. 33
	CCTV Camera	4	4	5	5	5	4	5	5	5	3	1	1	47	3.91
	Capture Video	4	5	3	2	3	4	3	5	5	4	5	3	46	3. 83
	TOC/DPS Visual Prompt	5	5	3	3	1	3	5	5	1	5	4	1	41	3. 41
	TOC/DPS Audible Prompt	5	5	4	3	1	3	5	5	1	5	2	1	40	3. 33
	Logging System	5	5	2	2	2	2	5	1	1	4	5	1	35	2.91

(Performance Measures: Reliable through Tested by ADOT)

Based on the performance measures and score, email notification scored the highest and should be used initially in the pilot deployment for notification transmission from a triggered detector back to the TOC. In addition, CCTV cameras should be used to locate a wrong-way vehicle on the highway. If possible during the pilot deployment, pre-set camera location stops should be developed based on detector locations to automatically set the camera view if a wrong-way alert is received. The capture video is also an important device that should be installed during the pilot deployment. This camera will capture photos or video prior to and right after a triggered wrong-way event. The capture camera should be used for confirmation of a wrong-way event into the highway system, and when triggered, images should appear automatically on TOC operator's computer screen and the video wall. TOC visual should be considered in the pilot deployment. However, audible prompts may also be needed depending upon further analysis after the pilot system is operational. An automated logging system should be considered in the future to archive wrong-way events for further research and analysis. For the pilot deployment; however, a manual logging system could be implemented initially until an automated logging system is developed and tested.

Table 11 scores candidate alternatives for both wrong-way driver warning elements and right-way driver warning elements. Wrong-way driver warning elements include those that would be installed on the off-ramp to notify the errant driver of their mistake. Right-way driver warning elements include those that would be installed on the highway system and used to notify the right way driver of an oncoming vehicle.

Table 11. Performance Measures for Warning Elements

Candidate Alternatives for the Warning Element		Performance Measures												Total Points Awarded	SCORE
		Constructible	Reliable	Accurate	Cost	Maintenance	Integration with the ADOT System	Adaptable to Future Changes	Resistance to Vandalism	Dual Functionality	Response Time	Safety	Tested by ADOT		
Wrong-Way Driver	LED Signal Heads Mounted On Top of Sign	5	5	5	5	4	5	5	2	1	5	3	3	48	4. 00
	LED Flashing Sign	4	5	5	4	4	4	4	3	1	5	4	3	46	3. 83
	In-Pavement Lights	3	5	5	3	3	3	4	5	1	5	4	1	42	3. 5
	Audible Notification	4	5	5	5	4	3	3	2	1	5	3	1	41	3. 41
	Small DMS	3	5	4	1	3	3	5	1	5	5	3	1	39	3. 25
Right-Way Driver	DMS	5	5	5	5	5	5	5	5	5	5	3	5	58	4. 83
	Ramp Meters	5	5	4	5	5	5	5	4	5	5	2	1	51	4. 25
	Lights along mainline	1	5	5	2	2	2	4	4	1	5	3	1	35	2.91
	Emergency Alert System	1	4	5	1	3	1	5	5	1	3	2	1	32	2. 67

For the wrong-way driver warning element, LED signal heads mounted on top of wrong-way signs ranked the highest with a score of 4.00. This warning element was followed by LED flashing wrong-way signing and in-pavement lights that cross the exit ramp. For the pilot deployment, the first three candidate alternative should be installed and observed to determine if one of the elements is more effective in correcting an errant driver's behavior than another element.

The most effective way of communicating to right-way drivers is through DMS. Automated messages should be considered as part of the pilot concept. However, software modifications will be required to send these messages automatically. The use of ramp meters as a notification to right way drivers is another existing FMS device that could be used for dual purpose. If a wrong-way vehicle is detected, ramp meters in the immediate vicinity could instantly hold a solid red signal until the wrong-way vehicle is stopped or passes and the entering traffic is no longer in danger. Because ramp meters currently do not accept changes from other devices, new software and ramp meter firmware will be required.

CHAPTER 6. PILOT DEPLOYMENT PLAN

The pilot plan was developed using the highest ranked alternatives from each element, as well as technical advisory committee input and engineering judgement. It is clear from the analyses and literature review that multiple candidate alternatives could be possible options for ADOT consideration in the pilot deployment plan. Using portions of the existing infrastructure (reconfigured for dual purpose) and new visual prompts, a viable pilot deployment can be implemented to automatically detect a wrong-way vehicle, to notify traffic management and law enforcement, and to warn the wrong-way driver of their mistake and the right way driver of an oncoming vehicle.

THE PILOT DEPLOYMENT PLAN

The proposed pilot deployment plan consists of:

1. Installing wrong-way detector devices on exit ramps
2. Reconfiguring the existing in-system loop detectors to activate when a wrong-way vehicle is present
3. Installing a wrong-way warning device to notify the errant driver of their mistake
4. Installing communications necessary from a wrong-way warning device to cabinet
5. Configuring McCain ramp meter firmware to accept inputs from a wrong-way detector
6. Preconfiguring ADOT TOC response behavior to meet the needs of the pilot plan
    a. Developing a wrong-way alert for operators (either audible or visual)
    b. Predetermining CCTV camera views and CCTV default distances upstream of all wrong-way detectors in the pilot deployment
    c. Predetermining DMS messaging and DMS proximity to activated detector device
    d. Predetermining the default distance upstream of the wrong-way detector for ramp meter activation to solid red
    e. Preparing an email recipients list when the wrong-way detector is triggered
7. Automatically performing the following actions when a wrong-way detection alert is received:
    a. Providing immediate notification to responders
    b. Posting DMS warning messages
    c. Moving nearest CCTV camera to preset command
    d. Creating an event on the ADOT HCRS Log
    e. Logging the wrong-way events and noting errant drivers who self-correct. Log should include date, time, location, wrong-way detectors activated, and DMS message displayed.

Figure 19 presents the equipment required for the suggested wrong-way detection and warning system.

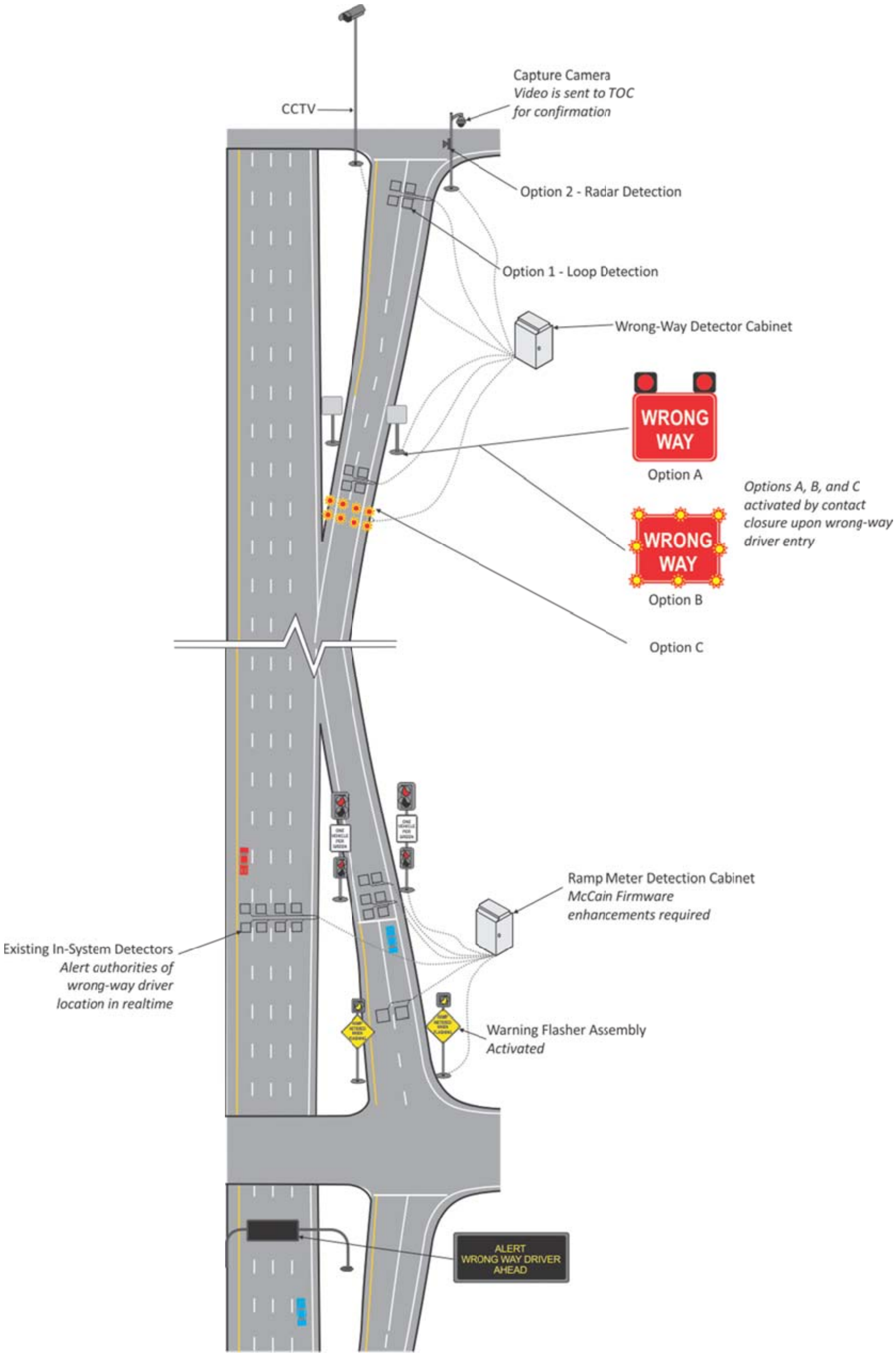


Figure 19. Suggested Wrong-Way Detection, Notification, and Warning System

For the detection element, the existing traffic loops should be used as part of the tracking system. As ADOT continues to test the feasibility of this option, using the loops on the mainline ranked the highest in the performance measures. As there are no existing loops on the off-ramps, new radar equipment could be installed as the preferred detection system (if ADOT chooses non-intrusive equipment for off ramp installation.) Otherwise, new detector loops could be installed on the off-ramps to detect wrong-way vehicles, and also to provide dual function, off-ramp vehicle counts, speed and occupancy data.

The notification element should initially consist of an email based system upon activation of the detectors. In the future, once the pilot is established, the system should automatically flash information onto the operator's monitor using both visual and audible tools. Additionally, a capture video should be installed at the off-ramp and flash onto the operators' workstation to verify if the errant driver realized their mistake and turned around, or if the errant driver continued onto the roadway. Either way, all triggers should be activated to notify DPS of the wrong-way entry. The existing CCTV should be used in wrong-way detection to track the errant vehicle on the highway. If plausible, the CCTV should be configured with auto stops at preset locations triggered by the wrong-way detectors. Ramp meters could also be activated upstream to hold right way drivers until the errant vehicle passes the on-ramp entry location, or the wrong-way event is concluded.

The warning element informs the errant driver of their mistake, and also the right way driver of an oncoming wrong-way vehicle. For the wrong-way driver, an illuminated sign received the highest ranking for the pilot deployment. However, if new research becomes available on impaired driver behaviors, then the warning element for the wrong-way driver should be modified and upgraded based on the new research. For the right-way driver, DMS should automatically activate at preset locations depending upon the triggered detector location for the pilot deployment. The DMS should be used to alert right-way drivers of the oncoming errant vehicle.

Figure 20 illustrates the pilot deployment in operation and the equipment that would be activated. Step 1 shows the wrong-way vehicle entry onto an off ramp. Step 2 illustrates how the equipment will activate based on a trigger from a freeway detector. The system could be implemented in segments and repeated within the urban areas where FMS along the freeway currently exists.

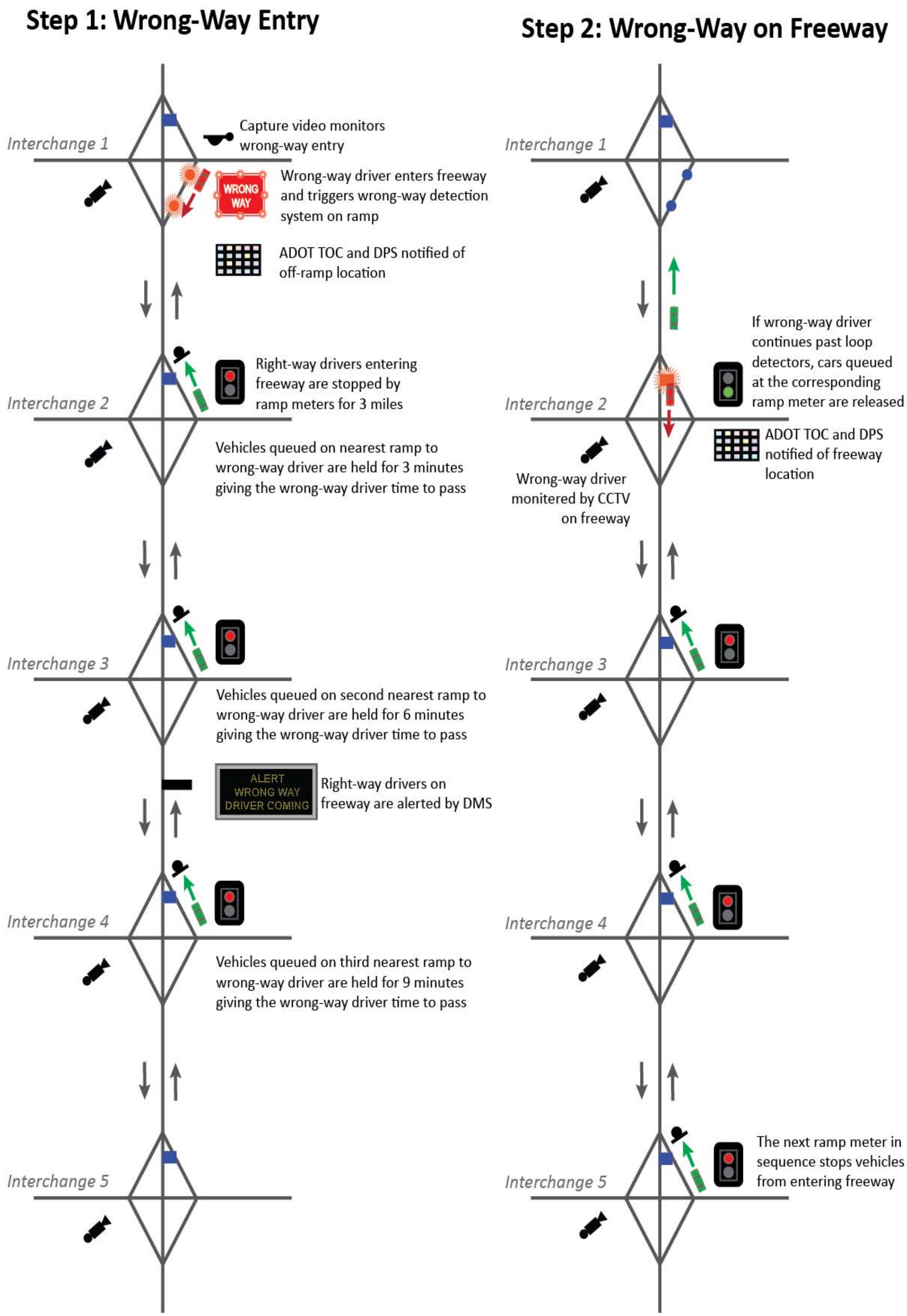


Figure 20. Suggested Plan for Pilot Deployment

DESCRIPTION OF THE PROPOSED SYSTEM

Software Modifications

Software changes at the TOC will be required to automate wrong-way detection. A general listing of changes required is as follows; however, these changes will need to be confirmed by ADOT TTG staff if the pilot deployment is implemented.

1. Changes to TransSuite software to handle wrong-way notifications within the TOC
2. Changes to McCain firmware to allow ramp meters input capabilities
3. Changes to GUI interfaces to support user interaction
4. Additional configurability modifications to enable or disable existing automated system functions

Wrong-Way Detection Response

Once the wrong-way detectors are deployed, TransSuite software will need to be configured for each new device. When the detector is triggered, it will send a signal to the TransSuite software. The software can be configured to automatically perform the following tasks:

1. Generate an alert
2. Create an event
3. Run a predetermined response plan based on the activated wrong-way detector
    a. Post warning messages to motorists on DMS (automatic or manual depending upon wrong-way entry location)
    b. Activate ramp meters to solid red
4. Provide an immediate alert to operators
    a. Pop-up the alert window with identification of the activated wrong-way detection device.
    b. Provide an audible tone until the alert is recognized.
    c. Pop-up the video view of the nearest upstream CCTV camera at the configured preset location.
5. Verify the wrong-way event with the CCTV camera, when possible.
6. Coordinate with law enforcement.
7. Log the wrong-way event for future analysis

LONG TERM

Agencies will require dedication and a commitment of budgetary support, as well as staff training and maintenance support for wrong-way detection systems to remain a viable component within traffic management. System expansion beyond the bounds of the urbanized areas will be necessary to address wrong-way events occurring near Flagstaff, Prescott, Yuma and the rural highways throughout Arizona. Development of a Statewide wrong-way detection master plan should be considered a long term goal, providing a basis for continued deployment, funding and development.

Ongoing advances in technology should be subject to monitoring every three years with a reassessment of effectiveness to update methods in dealing with wrong-way vehicles, because these strategies will change rapidly as technology advances. Considerations for future wrong-way detection include vehicle on-board units that present warnings to motorists of an oncoming wrong-way driver, or warnings to the wrong-way driver of their incorrect highway entry. GPS is an additionally promising system that in the future will address wrong-way vehicles.

CHAPTER 7. MONITORING PLAN

To determine if the wrong-way pilot deployment is achieving its objectives, a monitoring plan is presented, to assess and evaluate the deployed detection, warning, and notification systems. Two categories of testing/monitoring are considered: sub-system testing (to make certain the devices operate as intended) and an ongoing system monitoring to evaluate all components of the interconnected system.

SUB-SYSTEM TESTING

Upon initial pilot deployment, a series of stand-alone component tests should occur to test the functionality of various elements in their site-specific environments. The following describes component level tests intended to verify functionality or identify needed adjustments to achieve functionality.

Detection Element

Entry Point Detection

Entry point detection testing should confirm that the installed detection system is detecting vehicles moving as slow as 10 mph; can reliably detect vehicles as small as a 90 cc motorcycle; and can reliably distinguish a vehicle traveling in the defined wrong direction. These parameters should apply to all detection technology. All activations of the detection system should be logged by date, time and location to allow comparison to system-level logging occurring at the TOC.

Entry point detection testing should verify triggering of a verification camera system to allow confirmation that the vehicle is travelling in the wrong direction; supported by video imaging to the extent and time duration necessary to determine that the wrong-way driver entered the freeway and did not stop, or make a U-turn. All triggering of verification cameras should be logged to indicate date and time of activation, and any malfunction codes.

Entry point detection testing should confirm reliable initiation of a "trigger" message or data pack, from the detection device control unit to the ADOT TOC via the communications infrastructure of the FMS system. Testing should confirm initiation of the trigger from the roadside control unit; confirm consistently reliable transmission; and receipt at the TOC and identify any transmission latency issues that may cause unexpected delays.

Mainline Freeway Detection

Mainline freeway detection should confirm that the installed detection system is detecting vehicles moving as slow as 10 mph; can reliably detect vehicles as small as a 90 cc motorcycle; and can reliably distinguish a vehicle traveling the wrong direction. All wrong-way vehicle activations of the detection system should be logged by date, time and location locally to allow comparison to system-level logging occurring at the TOC.

Notification Element

Field Inputs

Testing of the detection elements should include verification and confirmation of receipt of triggers sent from the specific field detection sites (entry point and mainline locations) to the ADOT TOC. A log of initiated events should be maintained at the field site and compared to a log generated at the TOC to determine the level and frequency of errant transmissions. Frequency of this evaluation of logs should be weekly for the first two months. If an acceptable level of reliability is demonstrated by the system, less frequent evaluations may be considered. Automation of the log evaluation process will consume fewer labor hours for the evaluation agent.

System Outputs

Testing should be conducted to determine the functionality and reliability of manually initiated e-mail messages from the TOC operator to prove that the TOC/e-mail link is established. The next stage of testing is to confirm that any authorized TOC operator can manually initiate e-mail messages. A standard format/template for the subject and message content is strongly suggested so recipients will respect the importance of the message based on viewing the From and Subject fields of a transmitted e-mail message.

A group e-mail list of destinations/recipients should be established after successful template development and confirmation of the manual message initiation process. The destination group should be mutually developed and approved by ADOT and DPS management to ensure dissemination of emergency e-mail transmissions to appropriate personnel and updated and audited on a regular basis. The group e-mail transmission should be partially automated by having an established "group," but should still have manual initiation, after confirmation, to reduce the potential for false messages and the reliability of the message system put into question by recipients.

Ramp meter warning systems will require a trigger message to be transmitted from the TOC to the affected ramp meter locations to initiate operation of the warning system. Warning system operation may vary based on whether the ramp meter is otherwise in operation, or not. Testing should include confirmation and logging of transmitted triggers from the TOC, and logging of received triggers, initiation and duration of warning system operation as well as confirmation that all components of the ramp meter warning system are functioning as intended.

At the initial stages of the pilot deployment, the system should rely on trained TOC operators to receive and react to detection triggers and make a manual confirmation of a wrong-way event from the transmitted confirmation video obtained at the entry point detection sites. Once a wrong-way event is confirmed, the TOC operators should initiate CCTV observation upstream of the last confirmed detection (possibly in concert with audible input from the DPS field transmissions) at the same time while attempting to locate, monitor, and intercept the wrong-way vehicle.

Warning Element

Entry Point

Testing of the entry point driver notification system should include confirmation that the flashing sign warning device is actuated upon a valid wrong-way detection, and has no false calls and no failures in initiating flashing operation upon receipt of a valid trigger from the detection. The initiation and duration of the flashing operation should be logged for comparison to the entry point detection log, and evaluated to confirm that the entry point warning signs are operated with each confirmed wrong-way detection event. The event log can be maintained at the TOC based on communicated triggers from the warning device, or stored locally at the warning sign, if it has such capability.

DMS

Because the DMS are already a functional element of FMS operations, the electronic sign system itself would not need additional testing. The only initial deployment testing required would be to confirm that the warnings to drivers are successfully posted and visible to oncoming traffic. In the pilot deployment, the DMS involved in that program should be examined for dim or non-functional display elements. It should also be verified that the DMS control equipment will successfully receive and display remotely initiated wrong-way messages.

During the pilot deployment, the initiation and duration of wrong-way messages will depend on TOC operator intervention. Wrong-way messages on DMS should be terminated immediately upon termination of the wrong-way event, or with the passing of the wrong-way vehicle in order to maintain respect from drivers of the importance and urgency of such messages.

Ramp Meters

Testing of the ramp meter warning system intended to warn and prevent traffic from entering a section of freeway with an ongoing wrong-way event should include confirmation of receipt of the trigger message from the TOC; successful initiation of the warning display; and successful termination. The local controller should maintain an event log that records trigger initiation and termination data for comparison to TOC logs of trigger initiations sent to the site.

ONGOING SYSTEM MONITORING

Assuming successful component testing, as described above, the next level of testing and monitoring is system-wide. System-wide testing determines if the interoperability of the subcomponents provides the desired system functionality and reliability. The purpose of the ongoing system monitoring program is to demonstrate that the wrong-way detection system (consisting of hardware, software, communications, materials and construction) is properly installed, is free from defects and identified problems, exhibits stable and reliable performance, and completely complies with system intent and purpose.

During the ongoing system monitoring, ADOT shall ensure that all equipment is maintained in operable condition. ADOT should identify, isolate, diagnose, and correct all system problems and inconsistencies, as they arise. Potential solutions should be developed and implemented, where feasible, to attempt to fix any anomalies.

Device providers should provide the equipment needed to test, isolate, and correct all equipment deficiencies found during the ongoing system monitoring program. Technical personnel familiar with the design and construction of each system component shall be available to be on site within 48 hours of notification of a problem. During the ongoing system monitoring program, the TOC operators shall maintain an ongoing system monitoring program event log. This log should contain, at a minimum, the following information: date and time of failure, who reported the failure, description of the failure, troubleshooting performed, and date and time repair was completed.

The long range system vision is to automate the CCTV operation to react to a geo-referenced trigger. There is the potential to combine existing video detection methods with CCTV observation to semi-automate monitoring via images.

The initial pilot deployment will have manual intervention points for key decision making and imitation of key tasks until a comfort level is established to support "next step" automation. Automation can, and will likely occur in steps: automating parts of the notification process, such as automated CCTV positioning that identifies location, direction and speed, and automatically aims the CCTV to an upstream location for manual observation, and automated e-mail generation. The warning process will allow automated DMS message posting and ramp meter warning systems based on reliable detection and tracking.

Interconnected system testing combines every detection, notification and warning element. Testing should be based on observation and confirmation of every step of the wrong-way event:

- Entry point detection and warning
- Evaluation of confirmation video to test validity of wrong-way event
- Notification of DPS
- Position monitoring via CCTV and in-system detection
- Warning to right-way driver with DMS
- Wrong-way event termination

As a connected system, the process of the wrong-way event should be monitored, logged and recorded to identify element failures under the system application. Assuming all elements perform reliably, the system should detect, notify and warn as designed until the event is terminated.

Field elements may malfunction or not operate as intended during the initial pilot deployment. Depending on which element exhibits a malfunction or failure, the system process can fail and the wrong-way event could continue. Thus, the current procedures for dealing with wrong-way vehicles cannot be dismissed from practice and should be readily available to address wrong-way events during the pilot deployment in the event of discovered system anomalies.

A chronology of every identified wrong-way event should be developed during the pilot deployment to: identify date, time, light conditions, weather, entry point activation location, mainline detection locations, direction, speed (if available), lane (if available) and manual observations of TOC operators and DPS officers during and after the event. This level of detail will assist in determining system weaknesses, if any, and will help set the stage for future system evolution.

Elements suspected of operational or mechanical weakness will need to be evaluated to determine if adjustment of the element will improve performance or if replacement is necessary, either in kind or with different technology or philosophy.

False calls and missed calls are expected to be a high priority for monitoring and resolution. Based on the understanding that the detection element is the first trigger of the event process, failures and false triggers must be minimized for the system to perform successfully.

During pilot deployment, the review and analysis of the confirmation video will be the key source of information regarding false calls. False calls could be caused by weather, wind, animals, backing vehicles, or maintenance vehicles. The intended system should provide video based on the detector calls. Thus, the ability should exist to identify the cause of false calls, match all calls to the data logs and list false call causes to determine if there are ways to refine the detection system through adjusted or second stage technologies that serve as a redundant detection layer.

The issue of missed detection of a wrong-way vehicle is much more difficult to identify, unless a second detection source (such as radar, loops or video image analysis) and second confirmation video system are applied and logged. Logs between the primary and secondary entry point detection would be compared and deviations will be further analyzed to determine which detection system holds higher validity based on the confirmation videos.

CHAPTER 8. CONCLUSIONS

Wrong-way entries onto divided highways are a concern across the nation. The national annual average number of fatal wrong-way crashes (approximately 270 per year) has varied little from 2004 through 2011, even though the overall number of fatal crashes per year declined by approximately 22 percent during the same period, according to Baratian-Ghorghi, Zhou and Shaw (2014). An analysis of Arizona crash data from 2004 through 2014 shows no significant difference in Arizona's wrong-way crash statistics when compared to the national average. The data show that alcohol impairment plays a significant role in wrong-way driving, both in Arizona and across the country. In Arizona, approximately 65 percent of all wrong-way drivers were impaired compared to the national average of 60 percent. Wrong-way crashes occur primarily after dark between the hours of 7 p.m. and 4 a.m., peaking at 2 a.m. and on weekends.

Literature shows that public agencies and private corporations continue efforts to harness technology to reduce wrong-way driving. Some preventative measures include: the installation of larger, lower wrong-way signing; enhanced red reflective stripes and red reflective pavement markers; flashing LED border wrong-way signs and ITS wrong-way detection systems. In the future, ongoing advances in technology may lessen wrong-way driving with connected vehicle capabilities, such as GPS and in-vehicle guidance. However, this technology is not yet available for deployment.

Using readily deployable ITS technologies that eventually could be integrated with the ADOT existing FMS infrastructure, this research team developed a potential wrong-way detection and warning system for possible pilot deployment. The system would notify authorities immediately of a wrong-way entry; alert the wrong-way driver of their mistake; warn right-way drivers in the vehicle's path; and track a wrong-way vehicle on the highway system. The proposed wrong-way detection system would utilize the existing ADOT TOC, FMS fiber backbone, CCTV cameras, DMS, and ramp meters supplemented by new detection devices at highway exit ramps. For the system concept to work, software development would be required to modify the existing traffic operation components for dual function. Because the proposed pilot deployment would be the first of its kind, the challenge would be to develop, code, and test new software to successfully coordinate all the system components.

Upon installation, if a wrong-way vehicle entry is detected, the system would immediately alert the wrong-way driver of the error and notify the TOC. Once the wrong-way entry is confirmed, law enforcement would receive immediate notification of the exact entry point. If the errant driver continues onto the highway despite the warning, in-system detectors would notify the TOC of the wrong-way vehicle's location and speed as it travels, allowing law enforcement to more precisely coordinate officers in the field. They then could use their protocols and procedures to stop the wrong-way vehicle prior to a crash. While the system aims to notify a driver of their mistake, the focus is to enable law enforcement and TOC operators to track a wrong-way vehicle on the highway system in real time. The chances of successfully stopping a wrong-way vehicle before a collision become greater when officers know where the vehicle is and where it might be headed.

The pilot system is also designed to warn right-way drivers of the oncoming wrong-way vehicle. When a wrong-way vehicle is on the highway, the DMS along the projected path would display an automated warning. In addition, ramp meters could be modified to hold vehicles on the entry ramp until the wrong-way vehicle passes and the entry vehicles are clear of the danger. A practical monitoring program then would be helpful in assessing the effectiveness of preventing crashes through wrong-way driver notifications, right-way driver notifications, incident tracking, and entry point identification.

No detection system would offer a total preventative solution — whether installed in Arizona or implemented nationwide — because there is no current technology that can solve the issue of driver impairment, whether from alcohol or drugs. While research around the country and abroad explores countermeasure options in terms of technology and transportation engineering, the data point to the importance of continued coordinated efforts to prevent impaired driving. Because nationwide statistics show alcohol impairment as the leading factor in wrong-way driving, concerted public education and outreach campaigns on drinking and driving must be a top priority if a significant reduction is to be realized in incidents of wrong-way driving. In fact, as Table 5 showed, not only do fatal wrong-way crashes involve impaired drivers, but also an annual average of approximately 30 percent of all fatal Arizona highway crashes overall involve alcohol. Efforts to reduce alcohol-impaired drivers would have an impact on overall highway safety in Arizona beyond just reducing the risk of wrong-way crashes.

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