Final Report

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A Data-Driven Approach to Implementing Wrong-way Driving Countermeasures

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METRIC CONVERSION TABLE

U.S. UNITS TO SI* (MODERN METRIC) UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.400	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.610	kilometers	km
mm	millimeters	0.039	inches	in
m	meters	3.280	feet	ft
m	meters	1.090	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.200	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	2.590	square kilometers	km^2
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	2.470	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.570	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
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
NOTE: volumes greater than 1,000 L shall be shown in m^3.				

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

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16. Abstract

Wrong-way driving (WWD) crashes are rare and random, and hence, a system-wide deployment of WWD countermeasures requires careful consideration. An actionable and implementable plan is essential to systemically and strategically deploy WWD countermeasures at all the 1,642 off-ramp locations across Florida. It is therefore critical to identify the most suitable countermeasures at each of these off-ramps such that they yield the maximum benefit. The objective of this research was to develop a demographics-based methodology to identify regions that possess a combination of *pre-conditions* for increased likelihood of WWD incidents. This research has proactively identified the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each off-ramp in Florida.

The analysis focused on addressing the following factors that were considered to affect the occurrence of WWD incidents: *impaired drivers*, *drivers aged 65 years and older*, and *tourists.* The analysis was based on 6,880 WWD crashes that occurred in Florida from 2011-2015, demographic data obtained from the *2015 Census Block Groups* dataset, and land-use data obtained from the *2015 Florida Parcel Land-use* dataset.

The analysis results indicated that the density of alcohol sales establishments was highly associated with the WWD crashes involving impaired drivers. The relationship between the facilities that attract *drivers aged 65 years and older*, such as senior population and health facilities and the WWD crashes involving *drivers aged 65 years and older* was found to be somewhat associative. No observable relationship was found between the density of tourist facilities and WWD crashes involving *tourists*.

Finally, the study results were used to identify the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each of the off-ramps in Florida. A combination of red rectangular rapid flashing beacons (Red-RRFBs) and internally illuminated raised pavement markers (iiRPMs) could be considered to address the issue of *impaired drivers*. A combination of Light Emitting Diode (LED) lights surrounding the Wrong Way signs and iiRPMs could be considered to accommodate the *drivers aged 65 years and older*. Finally, either Red-RRFBs or LED lights surrounding the Wrong Way signs could assist tourist drivers. In addition to the aforementioned countermeasures, new signing and pavement markings (S&PM) could be considered at all the off-ramps. Findings from this study provide guidance to proactively deploy WWD countermeasures at all the off-ramps in Florida.

17. Key Word
Spatial analysis, wrong-way driving crashes, hotspots, demographic and land-use factors, countermeasures.

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EXECUTIVE SUMMARY

Wrong-way drivers pose a serious risk to the safety of themselves and other motorists. Although crashes involving wrong-way drivers are relatively few, they often lead to severe head-on collisions. Wrong-way driving (WWD) mitigation has therefore been on the national front, with states tackling this issue from several avenues, focusing on the 4*E's*, i.e., *Engineering*, *Education, Enforcement*, and *Emergency Medical Services*; policy-oriented changes; and adopting state-of-the-art technology to detect, verify, and respond to WWD incidents in real-time.

Understanding the seriousness of WWD incidents, the Florida Department of Transportation (FDOT) has endeavored to continually explore ways to strategically draft, design, and deploy countermeasures while proactively identifying areas that can help mitigate these incidents. FDOT's strategy has included policy-oriented changes propelled by the leadership's commitment and vision to create actionable WWD initiatives; extensive research on understanding the underlying WWD crash patterns and causes and driver behavior while intoxicated and to create motivation to implement and compare several pilot countermeasures. FDOT has always been on the forefront in investigating and deploying innovative methods and Intelligent Transportation Systems (ITS) applications to mitigate WWD incidents.

Since WWD crashes are rare and random, a system-wide deployment of WWD countermeasures requires careful consideration. FDOT needs an actionable and implementable plan to systemically and strategically deploy WWD countermeasures at all the 1,642 off-ramp locations across the state. It is therefore critical to identify the most suitable countermeasure(s) at each of these off-ramps such that they yield the maximum benefit. The objective of this research was to develop a demographics-based methodology to identify regions that possess a combination of *pre-conditions* for increased likelihood of WWD incidents. This research has proactively identified the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each off-ramp in Florida.

Descriptive analysis of WWD crashes and spatial analysis of demographic and land-use factors were conducted to identify the most predominant factor that could potentially contribute to WWD incidents at each of the 1,642 off-ramps. More specifically, the following three factors were analyzed: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*. The analysis was based on 6,880 WWD crashes that occurred in Florida from 2011-2015, demographic data obtained from the *2015 Census Block Groups* dataset, and land-use data obtained from the *2015 Florida Parcel Land-use* dataset.

The most predominant factor at each off-ramp was identified based on the following analyses:

1. *Analysis of WWD Hotspots:* The analysis combined both demographic and land-use factors and the WWD crashes that occurred on the public road network in Florida from 2011-2015. A total of ten hotspots were identified for each of the seven FDOT districts. The factors contributing to WWD crashes within each of the hotspots were identified. For each hotspot, one or more of the following factors were identified: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*.

2. *Analysis of WWD Crashes on Freeways:* The WWD crashes that occurred on freeways were analyzed to identify factors that could be associated with the off-ramps. All the off-ramps upstream of the WWD crash locations that could have potentially been associated with WWD crashes were first identified and analyzed. Again, the factors contributing to WWD crashes were identified. For each off-ramp associated with a WWD crash on a freeway, one or more of the following factors were identified: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*.

3. *Analysis of Demographic and Land-use Factors:* All the off-ramps that were not flagged in the analysis of WWD hotspots and the analysis of WWD crashes on freeways were analyzed to determine if these locations possess a combination of *pre-conditions* or *factors* for increased likelihood of WWD incidents. Demographic and land-use factors in the vicinity of these off-ramps were analyzed to identify if the locations have a higher density of alcohol sales establishments, senior population and health facilities, and/or tourist attractions that could potentially result in an increased likelihood of WWD incidents.

Finally, the results from the three analyses were combined to obtain the final predominant factors at each of the 1,642 off-ramps. The predominant factors were identified based on a conservative approach. If *impaired drivers* was identified as a predominant factor in any of the three analyses, it was considered to be the predominant factor to be addressed. Similarly, if *drivers aged 65 years and older* (or *tourists*) were identified as a predominant factor in any of the three analyses, then *drivers aged 65 years and older* (or *tourists*) was considered to be the predominant factor to be addressed. For each off-ramp location, the most predominant factor was identified in the following order: *impaired drivers*, *drivers aged 65 years and older*, and *tourist drivers*.

A combination of red rectangular rapid flashing beacons (Red-RRFBs) and internally illuminated raised pavement markers (iiRPMs) could be considered to address the issue of *impaired drivers*. A combination of Light Emitting Diode (LED) lights surrounding the Wrong Way signs and iiRPMs could be considered to accommodate the *drivers aged 65 years and older*. Finally, either Red-RRFBs or LED lights surrounding the Wrong Way signs could assist *tourist* drivers. In addition to the aforementioned countermeasures, new signing and pavement markings (S&PM) could be considered at all the off-ramps.

In general, the density of alcohol sales establishments was found to be highly associated with the WWD crashes involving *impaired drivers*. The relationship between the facilities that attract *drivers aged 65 years and older* and the WWD crashes involving *drivers aged 65 years and older* was somewhat associative. No observable relationship was found between the density of tourist facilities and WWD crashes involving *tourists*.

Findings from this study provide guidance on a proactive approach for identifying locations that are prone to WWD incidents, and the WWD incident categories to be addressed at these locations. In addition to implementing engineering countermeasures that target specific WWD crash categories, knowing at-risk locations can assist law enforcement agencies and advocacy groups in identifying where to focus their efforts to deploy resources such that their efforts can be most effective.

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LIST OF ACRONYMS/ABBREVIATIONS

ADOT	Arizona Department of Transportation
BAC	Blood Alcohol Content
Caltrans	California Department of Transportation
D1	Florida Department of Transportation District One
D2	Florida Department of Transportation District Two
D3	Florida Department of Transportation District Three
D4	Florida Department of Transportation District Four
D5	Florida Department of Transportation District Five
D6	Florida Department of Transportation District Six
D7	Florida Department of Transportation District Seven
DHSMV	Department of Highway Safety and Motor Vehicles (Florida)
DMS	Dynamic Message Signs
DOT	Department of Transportation
DUI	Driving Under the Influence
EPDO	Equivalent Property Damage Only
FDOT	Florida Department of Transportation
FGDL	Florida Geographic Data Library
FHP	Florida Highway Patrol
GIS	Geographic Information System
GPS	Global Positioning System
IDOT	Illinois Department of Transportation
iiRPM	Internally Illuminated Raised Pavement Marker
LED	Light-emitting Diode
NTSB	National Transportation Safety Board
PDO	Property Damage Only
RCI	Roadway Characteristics Inventory
RRFB	Rectangular Rapid Flashing Beacon
S&PM	Signing and Pavement Markings
WWD	Wrong-way Driving

CHAPTER 1
INTRODUCTION

1.1 Background

According to the National Transportation Safety Board (NTSB), wrong-way driving (WWD) is "vehicular movement along a travel lane in a direction opposing the legal flow of traffic on high-speed divided highways or access ramps" (NTSB, 2012). Wrong-way drivers on freeways pose a serious risk to the safety of themselves and other motorists. Although crashes involving wrong-way drivers are relatively few, they often lead to severe head-on collisions. As such, the fatality rate in WWD incidents is much higher compared to other crashes.

About 3% of all crashes that occur on high-speed divided highways involve wrong-way drivers, and most of these crashes result in fatal or serious injuries (NTSB, 2012). For example, Zhou et al. (2016) reported that each WWD crash results in 1.4 fatalities and 2.1 incapacitating injuries. Pour-Rouholamin et al. (2016) identified WWD crashes from the Fatality Analysis Reporting System (FARS) database for a ten-year period, from 2004 to 2013, in the United States. The authors found that on average, the 265 fatal WWD crashes that occurred on controlled-access highways resulted in 355 fatalities, at a rate of 1.34 fatalities per WWD fatal crash. This rate is quite high compared to the fatality rate of 1.10 fatalities per fatal crash for all other crashes on controlled-access highways. From the year 2007 to 2011, Florida had experienced approximately 386 WWD crashes in total, becoming the 3rd worst state for WWD crashes in the country (KDKA-CBS Pittsburgh, 2013).

The Florida Department of Transportation (FDOT) has been a pioneer in addressing the WWD issue. One of the initial and remarkable initiatives was the work that the FDOT Districts did to deploy a wide variety of pilot countermeasures at WWD incident locations across the state. Building on this effort, FDOT has recently completed a research project to compare these countermeasures and recommend a combination of countermeasures for future deployment consideration (Lin et al., 2017). While providing guidance on all countermeasures, that research effort has mainly recommended the following four countermeasures for future implementation on freeway off-ramps:

1. Red rectangular rapid flashing beacons (Red-RRFBs)
2. Wig/wag flashing beacons
3. Detection-triggered blank-out signs that flash "WRONG WAY"
4. Detection-triggered light-emitting diode (LED) lights around WRONG WAY signs

Since WWD crashes are rare and random, a system-wide deployment of countermeasures requires careful consideration. FDOT requires an actionable and implementable plan to systemically and strategically deploy WWD countermeasures at all the 1,642 off-ramp locations across the state. It is therefore critical to identify the most suitable countermeasures at each of these off-ramps such that they yield the maximum benefit.

The traditional approach to selecting the most suitable countermeasures has been based on crashes and crash contributing factors. However, WWD crashes being random and relatively rare, do not lend themselves to the traditional approaches. Other data sources such as traffic citations thus become an important input element and could be used to supplement the crash data to better understand WWD incidents. Nonetheless, this approach of using crash and citation data is *reactive* and is based on responding to events after they had happened. An effective approach is to be *proactive* and identify the most suitable locations for deploying countermeasures based on the *pre-conditions* of the region.

While the factors contributing to WWD incidents vary widely, previous studies have indicated that certain demographic factors may heighten the risk of WWD incidents. Macroscopic analysis of demographic and neighborhood land-use characteristics may provide a more accurate picture of the factors that might result in WWD incidents. This project, therefore, focuses on studying the impact of demographic and land-use factors on WWD crashes. It helps to identify and target the specific demographic groups and regions that are prone to WWD incidents.

1.2 Research Objective

The main objective of this research was to develop a demographics-based methodology to identify regions that possess a combination of *pre-conditions* for increased likelihood of WWD incidents, and to proactively identify the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each off-ramp in Florida.

The research objective was achieved through extensive *data visualization* and *spatial analyses* in ArcGIS. The macroscopic analysis involves aggregating WWD crashes over some geographic areas and spatially analyzing WWD crashes with an intent to identify demographic and land-use factors that may contribute to WWD incidents. This approach can shape long-term planning and policy implications in mitigating WWD incidents across the state, while supporting the development of a WWD Countermeasures Implementation Plan.

1.3 Report Organization

The rest of this report is organized as follows:

- Chapter 2 discusses the state-of-the-practice in WWD mitigation.
- Chapter 3 discusses the demographic and land-use variables that could potentially affect WWD incidents.
- Chapter 4 focuses on the framework adopted to identify WWD crash hotspots.
- Chapter 5 presents the demographics-based methodology to identify regions that possess a combination of *pre-conditions* for increased likelihood of WWD incidents.
- Chapter 6 discusses the approach used to systemically identify the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each off-ramp in Florida. It also presents the FDOT's approach to address the WWD issue.
- Chapter 7 provides a summary of this research effort and the relevant findings, conclusions, and recommendations.

CHAPTER 2
STATE-OF-THE-PRACTICE IN WRONG-WAY DRIVING MITIGATION

WWD crashes have a greater propensity to result in fatal and severe injuries. As such, several states and federal organizations have been working hard to mitigate WWD crashes. A majority of the efforts focused on identifying contributing factors and developing effective countermeasures. Several states including Arizona, California, Florida, Illinois, and Texas, have become pioneers in mitigating WWD incidents. This chapter discusses the efforts of these states in mitigating WWD incidents.

2.1 National Effort

In the United States, WWD crashes result in 300-400 fatalities every year (Moler, 2002). WWD mitigation has therefore been on the national front, with special emphasis being given to identifying effective and proven countermeasures. These countermeasures could be divided into the following four broad categories:

- countermeasures that address WWD driver-related factors,
- countermeasures that improve highway geometric conditions,
- countermeasures that provide WWD navigation alerts on vehicles, and
- countermeasures that adopt new and emerging technologies to detect and deter wrong-way drivers.

2.1.1 Driver

A majority of at-fault drivers involved in WWD crashes are either alcohol/drug impaired, or are drivers aged 65 years and older. This observation was confirmed by the fact that seven out of the nine WWD drivers investigated by NTSB in 2012 had Blood Alcohol Content (BAC) ≥ 0.15 (NTSB, 2012). For alcohol-impaired drivers, the NTSB report recommended considering passive safety devices such as the use of alcohol ignition interlock devices and new in-vehicle alcohol detection technologies. Considering the fact that drivers aged 65 years and older are over-represented in fatal WWD crashes, the report also recommended countermeasures focusing on the safety of drivers aged 65 years and older. More specifically, NTSB suggested that each individual state in the U.S. develop a comprehensive highway safety program for older drivers that incorporate the program elements outlined in the NHTSA *Highway Safety Program Guideline No. 13 - Older Driver Safety*. Within the State of Florida, a comprehensive statewide program to address older driver safety is recommended by the FDOT's Safe Mobility for Life Program.

2.1.2 Highways

Improving the highway geometric conditions is one of the proven ways to mitigate WWD crashes. The most common initiating event for WWD on controlled-access facilities is entering the mainline traffic lanes from an exit ramp. NTSB (2012) specifically emphasized the use of highway signage and traffic control devices that are designed to direct motorists onto controlled-access highway entrance ramps and discourage wrong-way movement onto ramp exits. These countermeasures aim at addressing factors that may influence WWD crashes due to road geometrics resulting in poor visibility, inadequate traffic control, lack of positive signing, and absence of street lighting. The report also recommended using reduced sign heights, adding red reflective tape to vertical posts, and using over-sized wrong-way signs for enhanced visibility. Additionally, the report suggested a few countermeasures to mitigate WWD crashes caused by drivers entering the highway using exit ramps. These recommendations include illuminating wrong-way signs which flash when a wrong-way vehicle is detected, and installing a second set of wrong-way signs at the exit ramp farther upstream from the cross roads. Other recommendations include the use of channelized striping to guide drivers onto the on-ramp.

2.1.3 Vehicle Safety Systems

Providing navigation system alerts that inform drivers of wrong-way movements onto controlled-access highway exit ramps before they reach mainline traffic could enhance safety. As such, using wrong-way navigation alerts on vehicles could help prevent WWD incidents. These in-vehicle systems will rely on the use of the vehicle's navigation system, combined with Global Positioning System (GPS). Note that GPS accuracy and the availability of (or, access to) updated maps are critical to the success of these in-vehicle systems. Moreover, "for wrong-way navigation alert systems to be reliable and effective, GPS providers must follow consistent human factors policies in messaging and alerting" (NTSB, 2012).

2.1.4 New and Emerging Technologies

Several new and emerging technologies are being deployed across the country to help detect and mitigate WWD incidents on limited-access facilities. Some of the promising applications include:

- *Thermal Cameras:* This system, deployed by Arizona DOT, uses thermal cameras to accurately detect WWD incidents entering the freeway system and track the real-time location of wrong-way drivers on the freeway. More information about this system is provided in Section 2.2.

- *Red Lights in Entrance Ramp Meters:* At freeway corridors with ramp meters, the freeway entrance ramp meter lights could be used to prevent 'right-way' drivers from entering the freeway when a wrong-way driver is detected on the freeway. This concept is being tested on I-17 in Phoenix, Arizona, as part of the agency's pilot wrong-way vehicle detection system (Frost, 2018).

- *Radar Technology:* This system, being considered for deployment on I-71 in Ohio, detects a vehicle going the wrong direction, and sets off flashing lights to alert the driver and notify safety officials. In addition to this technology, Ohio DOT is also considering directional arrows and wrong-way signs at lower levels on exit ramps (Weingartner, 2018).

2.2 Arizona

The Arizona Department of Transportation (ADOT) is advancing a $3.7 Million project to construct a first-in-the-nation WWD thermal detection system along a 15-mile stretch on I-17 in Phoenix, Arizona (ADOT, 2017). This project is being implemented following the end of the *Proof* *of Concept* phase whose objectives were to determine the viability of existing detector systems to identify entry of wrong-way vehicles onto the highway systems using the following five different technologies: microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors (ADOT, 2017). The system is designed to take a three-phase approach when a wrong-way vehicle is detected: alerting wrong-way drivers so they can self-correct, warning right-way drivers, and at the same time notifying law enforcement (Figure 2-1).

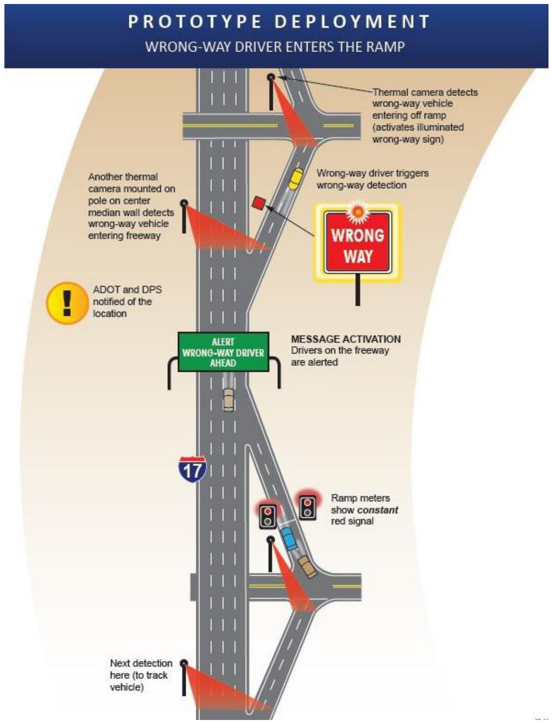


Figure 2-1: Wrong-way Driver Thermal Detection System (ADOT 2017)

The nomination application of the ADOT's Wrong Way Driver System using thermal cameras technology to the AASHTO Innovation Initiative provided the following information (Riley, n.d.): "The ADOT WWD detection and mitigation system using Forward Looking InfraRed (FLIR) thermal sensors consists of the following four major elements:

1. Thermal cameras located on exit ramps detecting initial entry of WWD
2. Thermal cameras located at 1-mile spacing on the freeway to track the location of the WWD
3. Internally-illuminated WRONG WAY sign with flashing lighted border, and
4. Decision support software to confirm WWD and activate countermeasures.

The system uses thermal cameras to accurately detect WWD incidents entering the freeway system and track their location on the freeway. Upon a WWD detection, the system (i) immediately triggers an oversized and highly visible internally-illuminated WRONG WAY sign with flashing lighted border, (ii) immediately streams CCTV feeds of adjacent cameras, (iii), immediately alerts law enforcement officers and dispatchers, and (iv) decision support software immediately alerts and provides video recording of WWD detection to operators in the ADOT Traffic Operations Center to confirm detection is actual WWD and quickly active countermeasures with "one click". Countermeasures activated through the decision support software consist of posting Dynamic Message Sign (DMS) warning messages to right-way drivers, and changing traffic signal timing and turning ramp meters red to limit new vehicles entering the affected freeway." (Riley, n.d.).

Additionally, larger and lowered "WRONG WAY" and "DO NOT ENTER" signs have been installed on hundreds of freeway ramps and overpasses in Phoenix and on rural highways in Arizona. Considering the fact that more than half of the WWD crashes in Arizona were due to impaired driving, ADOT understands that engineering and enforcement measures can only reduce the risk, but can't prevent wrong-way driving (Simpson and Bruggeman, 2015). Thus, ADOT has started the "*Drive Aware*" safety campaign that aims at helping motorists minimize the risk of being in a crash with a wrong-way vehicle. Specifically, the campaign details what drivers should do if they encounter a wrong-way vehicle, see an overhead sign warning of an oncoming wrong-way vehicle, and general tips that will keep drivers safer.

2.3 California

The California Department of Transportation (Caltrans) has focused on researching and identifying effective WWD countermeasures since the early 1960s (Tamburri, 1965). Several studies have focused on improving the signage, pavement marking, and roadway geometric design where low-mounted DO NOT ENTER signs mounted together with WRONG WAY signs countermeasures were recommended (Tamburri, 1965; Rinde, 1978). Note that the WWD crash rate was significantly reduced in California after implementing the research results in the 1970s and 1980s. More recently, in 2016, the California State Transportation Agency recommended using Caltrans's wrong-way monitoring program for identifying locations for WWD crash investigation (California State Transportation Agency, 2016).

2.4 Florida

FDOT has long been recognized as a pioneer in addressing the WWD issue. FDOT has begun tackling this issue from several fronts. It has focused on developing a policy-specific framework emphasizing on continual consultation, coordination, and communication. FDOT has also developed a strategic and coordinated research effort tackling all the issues with WWD incidents and assisting the agencies with developing an implementation strategy to mitigate WWD incidents.

Figure 2-2 presents the FDOT's framework with the backdrop of leadership-supported institutionalization to strategize road safety improvements. This policy-oriented framework aims to "address WWD incidents in a systematic manner and suggest a systemic discipline for transforming policy objectives to actionable outcomes." (Ponnaluri, 2016a).

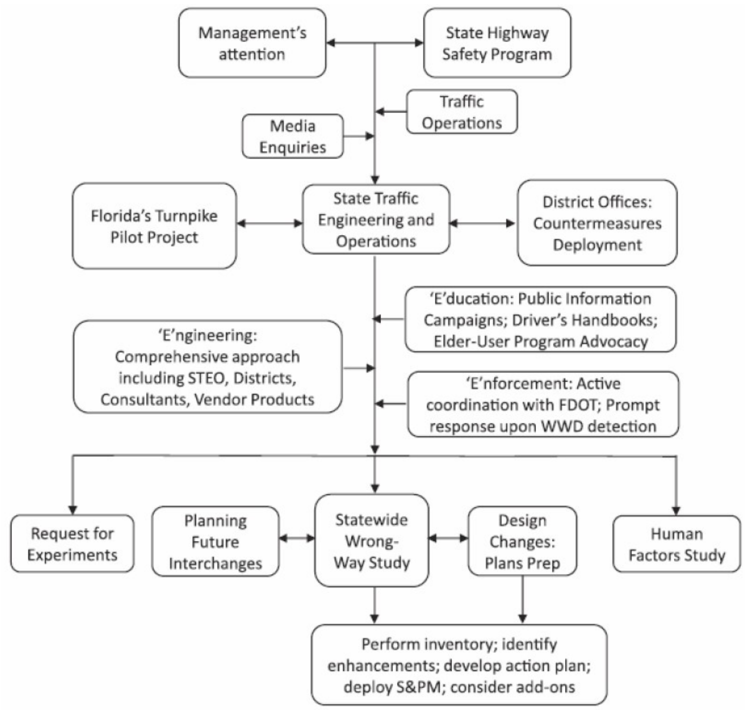


Figure 2-2: Mitigating WWD Incidents through FDOT Framework (Ponnaluri, 2016a)

In 2015, FDOT completed a statewide WWD crash study to understand the factors contributing to WWD crashes (Kittelson and Associates, 2015). In the same year, Boot et al. (2015) conducted a human factors study to understand the role of human cognition in driver decision-making process. On the deployment front, FDOT Districts have deployed the following pilot countermeasures at WWD incident locations across the state:

- Newly-developed signing and pavement marking (S&PM) standards (FDOT Plans Preparation Manual, Figures 7.1.1. and 7.1.2)
- Red rectangular rapid flashing beacons (Red-RRFBs)
- Red flush-mount internally illuminated raised pavement markers (iiRPMs)
- Detection-triggered light-emitting diode (LED) lights around "WRONG WAY" signs
- Detection-triggered blank-out signs that flash "WRONG WAY"
- Delineators along off-ramps
- Wigwag flashing beacons

Most recently, the aforementioned pilot countermeasures were compared, and a combination of countermeasures were recommended for future deployment consideration (Lin et al., 2017). In addition to the *Engineering* countermeasures, FDOT has also focused on the other 3*E's*, i.e., *Education*, *Enforcement*, and *Emergency Medical Services*. For example, FDOT considers July as

WWD Awareness Month, and works on educating the public regarding tips to follow to avoid being involved in WWD crashes. The "*StayRightatNight*" campaign urges drivers to avoid a crash with a wrong-way driver and has generated significant interest on social media (DHSMV, 2016).

FDOT is currently conducting a research project (Project BDV25 977-40) to test and evaluate selected freeway WWD detection systems currently in the market for their capabilities related to wrong-way vehicle detection using existing cameras in real-time and TMC notification. The evaluation is based on WWD detection system accuracy, percentage of false calls, actual WWD detection accuracy, and percentage of missed calls.

2.5 Illinois

In the 1980s, the Illinois Department of Transportation (IDOT) experimented with sensors embedded in the roadway to detect wrong-way traffic movement, which, if activated, would lower a signal arm across the road and initiate a DMS to alert the existing traffic about the WWD hazard ahead (Finley et al., 2014). More recently, Zhou et al. (2012) developed a new method that involved ranking high wrong-way crash locations based on the weighted number of wrong-way entries. The study further developed promising, cost-effective countermeasures to reduce the WWD errors and their associated crashes. In May 2014, the Illinois Center for Transportation and the IDOT published guidelines for reducing WWD crashes on freeways. The Illinois Guidebook contains information on several common countermeasures (e.g., signs and pavement markings), advance technologies, geometric elements, and related considerations, and enforcement and education strategies (Zhou et al., 2012; Zhou and Rouholamin, 2014). The guidebook also contains a Wrong Way Entry Field Inspection Checklist and WWD Road Safety Audit prompt list. However, the guidebook does not provide specific recommendations regarding the appropriate WWD countermeasures and mitigation methods based on specific site conditions.

Wang et al. (2018) identified and addressed the current limitation of 3*Es* (*Engineering*, *Education*, and *Enforcement*) in the context of WWD incidents, and recommended three strategies: *Connected Vehicle System*, *Access Management*, and *Traffic Safety Culture*. As the *Connected Vehicle System* is in the development process, the authors focused more on the latter two, which are practice-ready. The *Traffic Safety Culture* addresses intentional driver behaviors and includes those strategies that address social and cultural behaviors such as alcohol consumption, seatbelt usage, etc. For example, using *Designated Driver Strategy* to address driver impairment, where a person refrains from alcohol in social occasions or gathering in order to drive his/her companions who consumed alcoholic beverages. On the other hand, the *Access Management* strategies address both intentional and unintentional behaviors. They work with the regulations, and design of road and infrastructure geometry. For instance, the following measures could be taken to stop unintentional wrong-way drivers originating from roadside services: prohibiting left turns from service area by channelizing driveways, indicating to drivers the next U-turn by adding more signs, and closing driveways near divided highways when other access opportunities exist.

2.6 Texas

In the early 1970s, researchers at the Texas Transportation Institute (TTI) surveyed the state and local highway engineers and law enforcement personnel in an attempt to qualitatively determine the nature of WWD crashes in Texas (Friebele et al., 1971). In 2003, the Texas Department of

Transportation sponsored a WWD research following several severe WWD crashes across the state. The major findings from the research called for the use of reflectorized wrong way arrows on exit ramps, lowered DO NOT ENTER and WRONG WAY signs mounted together on the same sign support, and the development of a field checklist for wrong-way entry problem locations (Cooner et al., 2004a; Cooner et al., 2004b).

Since alcohol was a contributing factor in over one-third of the WWD crashes in Texas, researchers designed and conducted two nighttime closed-course studies to determine where alcohol-impaired drivers look in the forward driving scene, to provide insights into how alcohol-impaired drivers recognize and read signs, and finally to assess the conspicuity of selected WWD countermeasures from the perspective of alcohol-impaired drivers (Finley et al., 2014). The study findings indicated that alcohol-impaired drivers may tend to look less to the left and right, and more at the pavement in front of the vehicle. In addition, researchers confirmed that alcohol-impaired drivers do not actively search the forward driving scene as much as non-impaired drivers. Instead, alcohol-impaired drivers concentrate their glances in a smaller area within the forward driving scene. Researchers also confirmed that drivers at higher BAC levels took longer to locate signs and must be closer to a sign before they can identify the background color and read the legend. Since alcohol-impaired drivers tend to look more at the pavement in front of the vehicle, researchers recommended that wrong way arrows should be installed and maintained on all exit ramps on controlled-access highways.

The study also conducted a focus group discussion to obtain motorists' opinions regarding the design of WWD warning messages on DMS. Overall, the majority of the focus group participants thought that the warning message is supposed to have the word DANGER instead of WARNING, WRONG WAY DRIVER instead of ON COMING VEHICLE. They also recommended provision of location information and the approximate time (Finley et al., 2014).

2.7 Summary

Annually, WWD incidents result in 357 fatalities, accounting for about 2.8% of all fatal crashes on divided highways (NTSB, 2012). WWD crash mitigation has therefore gained significance, especially over the last decade. National efforts have focused on identifying and adopting driver-related, highway infrastructure-related, and vehicle safety systems-related strategies to mitigate WWD incidents. State DOTs have been exploring new and innovative ways to mitigate WWD incidents by detecting wrong-way drivers in real-time. Several pioneering states including Arizona, California, Florida, Illinois, and Texas, have adopted new technologies, including:

- thermal sensors and radar detection to detect wrong-way drivers on freeway mainlines;
- red lights on ramp signals to prevent right-way drivers from entering the freeway when a wrong-way driver is detected;
- dissemination of information on wrong-way driver via DMS, etc.
- detection-triggered LED-lights surrounding the WRONG WAY signs, red-RRFBs, etc. on off-ramps to alert the wrong-way driver;
- directional arrows and iiRPMs on off-ramps to inform the wrong-way driver; and
- strategies to inform the TMC personnel and other response agencies of the potential wrong-way driver.

CHAPTER 3
FACTORS INFLUENCING WRONG-WAY DRIVING INCIDENTS

This chapter focuses on identifying demographic and land-use variables that could potentially affect WWD incidents.

3.1 Factors Influencing WWD Crashes

The factors influencing WWD crashes are divided into the following three broad categories:

- Demographic factors
- Roadway geometric factors
- Temporal factors

3.1.1 Demographic Factors

WWD crashes were found to be affected by several demographic and socioeconomic factors including age, gender, socioeconomic background, etc. Table 3-1 summarizes the results from several studies that evaluated the impact of demographic factors on WWD crashes. For each study, the table also provides the specific demographic factors identified, the study period, the study region, and the analysis method. Note that the influential demographic and socioeconomic factors affecting WWD crashes were found to vary depending on analysis method, study period, etc.

3.1.2 Roadway Geometric Factors

In addition to demographic and socioeconomic factors, roadway geometric factors also affect WWD crashes. Table 3-2 summarizes the results from several studies that evaluated the impact of roadway geometric factors on WWD crashes. For each study, the table also provides the specific roadway geometric factors identified, the study period, the study region, and the analysis method.

Table 3-1: Demographic Factors Affecting WWD Crashes

Demographic Factors	Study Period	State	Method	Reference
Impaired driver	1967–1970	Texas	Descriptive statistics	Friebele et al., 1971
Intoxicated drivers; Urban areas	1983–1987	California	Descriptive statistics	Copelan, 1989
Male drivers; Drivers less than 34 years old; Intoxicated drivers; Urban areas	1997–2000	Texas	Descriptive statistics	Cooner et al., 2004a
Alcohol-related; Younger drivers; Older drivers; Interstate routes; Rural areas	2000–2005	North Carolina	Descriptive statistics	Braam, 2006
Intoxicated drivers; Older drivers; Male drivers; Passenger cars; Non-Hispanic and native Americans	1990–2004	New Mexico	Comparison group	Lathrop et al., 2010
Intoxicated drivers; Younger drivers; Older drivers; Male drivers	2005–2009	Michigan	Descriptive statistics	Morena and Leix, 2012
Younger drivers (16–24 years); Male drivers; Impaired drivers	2007–2011	Texas	Descriptive statistics	Finley et al., 2014
Older drivers; Younger drivers; Male drivers; Local drivers; Intoxicated drivers; Urban areas; Passenger cars; Single-occupant vehicles	2004–2009	Illinois	Descriptive statistics	Zhou et al., 2015
Older drivers; Intoxicated drivers; Physically impaired drivers; Driver residency distance (local drivers); Vehicles older than 15 years; Months of March, May, and November	2009–2013	Alabama	Firth's Penalized-Likelihood Logistic Regression	Pour-Rouholamin et al., 2014
Older drivers; Intoxicated drivers; Physically impaired drivers; Driver residency distance (local drivers); Vehicles older than 15 years	2009–2013	Alabama	Generalized ordered logit	Pour-Rouholamin and Zhou, 2016
Impaired drivers; Younger drivers	2009–2013	Florida	Descriptive statistics	Kittelson and Associates, 2015
Driver age; Driver gender; Driver condition (eyesight, fatigue, illness, seizure, epilepsy); Intoxicated drivers; Urban areas; Vehicle use	2003–2010	Florida	Logistic regression	Ponnaluri, 2016b
Urban areas; Driver impairment; Male drivers	2004-2014	Arizona	Descriptive statistics	Simpson and Bruggeman, 2015
Urban areas; Male drivers, Older drivers (> 65 years); Impaired drivers	2004–2013	Alabama	Conventional Log Linear Model	Jalayer et al., 2018
Older drivers; Impaired drivers; Urban areas (frequent WWD crashes); Rural areas (severe WWD crashes)	2009-2013	Alabama	Descriptive statistics; Firth's penalized-likelihood logistic regression	Zhang et al., 2017

Table 3-2: Roadway Geometric Factors Affecting WWD Crashes

Geometric Factors	Study Period	State	Method	Reference
Entrance by exit ramp; Diamond interchange; Partial interchange; Less than 1,000 feet of sight distance; Improper signing	1967–1970	Texas	Descriptive statistics	Friebele et al., 1971
Interchanges with short sight distance; Partial cloverleaf interchanges; Half and full diamond interchanges; Trumpet interchanges; Slip ramps; Buttonhook ramps; Scissors exit ramp; Left-side exit ramp; Five-legged intersections near exit ramps	1983–1987	California	Descriptive statistics	Copelan, 1989
Left-side exit ramps; One-way street transitioned into freeway	1997–2000	Texas	Descriptive statistics	Cooner et al., 2004a
Two-quadrant parclo interchanges; Full diamond interchanges	2000–2005	North Carolina	Descriptive statistics	Braam, 2006
Parclo interchanges; Trumpet interchanges; Tight diamond interchanges	2005–2009	Michigan	Descriptive statistics	Morena and Leix, 2012
Type of interchange	2004–2009	Illinois	Descriptive statistics	Zhou et al., 2015
Roadway condition	2009–2013	Alabama	Firth's Penalized-Likelihood Logistic Regression	Pour-Rouholamin et al., 2014
Dry road surface	2004−2013	Alabama	Conventional Log Linear Model	Jalayer et al., 2017
The distance from the ramp median to the left-turn stop line on a crossroad	2004–2013	Illinois	Descriptive statistics	Wang et al., 2017

3.1.3 Temporal Factors

Table 3-3 summarizes the results from several studies that evaluated the impact of temporal factors on WWD crashes. For each study, the table also provides the specific temporal factors identified, the study period, the study region, and the analysis method.

Table 3-3: Temporal Factors Affecting WWD Crashes

Temporal Factors	Study Period	State	Method	Reference
Darkness; Time of day	1983–1987	California	Descriptive statistics	Copelan, 1989
Early morning hours	1997–2000	Texas	Descriptive statistics	Cooner et al., 2004a
Time of day (midnight to 5:59 a.m.); Months of February and June	2000–2005	North Carolina	Descriptive statistics	Braam, 2006
Darkness; Month of November; Non-Hispanic and native Americans	1990–2004	New Mexico	Comparison group	Lathrop et al., 2010
Darkness; Time of the day (late night and early morning)	2005–2009	Michigan	Descriptive statistics	Morena and Leix, 2012
Time of day (7:00 p.m. to 12:00 p.m.)	2007–2011	Texas	Descriptive statistics	Finley et al., 2014
Weekends; Darkness; Time of day (midnight to 5:00 a.m.)	2004–2009	Illinois	Descriptive statistics	Zhou et al., 2015
Time of day (evening and afternoon); Months of March, May, and November	2009–2013	Alabama	Firth's Penalized-Likelihood Logistic Regression	Pour-Rouholamin et al., 2014
Time of day (evening and afternoon); Months of March, May, and November	2009–2013	Alabama	Generalized ordered logit	Pour-Rouholamin and Zhou, 2016
Months of January through April, June, and July; Weekends; Darkness	2009–2013	Florida	Descriptive statistics	Kittelson and Associates, 2015
Time of day; Darkness	2003–2010	Florida	Logistic regression	Ponnaluri, 2016b
Nighttime; Weekends	2004-2014	Arizona	Descriptive statistics	Simpson and Bruggeman, 2015
Nighttime; Unclear weather conditions	2004−2013	Alabama	Conventional Log Linear Model	Jalayer et al., 2018
Dark roadways with no lighting	2009-2013	Alabama	Descriptive statistics; Firth's penalized-likelihood logistic regression	Pour-Rouholamin et al., 2016

3.2 Study Data

Demographic, land-use, and roadway characteristics data were used in this study. The demographic factors were obtained from the US Census Bureau, the land-use variables were extracted from the Florida Geographic Data Library (FGDL), while information on the off-ramp configuration was manually collected.

3.2.1 Census Data

Census Block Groups in Florida

This dataset contains the 2015 census block groups for the State of Florida. The data are primarily extracted from the 2015 United States Census Bureau, with selected fields extracted from the 2011-2015 American Community Survey. The census block group is the smallest geographical unit for which the Bureau publishes sample data. Block groups generally contain between 600 and 3,000 people, with an optimum size of 1,500 people. The *2015 Florida Census Block Groups* GIS layer includes a total of 11,442 census block groups. The fields included in this dataset are total population, education, housing, and economic characteristics. The American Community Survey data are survey estimates distributed for one-, three-, and five-year time periods. Note that the five-year estimates are the only time period estimates that provide data at the block group level. Figure 3-1 shows the 2015 Census Block Groups in Florida.

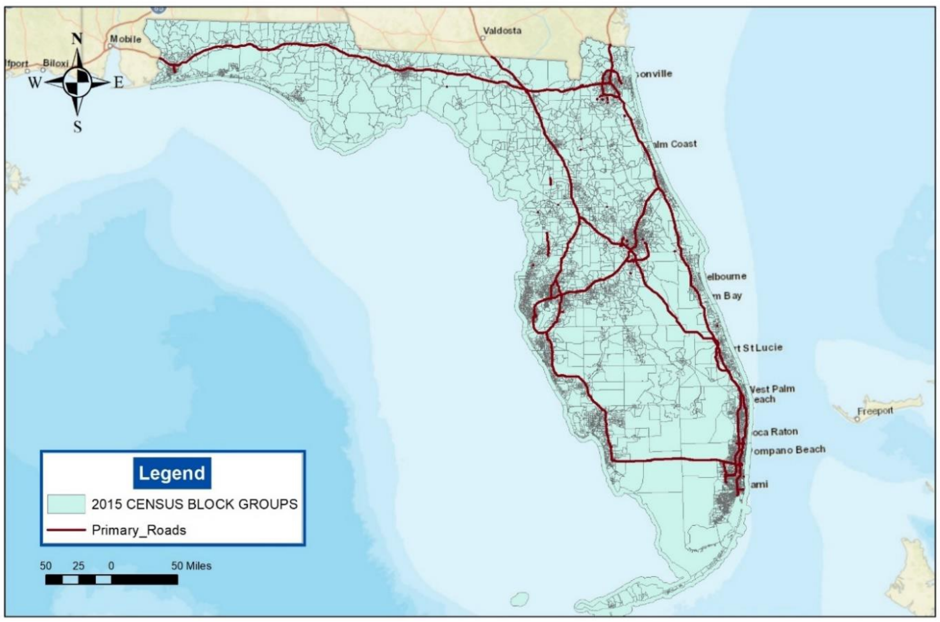


Figure 3-1: 2015 Florida Census Block Groups Map

Based on the 2015 Census Block Group data, Florida has a population of 20.3M, with a median age of 41.8 years and a median household income of $49,426. The population of Florida is 55.1% (~11.2M) White, 24.5% (~4.96M) Hispanic, 15.5% (~3.15M) Black, and 2.6% (~0.5M) Asian residents. About 29% of Floridians speak a non-English language, and 90.7% are U.S. citizens.

Data Attributes

The following five groups of attributes are considered in the *2015 Florida Census Block Groups* data: population, gender, age, income, and household. Table 3-4 lists the detailed attributes extracted from the *2015 Florida Census Block Groups* dataset.

Table 3-4: Key Attributes in 2015 Census Block Groups Dataset

Group	Attribute	Definition
Population	TOTALPOP	Total Population
Gender	MALE	Population Male
	FEMALE	Population Female
Age	AGE_UNDER5	Population Under 5 years
	AGE_5_17	Population 5 to 17 years
	AGE_18_21	Population 18 to 21 years
	AGE_22_29	Population 22 to 29 years
	AGE_30_39	Population 30 to 39 years
	AGE_40_49	Population 40 to 49 years
	AGE_50_64	Population 50 to 64 years
	AGE_65_UP	Population 65 years and up
Income	LESS_10K	# of Households (HH*) with HH Income in The Past 12 Months < $10,000
	I10K_14K	# of HH with HH Income in The Past 12 Months $10,000 to $14,999
	I15K_19K	# of HH with HH Income in The Past 12 Months $15,000 to $19,999
	I20K_24K	# of HH with HH Income in The Past 12 Months $20,000 to $24,999
	I25K_29K	# of HH with HH Income in The Past 12 Months $25,000 to $29,999
	I30K_34K	# of HH with HH Income in The Past 12 Months $30,000 to $34,999
	I35K_39K	# of HH with HH Income in The Past 12 Months $35,000 to $39,999
	I40K_44K	# of HH with HH Income in The Past 12 Months $40,000 to $44,999
	I45K_49K	# of HH with HH Income in The Past 12 Months $45,000 to $49,999
	I50K_59K	# of HH with HH Income in The Past 12 Months $50,000 to $59,999
	I60K_74K	# of HH with HH Income in The Past 12 Months $60,000 to $74,999
	I75K_99K	# of HH with HH Income in The Past 12 Months $75,000 to $99,999
	I100K_124K	# of HH with HH Income in The Past 12 Months $100,000 to $124,999
	I125K_149K	# of HH with HH Income in The Past 12 Months $125,000 to $149,999
	I150K_199K	# of HH with HH Income in The Past 12 Months $150,000 to $199,999
	I200KMORE	# of HH with HH Income in The Past 12 Months $200,000 or more
Household	HOUSEHOLDS	Total Households
	OWNER	Owner occupied housing units
	RENTER	Renter occupied housing units

* HH is households.

3.2.2 Land-use Data

The 2015 Florida Land-use layer includes a total of 9,117,116 parcels. Figure 3-2 shows the 2015 Florida Parcel Land-use map. This dataset contains parcel boundaries with each parcel's associated tax information from the Florida Department of Revenue's tax database. This feature class contains parcel polygons and the associated parcel attribute information. Attributes include Parcel ID, Alt Key, Section, Township, Range, Owner Name, Owner Mailing Address, Site Address, Most Recent Sales Information, Valuation, Land-use Codes, Building Details, Legal Description, etc. It includes the original 99 land-use classes, and the 15 generalized classes.

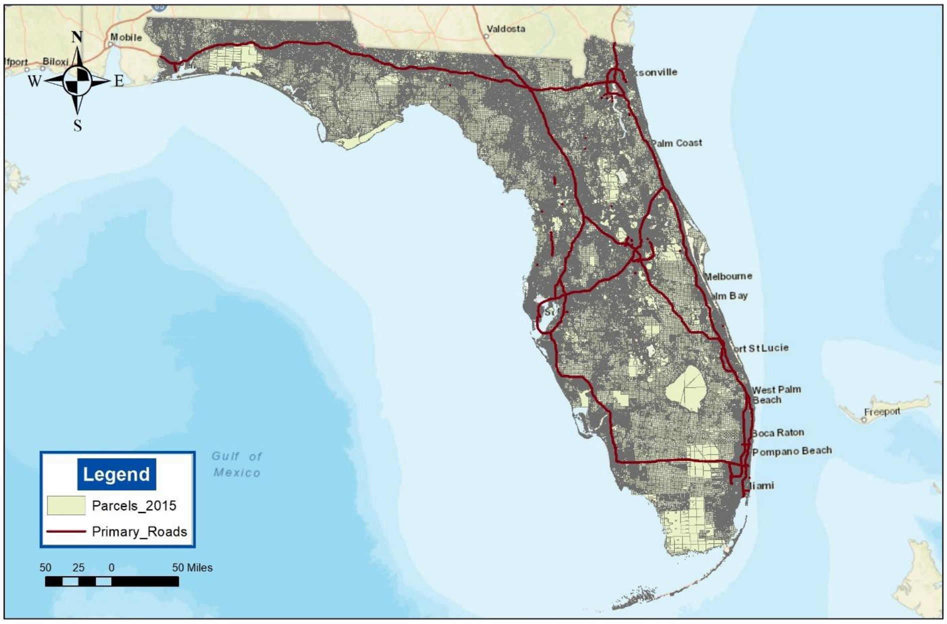


Figure 3-2: 2015 Florida Parcel Land-use Map

The following six groups of attributes were considered in the 2015 Florida Parcel Land-use dataset: shopping centers, transportation terminals, entertainment facilities, hotels, recreation facilities, and alcohol sales establishments. More details about this dataset are provided in Chapters 4 and 5.

3.2.3 Roadway Characteristics Data

Several studies in the literature have concluded that off-ramp configuration affects the occurrence of WWD incidents (e.g., Morena and Leix, 2012; Zhou et al., 2015; etc.). The FDOT GIS layers and the Roadway Characteristics Inventory (RCI) do not have detailed information about the off-ramp configuration. As such, a major effort has been undertaken to manually collect this information from Google Maps.

As part of a previously completed research project with the FDOT Research Center, the research team had manually collected information on all ramps in Florida. This shapefile had information on ramp location (latitude and longitude), ramp type (on-ramp, or off-ramp), and ramp configuration (i.e., diamond, partial diamond, trumpet, partial cloverleaf, other). This shapefile had information on 1,314 off-ramps (see Figure 3-3). Note that this shapefile was incomplete. As such, a major effort was undertaken to verify and update this dataset. Information on the missing off-ramps was collected using Google Earth (see Figure 3-4). The original dataset was updated with information on additional 328 off-ramps. The final dataset included 1,642 off-ramps in Florida.

Figure 3-3: The Original Off-ramp Layer in Florida

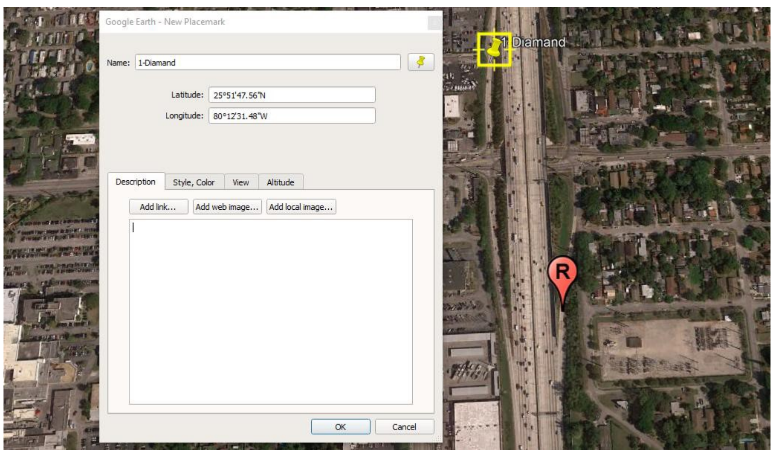


Figure 3-4: Off-ramp Data Collection Effort

3.3 Variables of Interest

Based on the detailed literature review and consultation with the experts in WWD mitigation strategies, the following factors were identified to affect the occurrence of WWD incidents:

- Impaired drivers (i.e., drivers who are under the influence of alcohol and/or drugs)
- Drivers aged 65 years and older
- Tourists and visitors

- Roadway geometric conditions

The following demographic, land-use, and roadway geometric variables were considered in the analysis.

- Drivers Aged 65 Years and Older
  - Percent of population aged 65 years and older
  - Health facilities

- Tourists and Visitors
  - Shopping centers
  - Transportation terminals
  - Parks and recreational facilities
  - Hotels
  - Theaters and auditoriums
  - Bowling alleys, race tracks, skating rinks, and enclosed arenas
  - Restaurants and cafeterias

- Impaired Drivers
  - Restaurants and cafeterias
  - Bowling alleys, race tracks, skating rinks, and enclosed arenas
  - Night clubs, bars, and cocktail lounges

- Roadway Geometric Conditions
  - Off-ramp configuration

3.3.1 Drivers Aged 65 Years and Older

Drivers aged 65 years are older are often overrepresented in WWD crashes. This could be because they may have poor vision, and often get confused by the roadway geometry, especially if they are driving at night. Hence, it could be hypothesized that the locations where the population aged 65 years and older live and drive could be more prone to WWD incidents. The impact of the regions with a relatively high percentage of population aged 65 years and older and health facilities on WWD crashes was analyzed in this study.

Figure 3-5 shows the distribution of population 65 years and older within the 2015 Census Block Groups in Florida. Health facilities were extracted from the 2017 Hospital Facilities GIS layer obtained from the Florida Geographic Data Library (FGDL). This dataset contains selected fields denoting the name, physical address, and other facility information for hospitals located in Florida. This dataset includes 349 health facilities. Figure 3-6 shows the density map of health facilities in Florida.

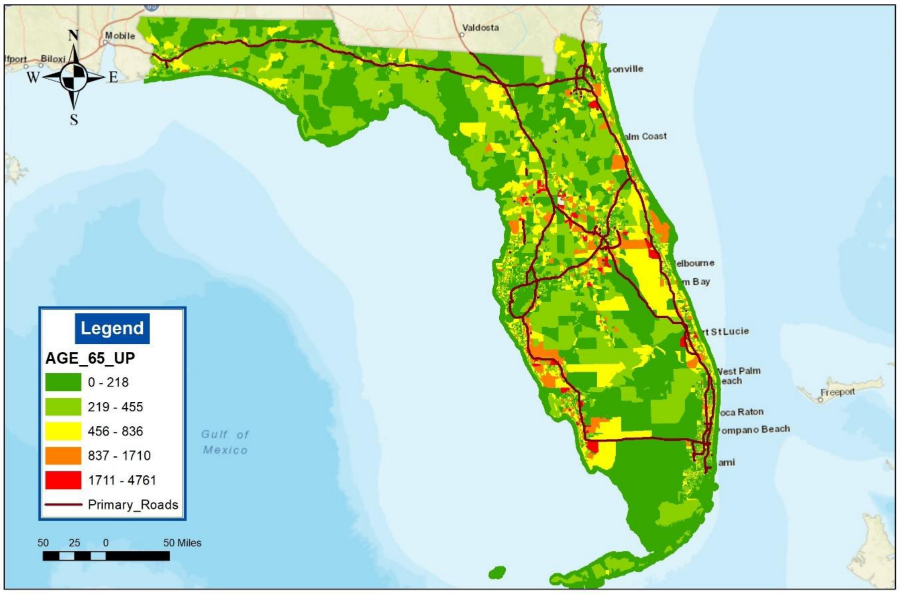


Figure 3-5: Distribution of Population 65 Years and Older in 2015 Census Block Groups

Figure 3-6: Density Map of Health Facilities

3.3.2 Tourists and Visitors

Tourists and visitors are often unfamiliar with the road network, and hence, have a greater probability of driving in the wrong way. The following five groups of attributes were considered for tourists and visitors in the *2015 Florida Parcel Land-use* dataset: shopping centers, transportation terminals, entertainment facilities, hotels, and recreation facilities. Table 3-5 lists the detailed tourists and visitors attributes extracted from *2015 Florida Parcel Land-use* dataset. Note that shopping facilities include shopping malls and supermarkets. Entertainment facilities include theaters, stadiums, arenas, and race tracks. Recreation facilities include attractions, camps, and parks. Figures 3-7 through 3-11 show the density maps of these five groups.

Table 3-5: Key Attributes for Tourists in the *2015 Florida Parcel Land-use* Dataset

Group	Attribute	Number
Shopping Centers	Supermarket	2,511
	Regional shopping malls	413
	Community shopping centers	8,278
Transportation Terminals	Airports, marinas, bus terminals, and piers	4,117
Entertainment Facilities	Drive-in theaters, open stadiums	53
	Enclosed theaters, auditorium	290
	Bowling alleys, skating rinks, arenas	527
	Race horse, auto, and dog tracks	141
Hotels	Hotels, motels	13,286
Recreation Facilities	Tourist attractions	720
	Camps	460
	Outdoor recreational	6,204

Figure 3-7: Density Map of Shopping Facilities

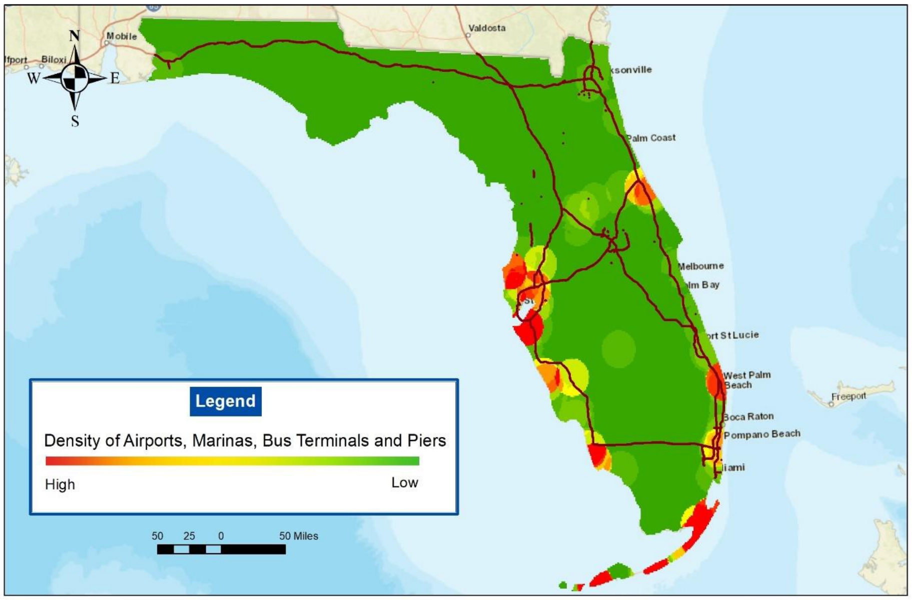


Figure 3-8: Density Map of Transportation Terminals

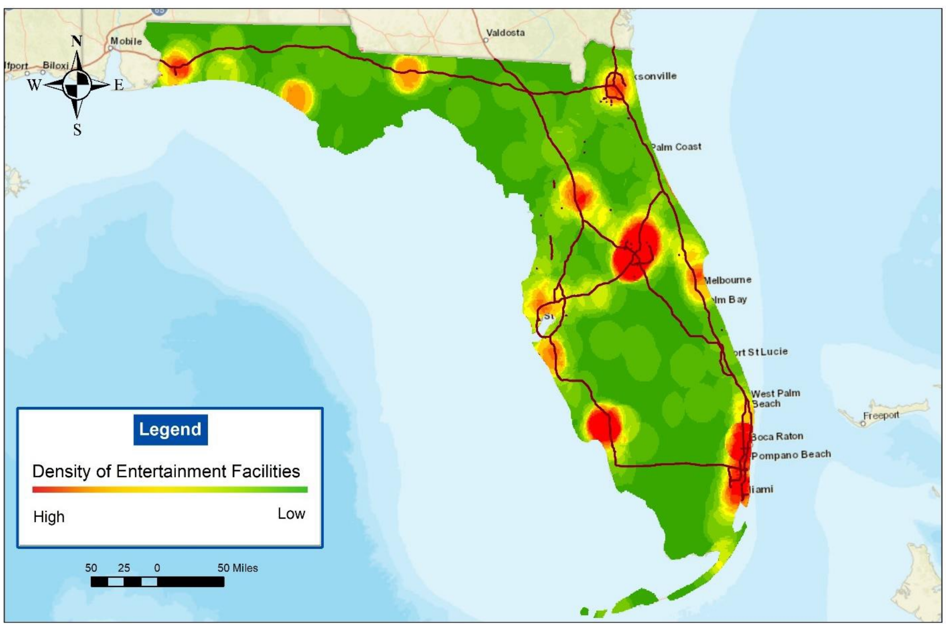


Figure 3-9: Density Map of Entertainment Facilities

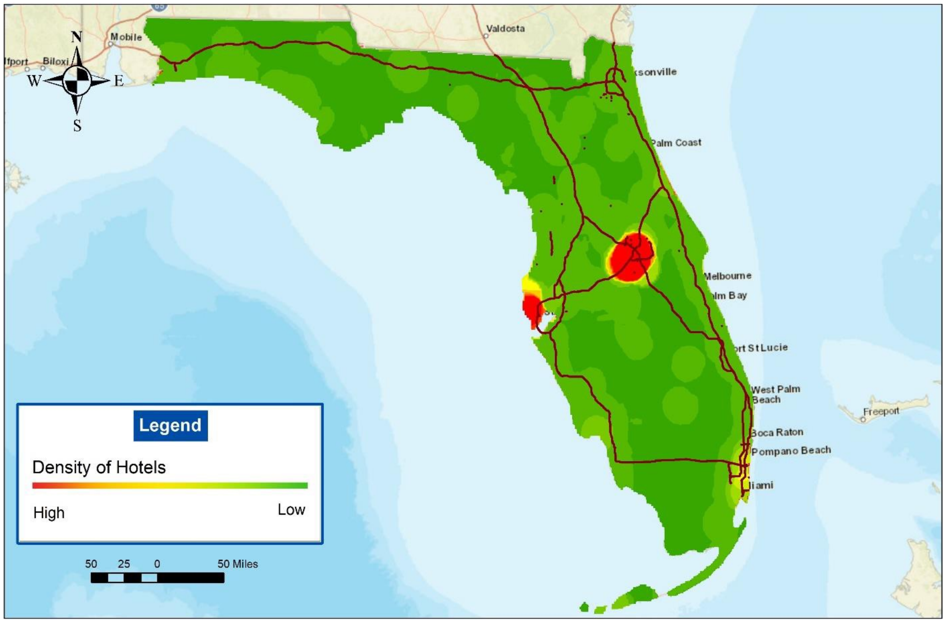


Figure 3-10: Density Map of Hotels

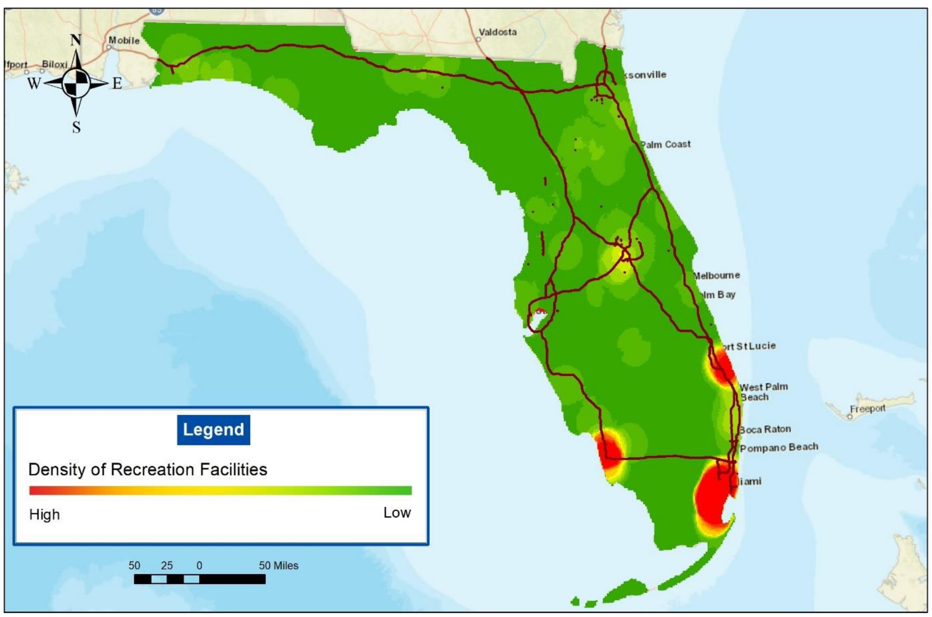


Figure 3-11: Density Map of Recreation Facilities

3.3.3 Impaired Drivers

Driving Under the Influence of alcohol and/or drugs (DUI) is identified as one of the most common factors contributing to WWD incidents. It was hypothesized that regions with alcohol sales establishments are more prone to WWD incidents. As such, information on restaurants, cafeterias, night clubs, bars, and cocktail lounges was extracted from the *2015 Florida Parcel Land-use* dataset, and was included in the analysis. Table 3-6 lists the detailed attributes of alcohol sales establishments extracted from the *2015 Florida Parcel Land-use* dataset. Figure 3-12 shows the density map of alcohol sales establishments in Florida.

Table 3-6: Key Attributes of Alcohol Sales Establishments in the *2015 Florida Parcel Land-use* Dataset

Group	Attribute	Numbers
Alcohol Sales Establishments	Restaurants, cafeterias	8,523
	Drive-in restaurants	4,442
	Night clubs, bars, and cocktail lounges	1,873

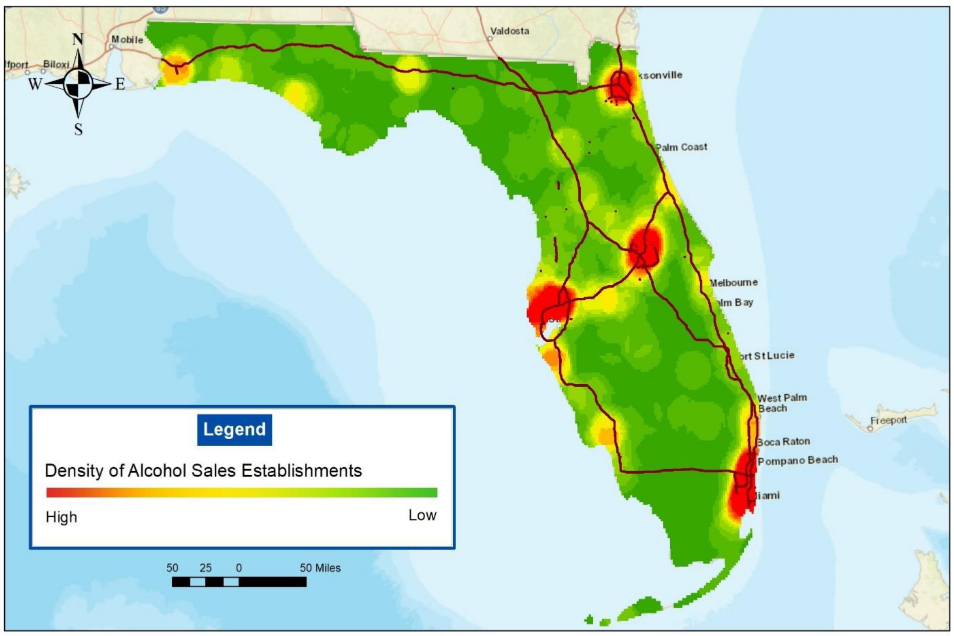


Figure 3-12: Density Map of Alcohol Sales Establishments

3.3.4 Off-Ramp Configuration

As mentioned earlier, the type of off-ramp configuration affects the occurrence of WWD incidents. Information on a total of 1,642 off-ramps in Florida was considered in the analysis. Table 3-7 provides descriptive statistics of the off-ramps in Florida.

Table 3-7: Descriptive Statistics of Off-ramps in Florida

Off-ramp Configuration	Number of Off-ramps
Diamond	789
Partial Diamond	271
Parclo Loop	50
Trumpet	118
Other	275
Partial Loop	139
Total	**1,642**

3.3.5 WWD Crashes

WWD crashes that occurred on all public roads in Florida for the years 2011 through 2015 were included in the analysis. Figure 3-13 shows the spatial distribution of these WWD crashes. Figure 3-14 shows the density map of WWD crashes. Table 3-8 summarizes these crashes by year and crash severity.

Table 3-8: WWD Crash Statistics by Year and Crash Severity

Year	Property Damage Only		Injury		Fatal		Total
	No.	%	No.	%	No.	%	
2011	463	40%	641	55%	65	6%	1,169
2012	522	42%	656	53%	67	5%	1,245
2013	643	47%	680	49%	55	4%	1,378
2014	671	45%	763	51%	72	5%	1,506
2015	770	49%	741	47%	71	4%	1,582
Total	**3,069**	**45%**	**3,481**	**51%**	**330**	**5%**	**6,880**

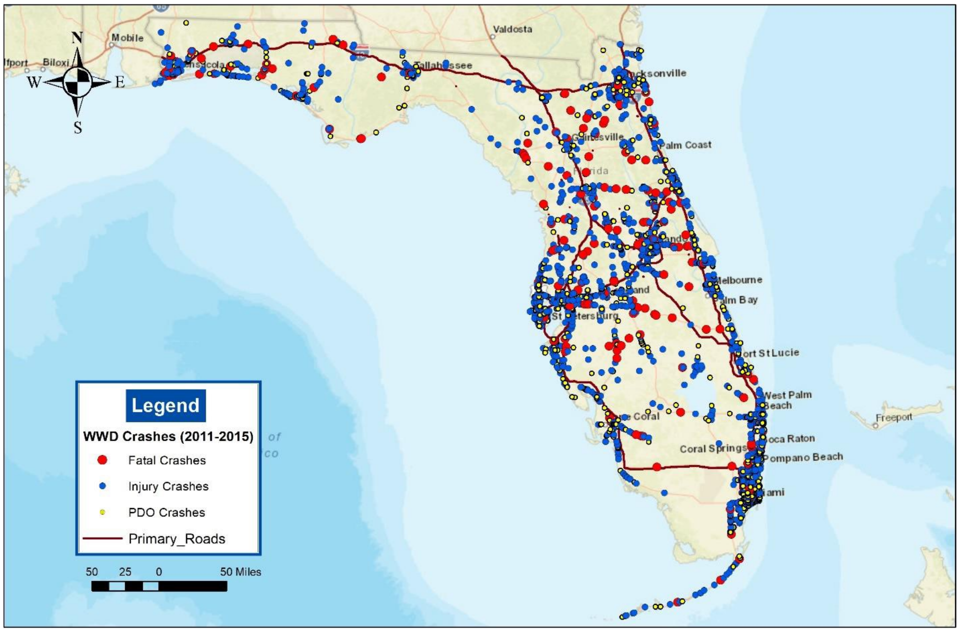


Figure 3-13: WWD Crashes on the Public Road Network in Florida from 2011-2015

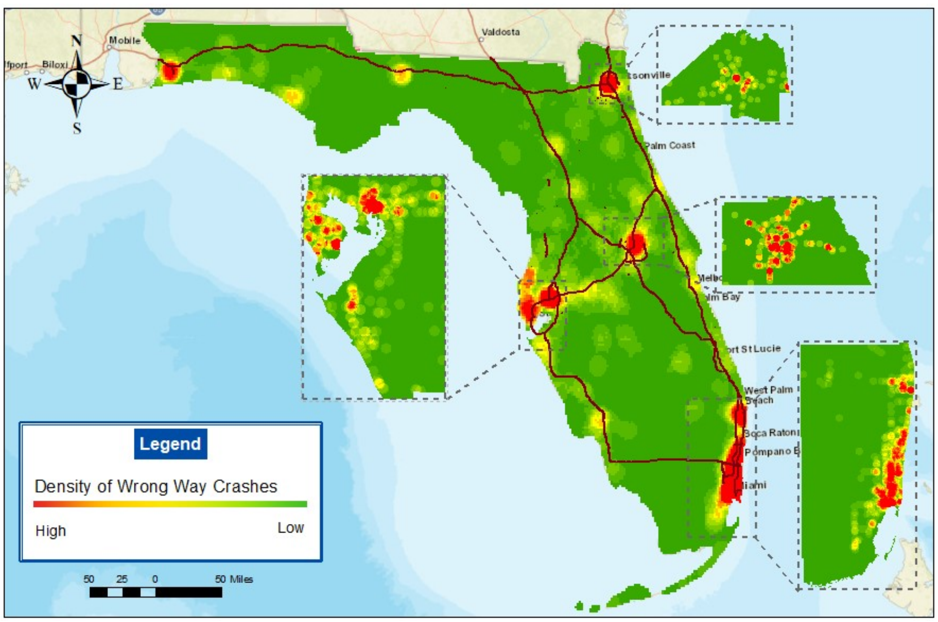


Figure 3-14: Density Map of WWD Crashes from 2011-2015

3.4 Summary

The factors that affect the occurrence of WWD incidents could be divided into the following four broad categories. Table 3-9 summarizes the variables considered in the analysis, along with their data sources.

- Impaired drivers
- Drivers aged 65 years and older
- Tourists and visitors
- Roadway geometric characteristics

Table 3-9: Summary of the Variables Considered in the Analysis

Category	Variable	Source
Drivers Aged 65 Years and Older	Percent of Population 65 Years and Older	Census Data from US Census Bureau
	Health Facilities	Land-use Data from FGDL
Tourists and Visitors	Shopping Centers	
	Transportation Terminals	
	Entertainment Facilities	
	Hotels	
	Recreation Facilities	
Impaired Drivers	Restaurants	
	Bars	
Roadway Geometry	Off-ramp Configuration	Manually Collected from Google Earth

CHAPTER 4
WRONG-WAY DRIVING CRASH HOTSPOTS

This chapter focuses on identifying WWD crash hotspots in Florida. The analysis was based on five years of WWD crash data from 2011-2015. Spatial analysis in ArcGIS was conducted to identify WWD crash hotspots in each FDOT District. The chapter also includes a discussion on the potential of using WWD arrests data in addition to WWD crash data to identify WWD crash hotspots. Finally, the chapter discusses the analysis of WWD crashes on freeways.

4.1 WWD Crash Data

The analysis was based on five years of crash data from 2011-2015. The crash data shapefiles for the years 2011-2014 were downloaded from the Florida Department of Transportation (FDOT) Unified Basemap Repository (UBR) for both on-system and off-system roads. The variable FL_WRNGWAY, a yes/no flag that indicates WWD involvement, was used to identify WWD crashes. The 2015 crash data shapefiles were not available at the time of this research. WWD crashes for the year 2015 were identified using the following code in the vehicle-driver-passenger extract file obtained from the FDOT's Crash Analysis Reporting (CAR) System: *Driver Action at Time of Crash = "21" (wrong side or wrong way).*

4.1.1 WWD Crash Frequency

Table 4-1 summarizes the WWD crash frequencies from 2011 to 2015. Note that year 2015 experienced a total of 1,876 WWD crashes; however, coordinates (i.e., latitude and longitude) are available only for 1,582 WWD crashes. As can be inferred from Figure 4-1, WWD crashes increased by 60% from 2011 to 2015.

Table 4-1: Annual WWD Crash Statistics

<table>
<tr><th>WWD Crashes</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>Total</th></tr>
<tr><td>Total WWD Crashes</td><td>1,169</td><td>1,245</td><td>1,378</td><td>1,506</td><td>1,876</td><td>7,174</td></tr>
<tr><td>WWD Crashes on On-system Roads</td><td>527</td><td>539</td><td>622</td><td>681</td><td rowspan="2">n/a</td><td rowspan="2">n/a</td></tr>
<tr><td>WWD Crashes on Off-system Roads</td><td>642</td><td>706</td><td>756</td><td>825</td></tr>
<tr><td>WWD Crashes with Valid Coordinates</td><td>1,169</td><td>1,245</td><td>1,378</td><td>1,506</td><td>1,582</td><td>6,880</td></tr>
</table>

n/a: Detailed data unavailable.

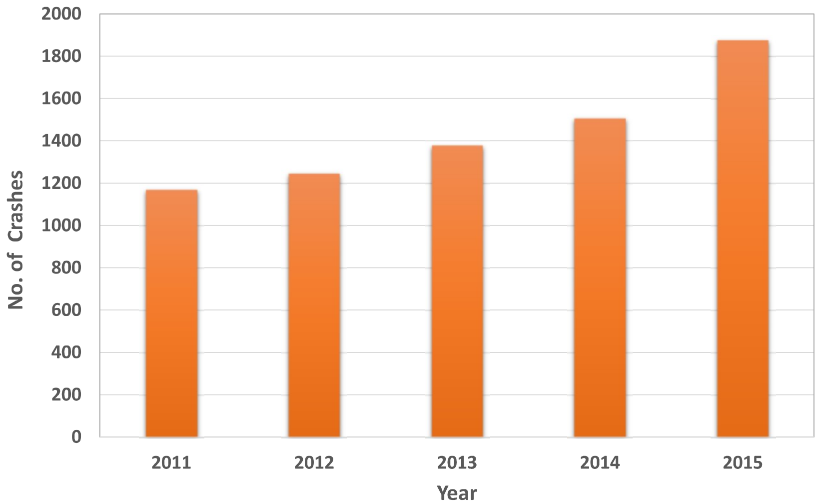


Figure 4-1: WWD Crashes from 2011-2015

4.1.2 Crash Severity

Table 4-2 summarizes WWD crashes by year and crash severity. Figure 4-2 shows the spatial distribution of these WWD crashes by severity. Overall, about 5% of all WWD crashes were fatal, while approximately 51% resulted in injuries.

Table 4-2: Annual WWD Crash Statistics by Crash Severity

							Total
					No.	**%**	
2011	463	40%	641	55%	65	6%	1,169
2012	522	42%	656	53%	67	5%	1,245
2013	643	47%	680	49%	55	4%	1,378
2014	671	45%	763	51%	72	5%	1,506
2015	770	49%	741	47%	71	4%	1,582
	3,069	**45%**	**3,481**	**51%**	**330**	**5%**	**6,880**

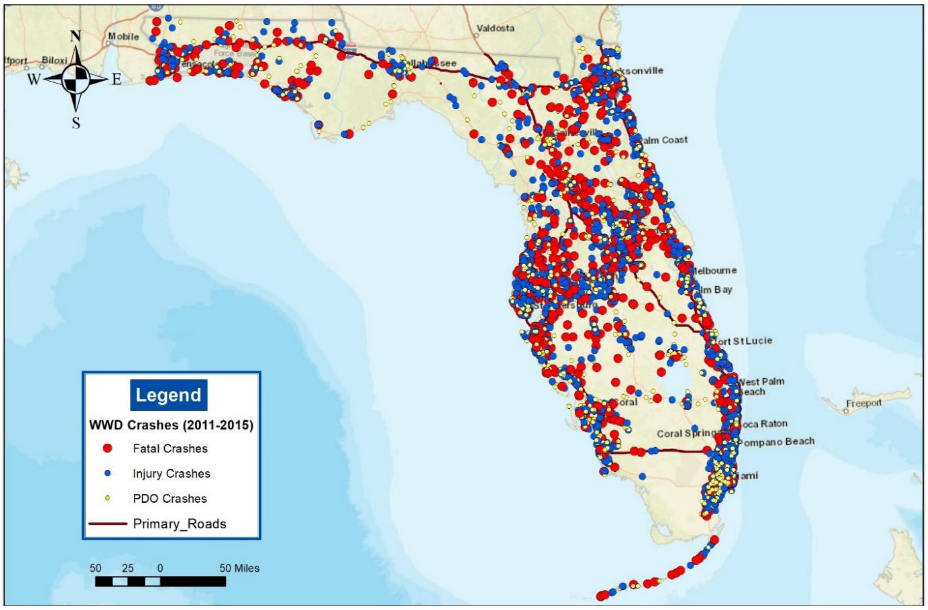


Figure 4-2: Spatial Distribution of WWD Crashes by Crash Severity

4.1.3 Day of Week

Table 4-3 provides the WWD crash statistics by day of week (i.e., weekday vs. weekend). A weekday is defined from Monday at 6 AM through Friday Noon. The number of WWD crashes on the weekend were found to be approximately 40% of total number of WWD crashes. Figure 4-3 shows the spatial distribution of these crashes.

Table 4-3: Annual WWD Crash Statistics by Day of Week

	Weekday		Weekend		
	No.	**%**	**No.**	**%**	
2011	689	59%	480	41%	1,169
2012	738	59%	507	41%	1,245
2013	820	60%	558	40%	1,378
2014	868	58%	638	42%	1,506
2015	885	56%	697	44%	1,582
Total	**4,000**		**2,880**		**6,880**

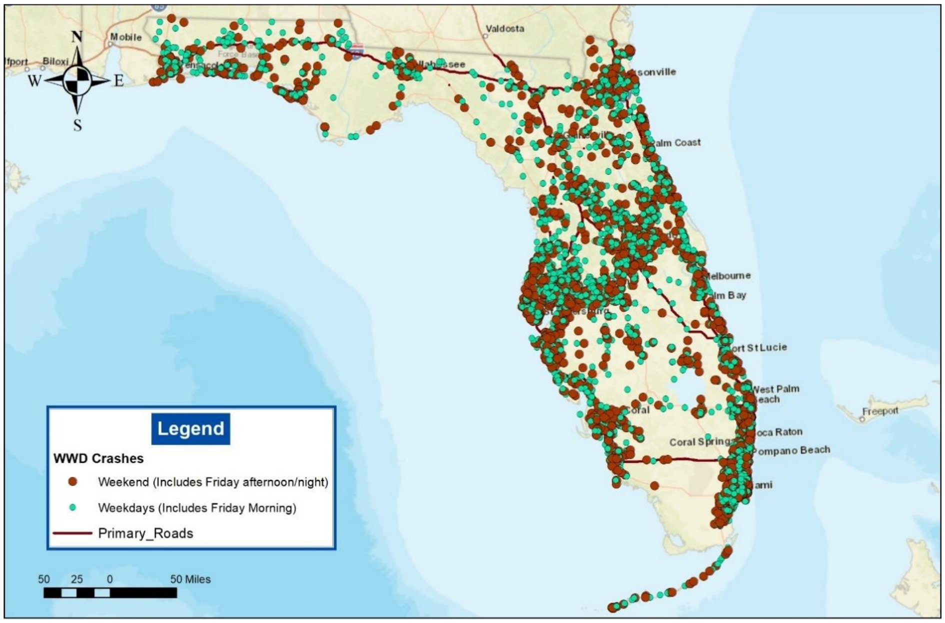


Figure 4-3: Spatial Distribution of WWD Crashes by Weekday or Weekend

4.1.4 Time of Day

Table 4-4 provides the WWD crash statistics by time of day (i.e., night vs. day). Note that "night" includes dusk, dawn, and other dark conditions. Figure 4-4 shows the spatial distribution of these crashes. The number of WWD crashes at night were found to be slightly over 50% of total WWD crashes.

Table 4-4: Annual WWD Crash Statistics by Time of Day

Year	Day		Night		Total
	No.	%	No.	%	
2011	580	50%	589	50%	1,169
2012	578	46%	667	54%	1,245
2013	668	48%	710	52%	1,378
2014	755	50%	751	50%	1,506
2015	797	50%	785	50%	1,582
Total	**3,378**	**49%**	**3,502**	**51%**	**6,880**

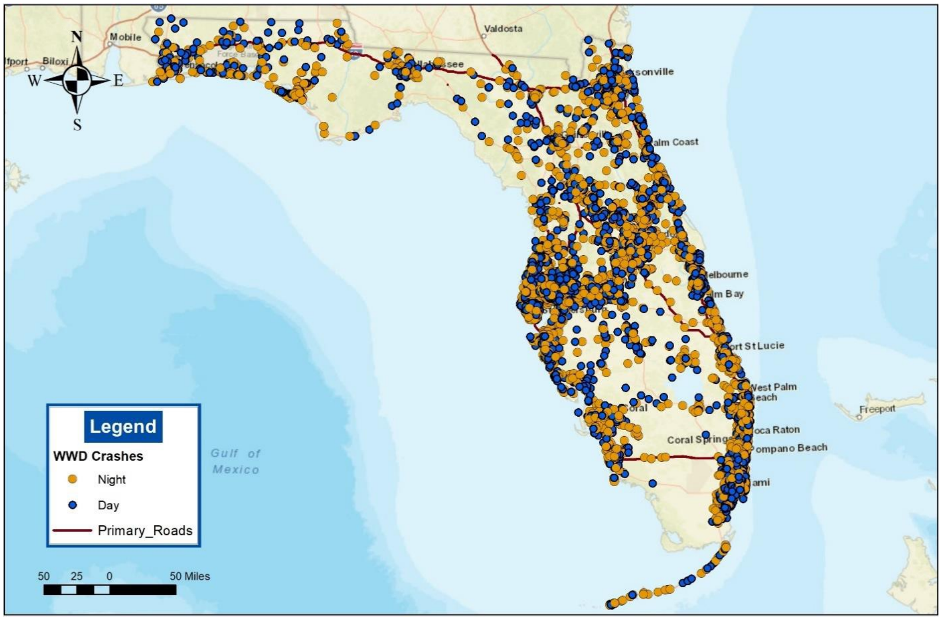


Figure 4-4: Spatial Distribution of WWD Crashes by Time of Day

4.1.5 Driver Age

Table 4-5 provides the WWD crash statistics by driver age. Figure 4-5 shows the spatial distribution of these crashes by age. Note that "age" is divided into three groups, Young (< 30 years), Adult (30-64 years) and Senior (≥ 65 years). The number of WWD crashes by young and senior people were found to be about 55% of total WWD crashes.

Table 4-5: Annual WWD Crash Statistics by Driver Age

Year	Young		Adult		Senior		Total
	No.	%	No.	%	No.	%	
2011	508	43%	522	45%	139	12%	1,169
2012	519	42%	567	46%	159	13%	1,245
2013	569	41%	619	45%	190	14%	1,378
2014	545	36%	715	47%	246	16%	1,506
2015	668	42%	699	44%	215	14%	1,582
Total	**2,809**	**41%**	**3,122**	**45%**	**949**	**14%**	**6,880**

4.1.6 Alcohol Involvement

Table 4-6 provides the WWD crash statistics based on alcohol/drug involvement. Figure 4-6 shows the spatial distribution of alcohol-related WWD crashes. Approximately 32% of all WWD crashes involved intoxicated drivers.

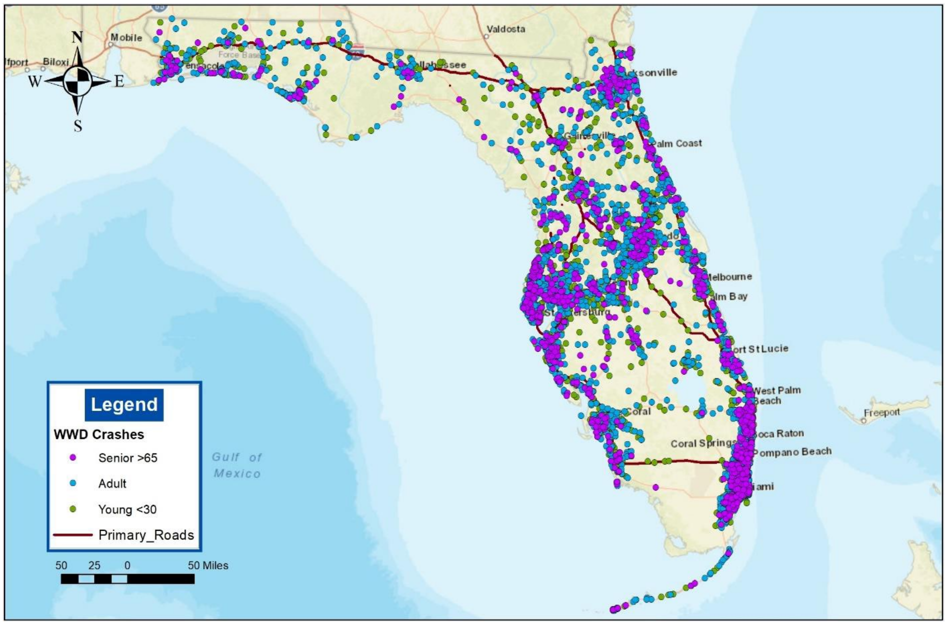


Figure 4-5: Spatial Distribution of WWD Crashes by Driver Age

Table 4-6: Annual WWD Crash Statistics by Alcohol Involvement

Year	No Alcohol/Drug Involvement		Alcohol/Drug Involvement		Total
	No.	%	No.	%	
2011	802	69%	367	31%	1,169
2012	833	67%	412	33%	1,245
2013	984	71%	394	29%	1,378
2014	889	59%	617	41%	1,506
2015	1,204	76%	378	24%	1,590
Total	**4,712**	**68%**	**2,168**	**32%**	**6,880**

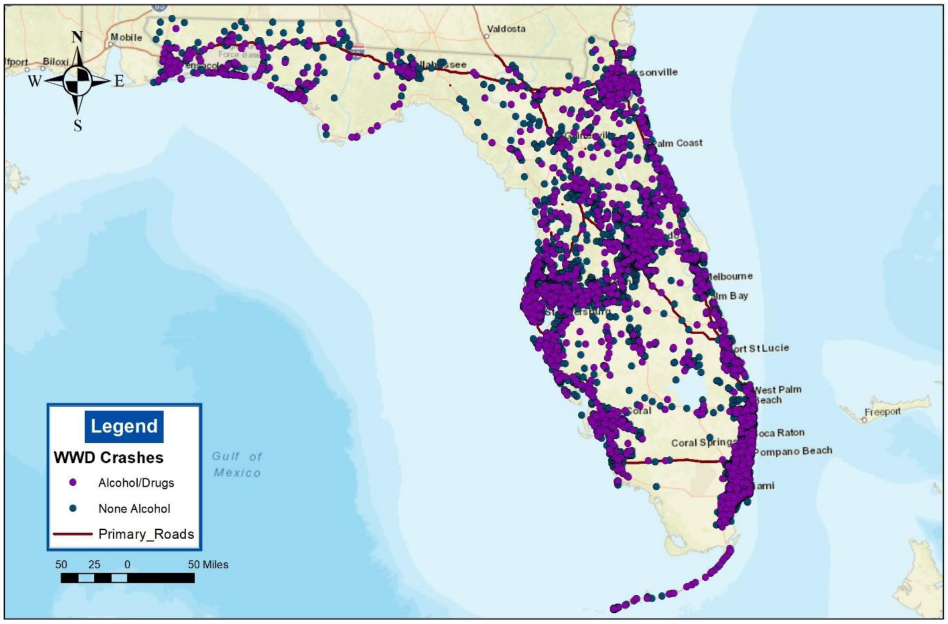


Figure 4-6: Spatial Distribution of WWD Crashes by Alcohol Involvement

4.1.7 Summary

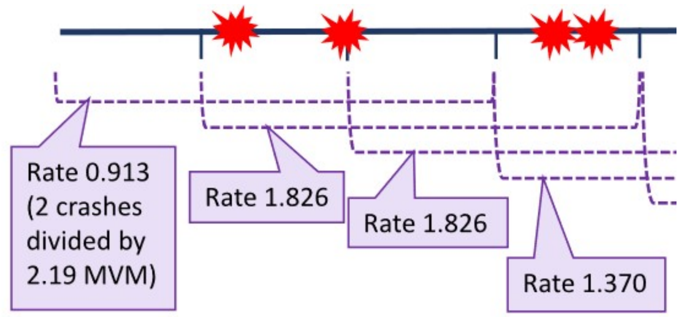
The descriptive trend analysis of WWD crash data from 2011-2015 identified the following crash patterns and trends:

- WWD crashes were on an increasing trend since 2011.
- The proportion of fatalities and injuries involving WWD incidents were on a slightly decreasing trend in recent years.
- About 40% of WWD crashes occurred on weekends (Friday noon till Monday 6 AM).
- Over 50% of WWD crashes occurred at night.
- About 55% of WWD crashes involved young (< 30 years) and senior (≥ 65 years) drivers.
- Approximately 32% of all WWD crashes involved intoxicated drivers.

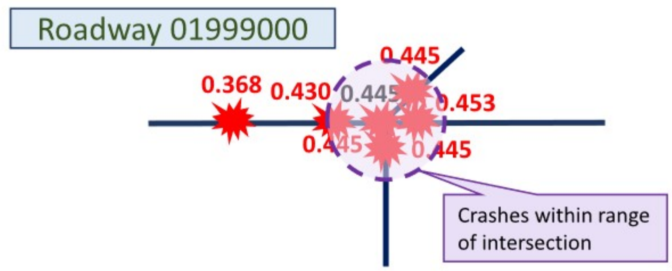
4.2 WWD Crash Hotspots

4.2.1 Background

The traditional crash hotspot identification methods are based on road segments and individual intersections. As can be inferred from Figure 4-7, when crash frequencies, crash rates, and/or safety indices are used to identify crash hotspots, the analysis is usually based on the number of crashes along a segment or at an intersection. This approach, based on a line or a point feature, may not be suitable for WWD crash hotspot analysis. A more suitable approach could be to identify WWD crash hotspots across a broader geographic region by integrating demographic and land-use characteristics of the region.



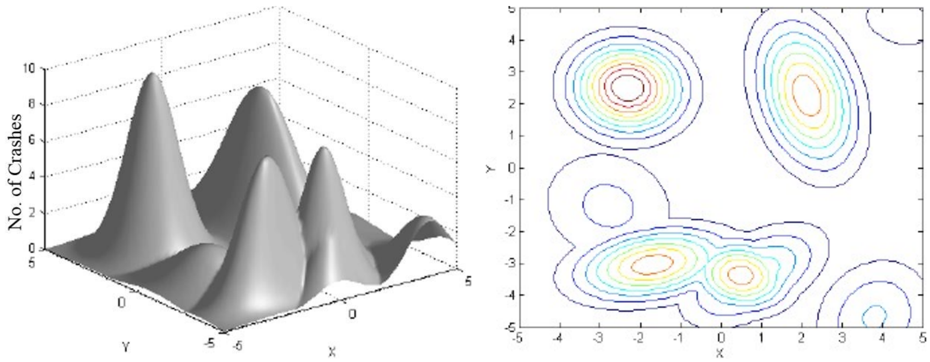
(a) Crash Hotspot Identification on Segments



(b) Crash Hotspot Identification on Intersections

Figure 4-7: Traditional Approach to Identify Crash Hotspots

A new method, inspired by the global optimization technique, was adopted in this research to identify WWD crash hotspots. Determining crash hotspots is similar to searching for the peak of the tallest mountains in an appointed landscape. Figure 4-8 (a) shows an example of mapped hotspot locations, represented by mountain peaks in an appointed landscape. For this study, the appointed landscapes are the seven FDOT Districts, and the height, or peak, of each mountain represents the number of WWD crashes. The area affected by WWD crashes, or size of each mountain, is analogous to a topographical contour map, as shown in Figure 4-8 (b). The contour lines represent the core area (i.e., high number of crashes) surrounded by the areas with fewer crashes until the distribution of WWD crashes reaches zero (i.e., the foot of the mountain).



(a) Crash hotspot locations
(Mountain peaks)

(b) Crash hotspot areas
(Size of mountains)

Figure 4-8: Global Optimization of Crash Hotspots (Yuan, n.d.)

4.2.2 Framework

Figure 4-9 illustrates the framework adopted to determine the location of WWD crash hotspots in each FDOT District. The following steps constituted the framework:

- Set Parameters
- Identify Service Area for Each Crash
- Merge Overlapped Service Areas
- Group Nearby Service Areas
- Verify if the Minimum Area Criteria is Met
- Identify Candidate Crash Hotspots
- Assign Equivalent Property Damage Only (EPDO) Weighting
- Identify Top WWD Crash Hotspots in each District

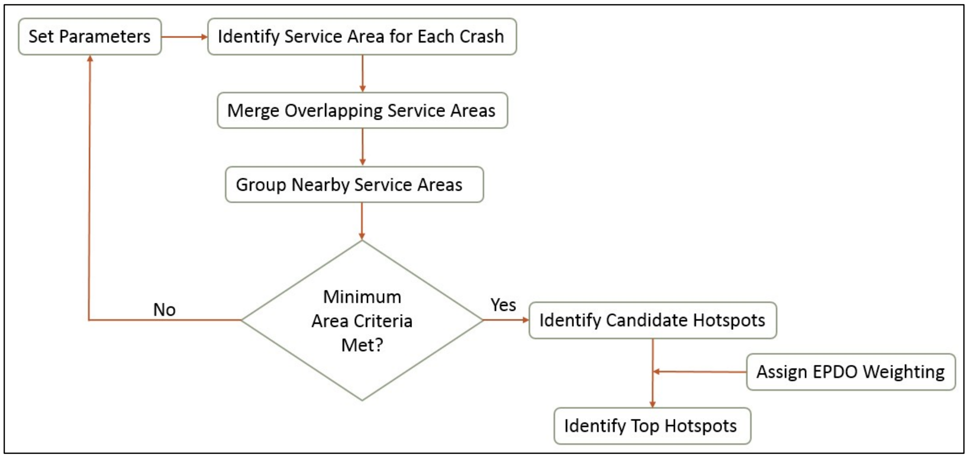


Figure 4-9: Framework for Identifying WWD Crash Hotspots

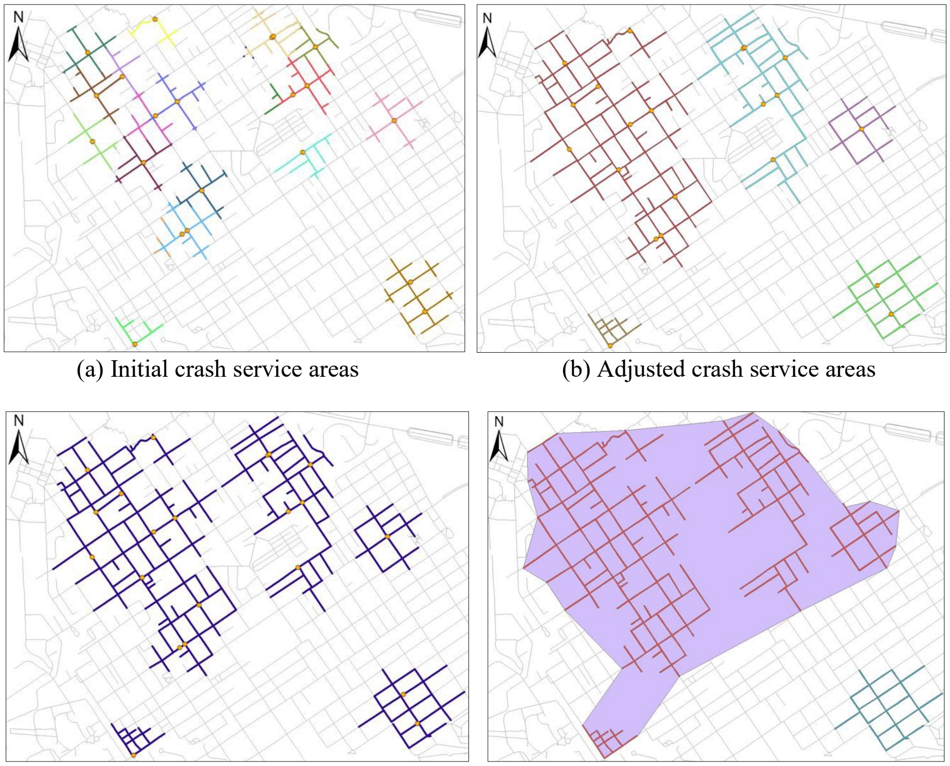
The first step involved determining values for two parameters: *radius of the WWD crash service area* and *searching step length*. The *radius of the WWD crash service area* parameter is needed to determine the total number of WWD crashes that occurred within the core area (i.e., the height of the mountain). The larger the radius, the greater the number of crashes and, consequently, the larger the mountain, in general. The second parameter, *searching step length*, is required to determine the distance between the core crash area and the nearby area with fewer or zero crashes.

Establishing appropriate values for these two parameters is critical since they determine the size of each influence area of the crash, i.e., the potential crash hotspot. If the values are too big, the hotspot region will cover a very large area, such as half of a county. If the values are too small, the hotspot region will only cover one or two census block groups. A one-size-fits-all approach is not suitable, especially since some regions have lower road densities compared to other regions.

The network dataset was developed using the 2015 Florida Street Network extracted from the NAVTEQ NAVSTREETS database. The service area for each of the 6,880 WWD crashes was first established to identify the impact area of the crash. Figure 4-10 (a) shows an example of service areas for 21 WWD crashes in Key West, Florida, where each individual crash service area is differentiated by a different color. To maintain the original street network, service areas that ended mid-block were extended to the end of each respective roadway segment, as shown on Figure 4-10 (b). This process resulted in overlapping, yet independent, service areas.

The next step involved merging the overlapped service areas into aggregated service areas to determine the total number of WWD crashes that occurred within the core area (i.e., the height of the mountain). Shown in Figure 4-10 (c), merging the overlapping service areas of the 21 WWD crashes in Key West resulted in five aggregated service areas. The largest area network depicted in Figure 4-10 (c) experienced 11 WWD crashes, and was deemed the core area, or mountain peak.

The core area and nearby service areas were then grouped to form a larger crash service area. As shown in Figure 4-10 (d), four of the five aggregated service areas that were in close proximity were grouped (i.e., merged) into one service area.



(a) Initial crash service areas

(b) Adjusted crash service areas

(c) Merged service areas

(d) Grouped nearby service areas

Figure 4-10: WWD Crash Service Areas in Key West, Florida

The size of the grouped service area was then reviewed to determine if it met the minimum area criteria to be considered as a potential WWD crash hotspot. If the service area size was smaller than one square mile or larger than ten square miles, the preceding steps were repeated using different parameters for the *radius of WWD crash service area* and *searching step length*.

The final step in the process of identifying WWD crash hotspots involved the consideration of crash severity. The Equivalent Property Damage Only (EPDO) weighting method was used to calculate the EPDO score of candidate high crash locations based on injury weighting. The EPDO score reflects the severity of crashes by assigning greater weight to fatal and injury crashes over PDO crashes. Table 4-7 provides the EPDO weighting scores for different injury severity levels based on the High Crash Analysis Report Section of CAR Online. Fatal and serious injury crashes were assigned an EPDO weight of 234.69, calculated as the ratio of fatal and serious injury crash cost to the PDO crash cost. Similarly, lesser injury crashes were assigned an EPDO weight of 15.72, and PDO crashes were assigned a weight of 1.0. Finally, the top WWD crash hotspots in each FDOT District were identified based on EPDO weighting factors.

Table 4-7: EPDO Weighting Scores for Different Injury Severity Levels

Injury Weighting	Crash Count	Crash Cost – Total	Cost Per Crash	Weight
Property Damage Only	567,140	$4,310,264,000	$7,600.00	1.00
Other Injury	378,337	$45,195,589,720	$119,458.55	15.72
Fatal + Serious Injury	60,041	$107,093,696,640	$1,783,676.09	234.69

* Based on 2013 cost estimates.

The process shown in Figure 4-9 was repeated to identify WWD crash hotspots in each of the seven FDOT Districts for the study period, 2011-2015. A total of 70 WWD crash hotspots were identified statewide. Table 4-8 shows the hotspots in each District. Figures 4-11 through 4-17 show the WWD hotspots map in each District, respectively.

Unlike the other districts that constitute counties (i.e., polygons), Florida's Turnpike System (also considered as FDOT District 8) constitutes toll roads, i.e., polylines. Crash hotspots on the Turnpike System cannot be identified using the framework proposed in this research. Hence, hotspots were identified based on a simple cluster analysis, using the following two rules:

- Crashes in each hotspot should have the same route name.
- The distance between the two nearest crashes is less than 10 miles.

A total of 10 hotspots were selected based on the 43 WWD crashes that occurred on the Turnpike System from 2011-2015. Table 4-8 also includes these hotspots. Figure 4-18 shows these hotspots on a map.

Table 4-8: Top WWD Crash Hotspots in Each District

District	Rank	Location	Total Crashes	Fatal/ Severe Crashes	Minor Injury Crashes	PDO Crashes	EPDO Score
1	1	Bradenton	36	7	10	19	1,819.04
1	2	Fort Myers	23	4	6	13	1,046.09
1	3	Fort Myers South	17	3	9	5	850.55
1	4	Venice	9	3	2	4	739.52
1	5	Sarasota West	9	3	1	5	724.80
1	6	Fort Myers Beach	7	2	3	2	518.54
1	7	Okeechobee	10	2	2	6	506.82
1	8	Lakeland East	10	2	2	6	506.82
1	9	Lakeland North	9	1	6	2	331.00
1	10	Sarasota East	10	1	4	5	302.57
2	1	Jacksonville	147	17	63	67	5,517.44
2	2	St. Augustine	19	3	10	6	867.26
2	3	Orange Park	20	3	4	13	843.83
2	4	Killarney Shores	2	2	0	0	593.42
2	5	Fleming Island	6	1	2	3	520.54
2	6	Gainesville	13	0	5	8	86.59
2	7	St. Augustine Beach	3	0	3	0	47.15
2	8	St. Augustine West	3	0	3	0	47.15
2	9	Loretto West	8	0	2	6	37.44
2	10	Southside	3	0	1	2	17.72
3	1	Pensacola	73	10	33	30	2,895.64
3	2	Tallahassee	76	7	32	37	2,182.84
3	3	Panama City	35	7	9	19	1,803.32
3	4	Fort Walton Beach	10	3	3	4	755.24
3	5	Laguna Beach	10	2	6	2	565.70
3	6	Pensacola West	9	2	5	2	549.98
3	7	Gonzalez	8	2	3	3	519.54
3	8	Panama City Beach	5	2	2	1	501.82
3	9	Lynn Haven	10	1	5	4	317.29
3	10	Pensacola North	6	0	5	1	79.59
4	1	Greenacres	62	9	30	23	2,606.79
4	2	Lake Worth	41	2	18	21	773.32
4	3	Boynton Beach	11	1	6	4	333.00
4	4	Hollywood West	12	1	5	6	319.29
4	5	Pompano Beach	11	1	5	5	318.29
4	6	Davie East	13	1	3	9	290.85
4	7	Hollywood South	13	1	2	10	276.13
4	8	Delray Beach	26	0	10	16	173.18
4	9	Hollywood	12	0	8	4	129.75
4	10	Boca Raton	7	0	2	5	36.44

Table 4-8 (Cont'd): Top WWD Crash Hotspots in Each District

District	Rank	Location	Total Crashes	Fatal/ Severe Crashes	Minor Injury Crashes	PDO Crashes	EPDO Score
5	1	Orlando	60	15	20	25	3,859.78
5	2	Melbourne	24	6	9	9	1,558.63
5	3	Orlando Center	36	5	19	12	1,484.12
5	4	Palm Coast	26	4	11	11	1,122.68
5	5	Orlando West	38	3	22	13	1,062.88
5	6	Sanford	21	3	12	6	898.70
5	7	Clermont	11	3	3	5	756.24
5	8	Merritt Island	9	3	2	4	739.52
5	9	Daytona Beach	45	1	19	25	558.34
5	10	Ocala	16	1	5	10	323.29
6	1	Miami Downtown	247	22	69	156	6,403.83
6	2	Key West	19	3	8	8	837.83
6	3	Miami Gardens	16	2	3	11	527.54
6	4	Flagami	13	2	2	9	509.82
6	5	Little Haiti	8	2	1	5	490.11
6	6	North Miami	19	1	12	6	429.31
6	7	Miami Beach	35	1	7	27	371.72
6	8	Hialeah South	17	1	6	10	339.00
6	9	Hialeah North	16	1	5	10	323.29
6	10	Hialeah Center	12	1	2	9	275.13
7	1	St. Petersburg East	80	6	25	49	1,850.12
7	2	Tampa	68	4	30	34	1,444.32
7	3	St. Petersburg Center	21	4	10	7	1,102.96
7	4	Holiday	16	3	7	6	820.11
7	5	Seven Springs	6	3	2	1	736.52
7	6	Tampa Southwest	10	1	5	4	317.29
7	7	Tampa West	15	1	4	10	307.57
7	8	Hudson	8	1	4	3	300.57
7	9	St. Petersburg West	6	1	4	1	298.57
7	10	Tampa North	4	1	2	1	267.13
Turnpike	1	Sanford	6	4	1	1	955.50
Turnpike	2	Homestead	6	3	2	1	736.52
Turnpike	3	Orlando	8	2	2	4	504.82
Turnpike	4	Palm Beach	5	2	2	1	501.82
Turnpike	5	Tamiami	3	1	1	1	251.41
Turnpike	6	Coral Springs	3	1	0	2	236.69
Turnpike	7	Canoe Creek	2	1	0	1	235.69
Turnpike	8	Lakeland	2	1	0	1	235.69
Turnpike	9	Titusville	1	1	0	0	234.69
Turnpike	10	Golden Glades	1	1	0	0	234.69

Note: When two hotspots in the same district have the same EPDO score, the hotspot with the smaller area was ranked lower among the two.

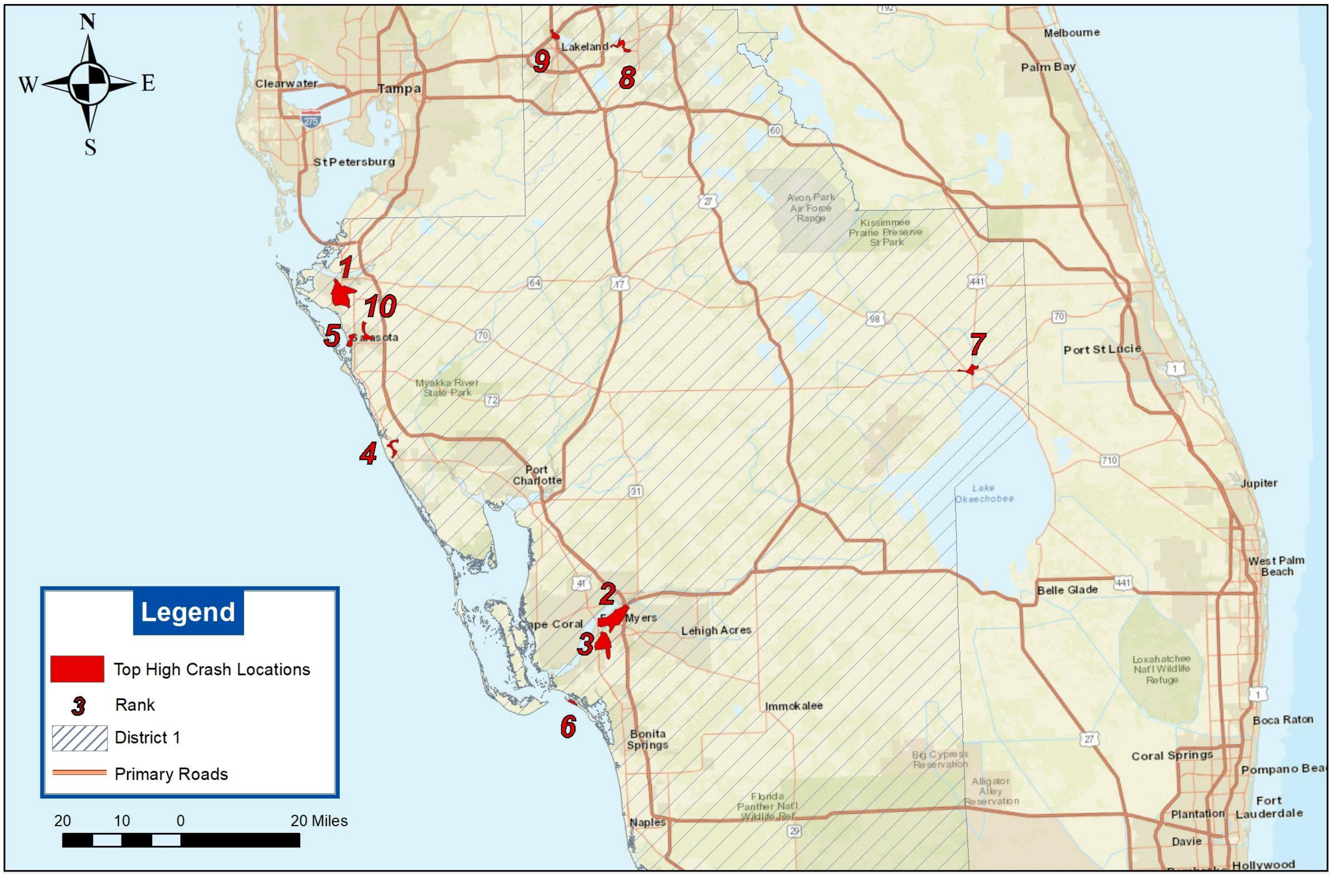


Figure 4-11: Top 10 WWD Crash Hotspots in District 1

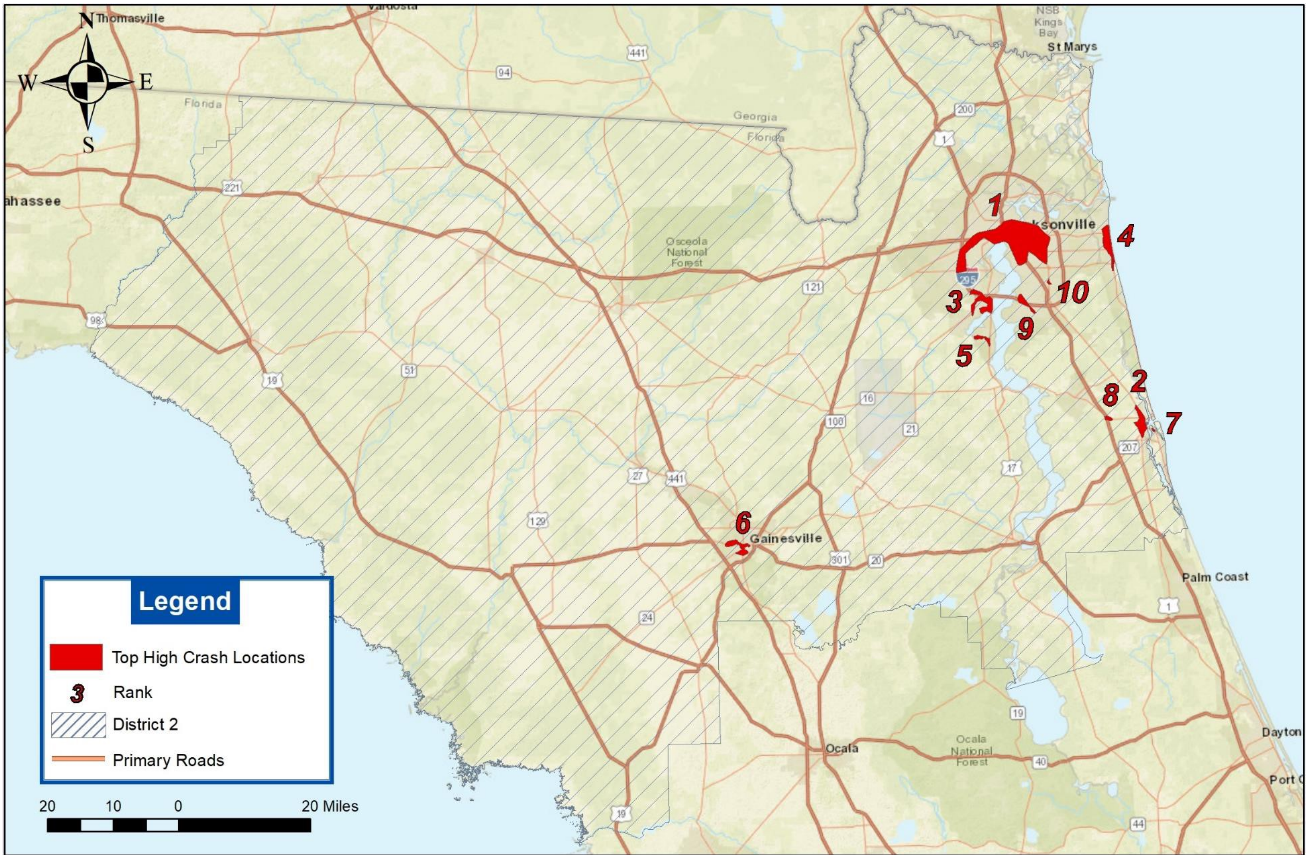


Figure 4-12: Top 10 WWD Crash Hotspots in District 2

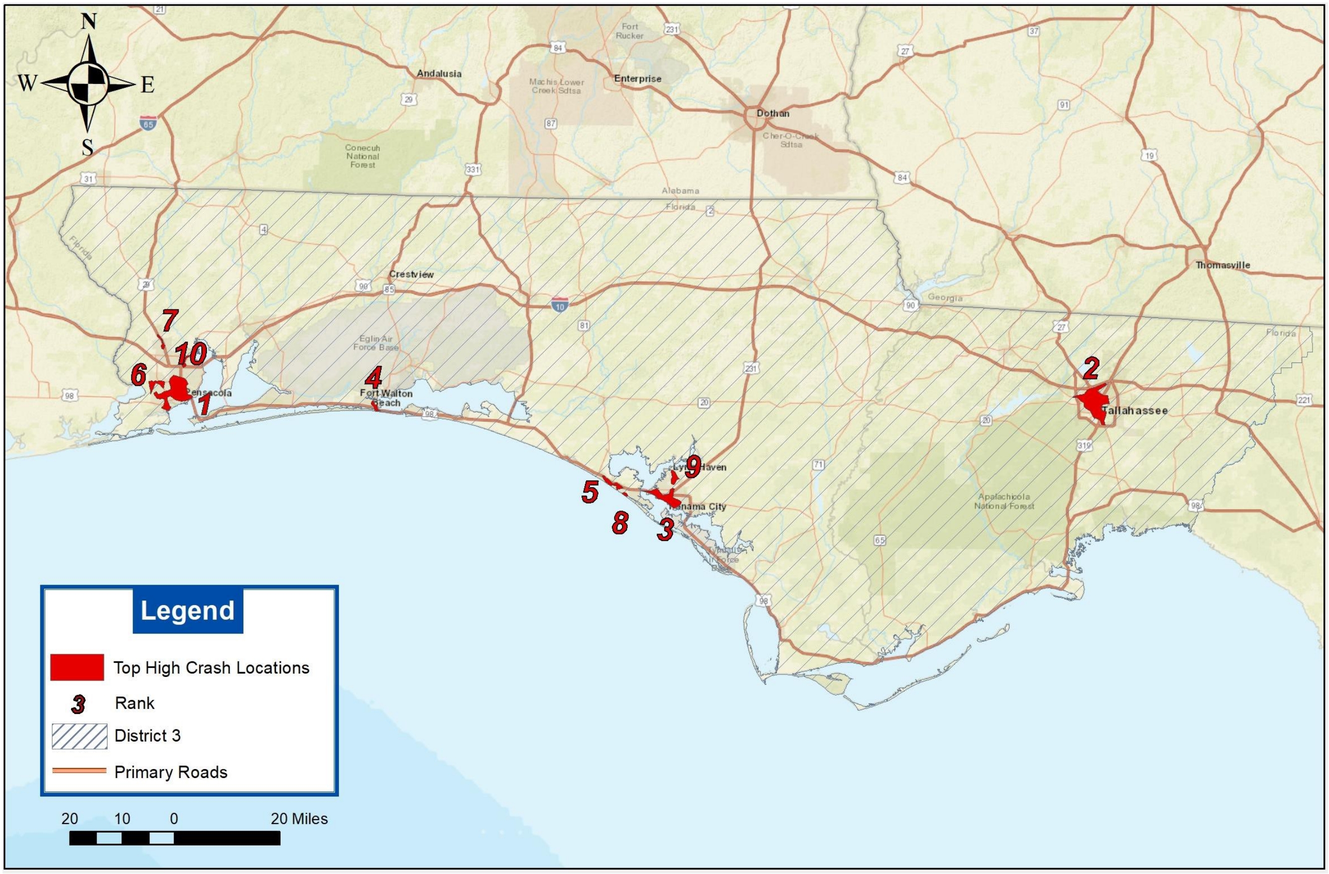


Figure 4-13: Top 10 WWD Crash Hotspots in District 3

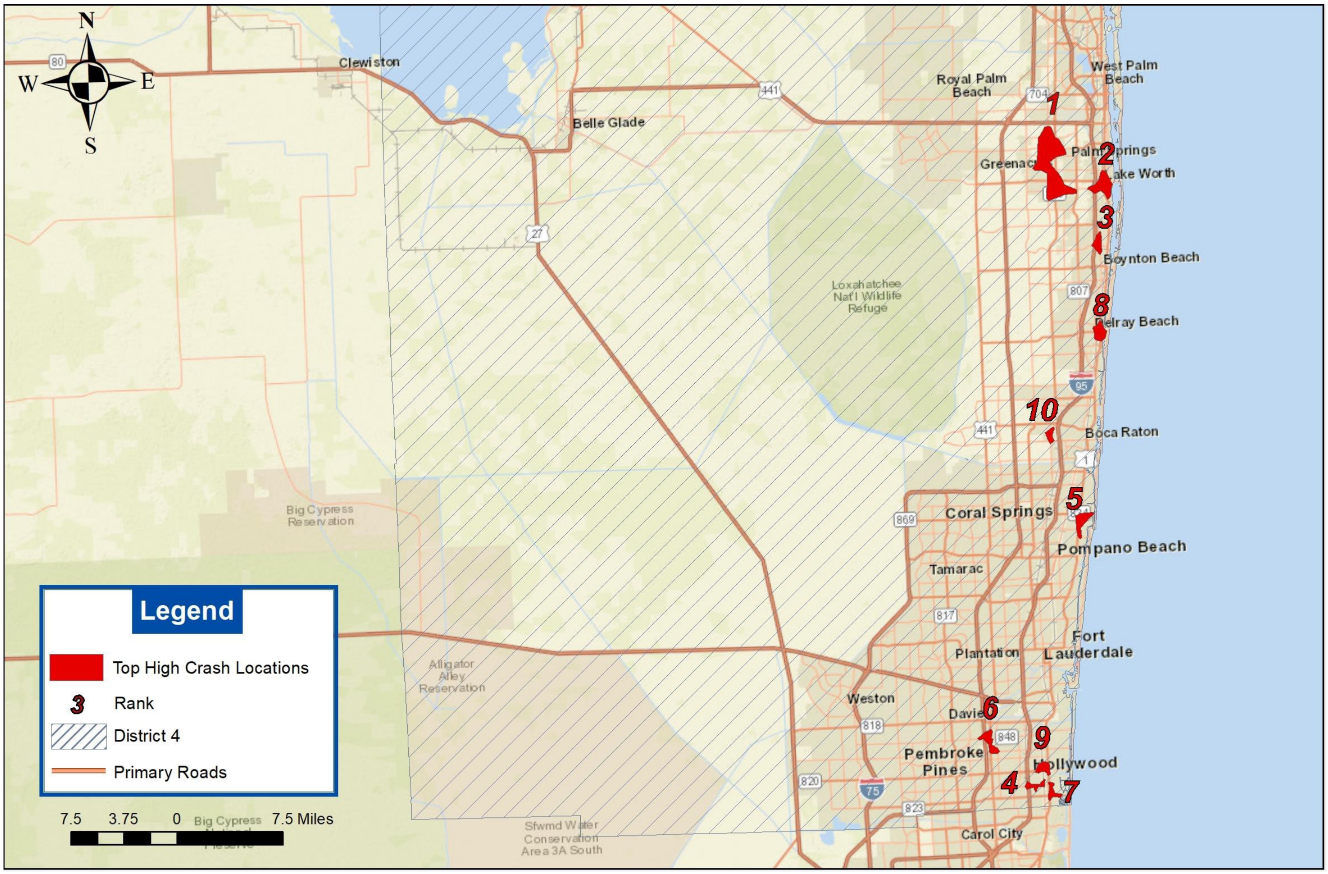


Figure 4-14: Top 10 WWD Crash Hotspots in District 4

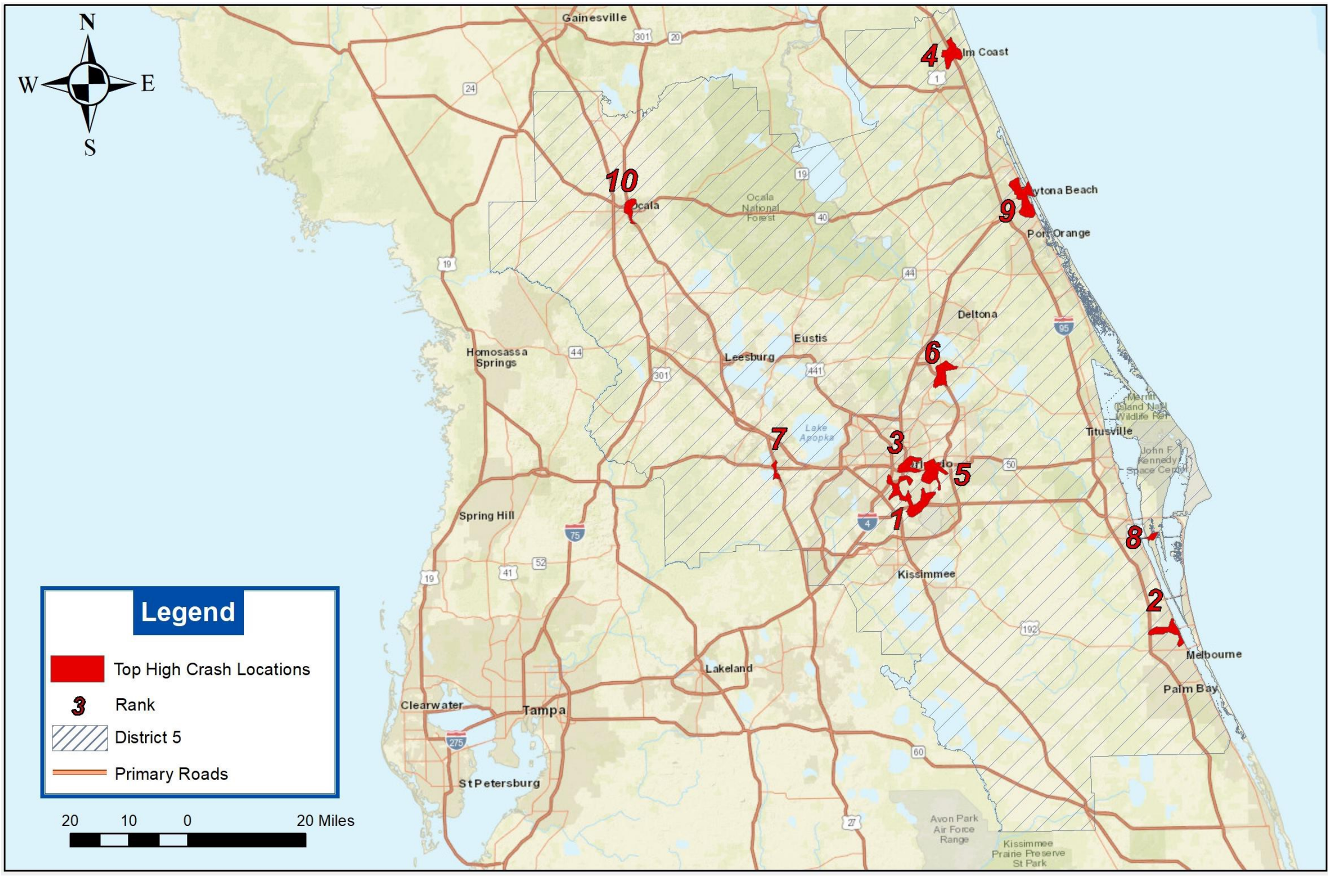


Figure 4-15: Top 10 WWD Crash Hotspots in District 5

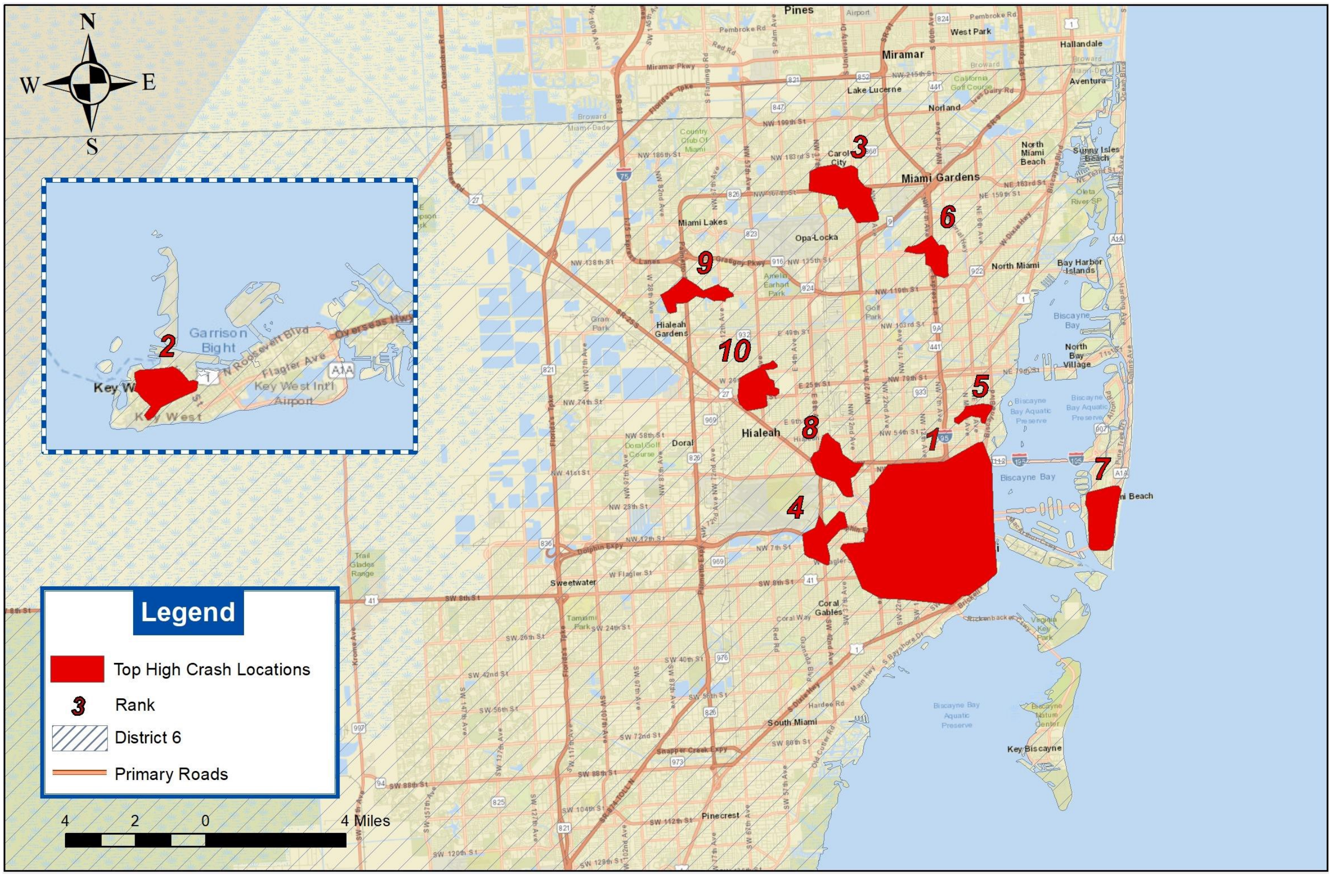


Figure 4-16: Top 10 WWD Crash Hotspots in District 6

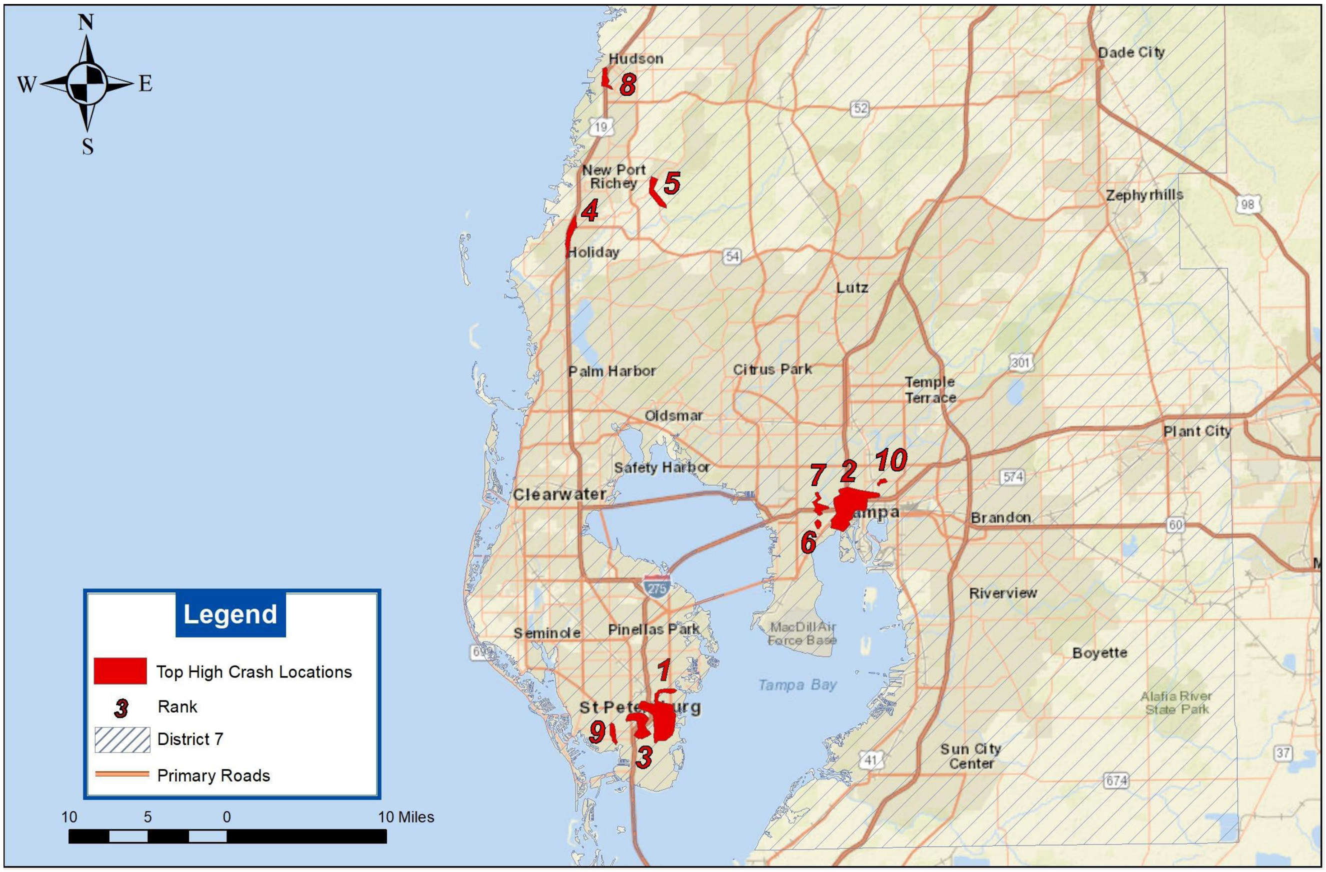


Figure 4-17: Top 10 WWD Crash Hotspots in District 7

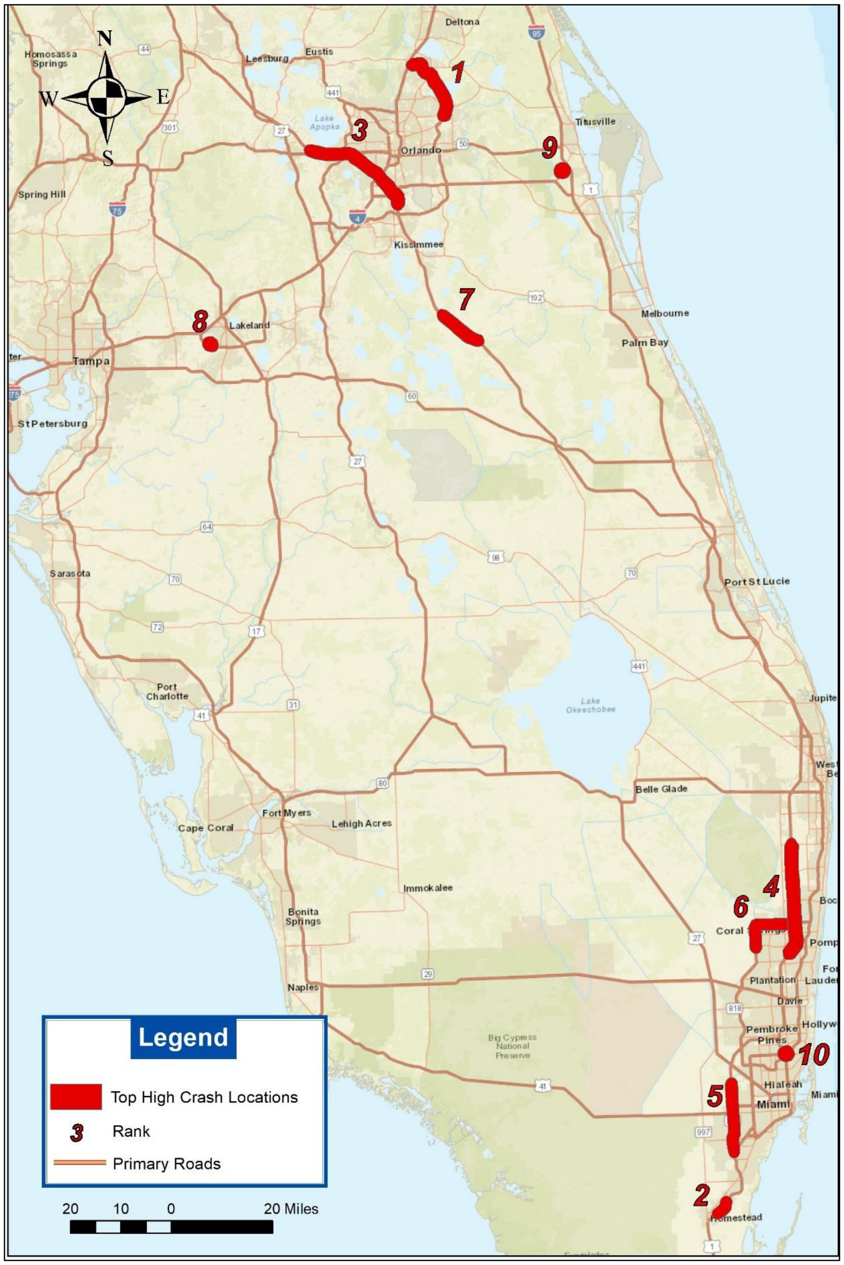


Figure 4-18: Top 10 WWD Crash Hotspots on the Turnpike System

4.3 WWD Arrests Data

Not all WWD incidents result in crashes; wrong-way drivers are often intercepted, and stopped by the highway authority before they are involved in a crash. In other words, WWD crashes are often just a small subset of all WWD incidents. WWD citation information, if available, provides a more complete picture of the WWD scenario. However, citation data are often not readily available. As a case study to investigate the potential of using citation data, WWD arrests data were obtained for Hillsborough County in FDOT District 7 for the time period 04/12/2014 to 01/29/2018. This database included a total of 329 citations. Of these 329 citations, 324 involved impaired drivers.

Table 4-9 shows the sample citation form. As can be observed from the table, the database did not include the specific location (i.e., geographic coordinates) of the WWD incidents. This information was manually collected by reviewing the description of the WWD arrests location in the database. Once the location information was collected, all the citations were manually imported into ArcGIS. Figure 4-19 shows the spatial distribution of these citations.

The WWD citation hotspots were identified using the same approach used to identify WWD crash hotspots. Section 4.2 discusses this approach in detail. Note that the rank of WWD crash hotspots was based on EPDO score, while the rank of citation hotspots was only based on the number of citations. Figure 4-20 provides the map of the top 10 citation hotspots in Hillsborough County. In the figure, the number in parentheses is the number of citations included in each hotspot. The top 10 citation hotspots included over half of all the citations in Hillsborough County. Moreover, the top three hotspots included the highest number of citations.

Figure 4-21 shows the comparison of the top 10 citation hotspots and the top 10 WWD crash hotspots in FDOT District 7. The citation Hotspots 1, 2, 3, 5, and 6 overlapped with the crash Hotspots 2, 6, and 7. This proves that the citation data and the crash data are consistent in identifying the locations with a high proportion of WWD incidents.

Table 4-9: Sample Citation Form

WWD Arrested Locations	County	Date	Time	Day or Night	Alcohol or Drug Use
Northbound I-75 at Fletcher Avenue	Hillsborough	Sat, 04/12/2014	4:00 AM	Night	Alcohol
Northbound I-275 near I-75	Hillsborough	Wed, 07/09/2014	2:08 AM	Night	Alcohol
Southbound I-75 at Gibsonton Road	Hillsborough	Sun, 09/21/2014	3:50 AM	Night	Alcohol
Northbound SR 589 at Lutz Lake Fern Road	Hillsborough	Wed, 10/01/2014	1:22 AM	Night	Alcohol
Northbound SR 589 at County Line Road	Hillsborough	Thu, 10/02/2014	3:07 AM	Night	Alcohol
Northbound I-275 north of Howard & Armenia Ave	Hillsborough	Sun, 10/26/2014	3:13 AM	Night	Alcohol

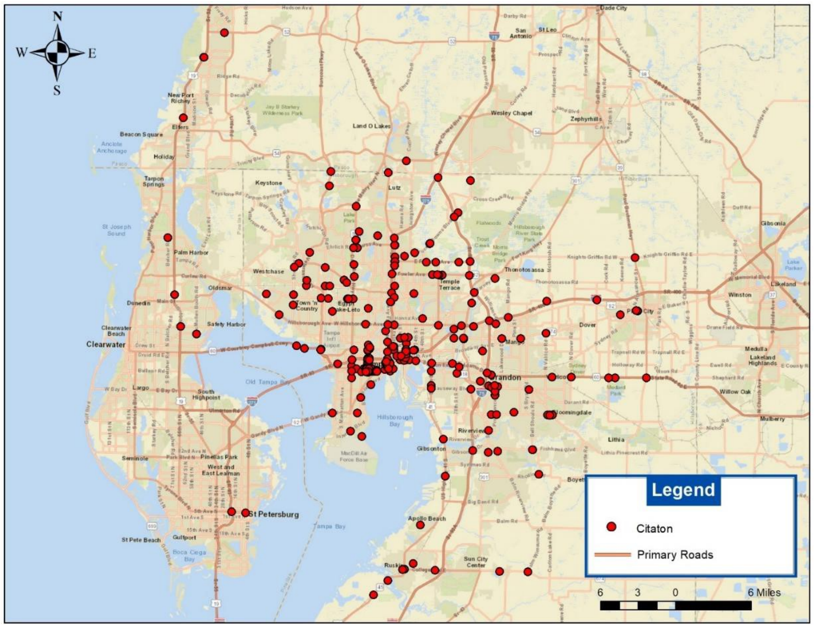


Figure 4-19: Spatial Distribution of WWD Citations in Hillsborough County

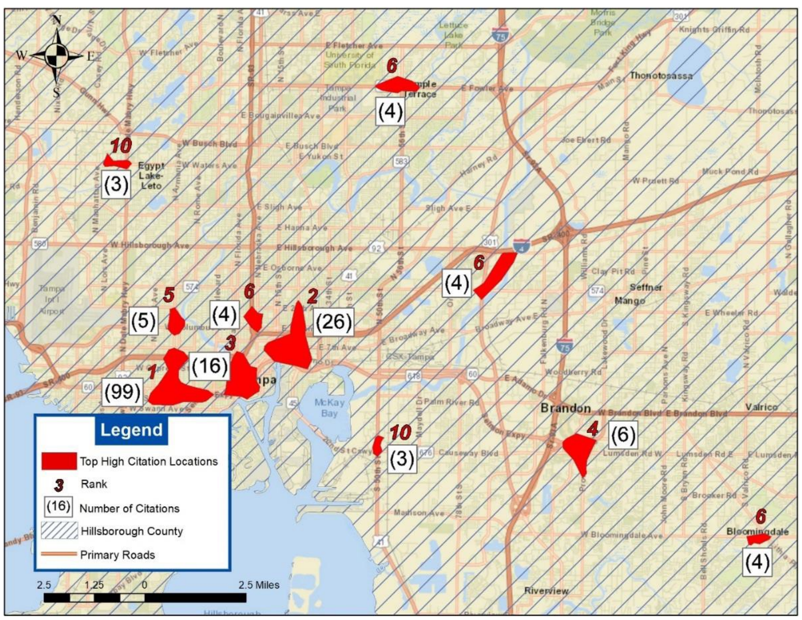


Figure 4-20: Top 10 WWD Citation Hotspots in Hillsborough County

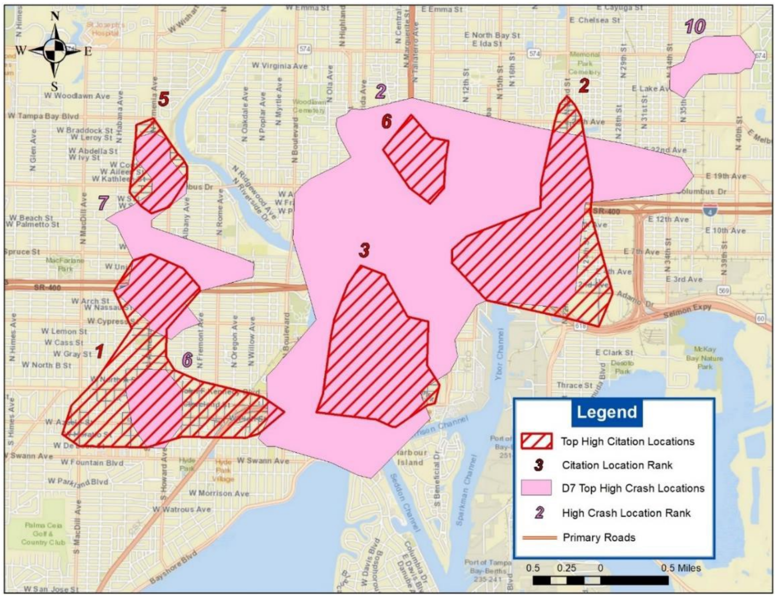


Figure 4-21: Comparison of Top 10 WWD Citation Hotspots and the Top 10 WWD Crash Hotspots in FDOT District 7

4.4 WWD Crash Hotspots on Freeways

This section focuses on analyzing WWD crashes on limited access facilities. A total of 281 WWD crashes occurred on limited access facilities in Florida during the years 2011 through 2015. Table 4-10 summarizes these crashes by year. Figure 4-22 shows the spatial distribution of these WWD crashes.

Table 4-10: Descriptive Statistics of WWD Crashes on Freeways

Year	Number of WWD Crashes
2011	49
2012	66
2013	55
2014	56
2015	55
Total	**281**

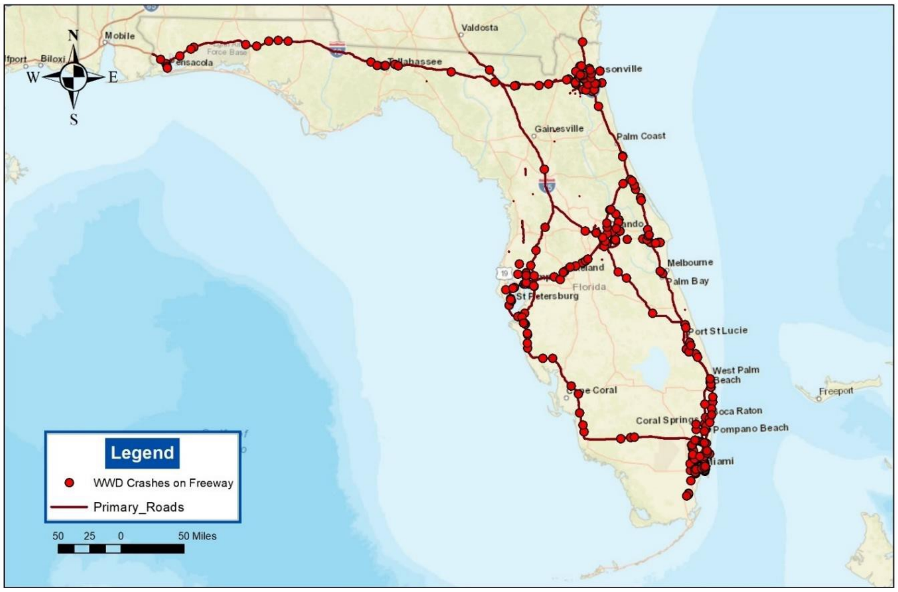


Figure 4-22: WWD Crashes on Limited Access Facilities in Florida from 2011-2015

4.4.1 Data Collection and Preparation Efforts

The analysis of WWD crashes on freeways has two issues. First, the direction of the wrong-way driver is not consistently recorded in the crash summary records. In other words, if a WWD crash occurred on I-95, it cannot be determined from the summary records whether the wrong-way driver was driving SB on NB lanes, or NB on SB lanes. Another issue is with the WWD crash location. The specific location (usually, off-ramp) where the wrong-way driver entered the freeway is not available in the crash summary records and in the police reports. Moreover, since a wrong-way driver could potentially drive several miles on the freeway before being involved in a crash, it is not reasonable to assume that the wrong-way driver entered the freeway through the upstream off-ramp that is closest to the WWD crash location. As such, the police reports of all the 281 WWD crashes that occurred on limited access facilities were reviewed to collect the following information:

- Whether or not the crash is a WWD crash
- The direction of the wrong-way driver involved in the crash
- Whether or not the WWD crash occurred on an off-ramp
- Whether or not the wrong-way driver entered the freeway from an off-ramp
  - If the wrong-way driver originated from an off-ramp, the types of the nearest three upstream off-ramps which could have potentially been used by the wrong-way driver.

Table 4-11 summarizes the WWD crashes that occurred on freeways. Of the total of 281 WWD crashes, 205 crashes were found to involve a wrong-way driver entering the freeway from an off-ramp. A total of 31 WWD crashes were found to have occurred on the off-ramp. The remaining

46 WWD crashes that occurred on the mainline were found to not have originated by a wrong-way driver who entered the freeway from an off-ramp. In other words, there is no relation between these WWD crashes and the type of the interchange. For example, some WWD crashes on freeways were caused by drivers making a U-turn on the mainline instead of entering the freeway from an off-ramp. Figure 4-23 shows an example of such a WWD crash. The analysis on WWD crashes on freeways therefore only focused on the 235 WWD crashes that either occurred on off-ramps or that involved wrong-way drivers who entered the freeway from an off-ramp.

Table 4-11: Summary of WWD Crashes on Freeways

WWD Crash	Number
WWD crashes originated from off-ramps	204
WWD crashes that occurred on off-ramps	31
WWD crashes where wrong-way driver did not enter the freeway from an off-ramp	46
Total WWD crashes on freeways	**281**

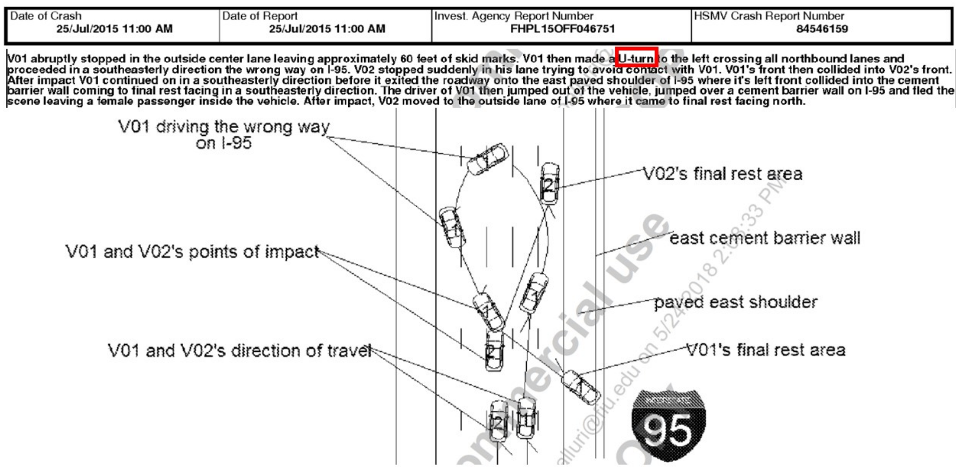


Figure 4-23: A WWD Crash Caused by Driver Making a U-turn on Mainline

For the 204 WWD crashes that either occurred on the freeway mainline or that were originated from the off-ramps, the three upstream off-ramps that could have been potentially used by the wrong-way driver to enter the freeway were identified. Figure 4-24 shows an example of a WWD crash (crash # 82828904) on the freeway where the three upstream off-ramps (#592, #595, and #596) were identified. For some WWD crashes, only one upstream off-ramp was identified since the next closest off-ramp was at least 15 miles away. Since the probability of a wrong-way driver driving more than 15 miles before getting involved in a crash is low, the wrong-way driver might not have entered the freeway from an off-ramp that is over 15 miles upstream of the WWD crash location.

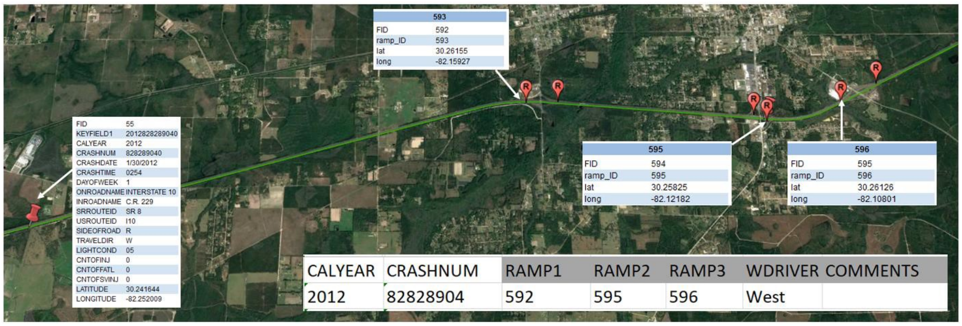


Figure 4-24: Three Upstream Off-ramps Potentially Associated with WWD Crashes

Information on a total of 1,642 off-ramps in Florida was considered in the analysis. Table 4-12 provides descriptive statistics of the off-ramps in Florida. As can be observed from the table, about 64.6% of all off-ramps in Florida are either Diamond or Partial Diamond.

Table 4-12: Descriptive Statistics of the Type of Off-ramps in Florida

Off-ramp Type	Number of Off-ramps	Percentage
Diamond	789	48.1%
Partial Diamond	271	16.5%
Parclo Loop	189	11.5%
Trumpet	118	7.2%
Other	275	16.7%
Total	**1,642**	**100.0%**

4.4.2 Analysis of WWD Crashes on Freeway Mainline

Table 4-13 provides the statistics of the types of off-ramps that could potentially be associated with WWD crashes on freeways. As can be inferred from the table, while 48.1% of all off-ramps in Florida are diamond, 47.1% of all the off-ramps potentially associated with WWD crashes were found to be diamond. Similar statistics were observed with trumpets. While 7.2% of all off-ramps in Florida are trumpets, 7.3% of all the off-ramps potentially associated with WWD crashes were found to be trumpets. Partial diamonds were found to be relatively safe; while 16.5% of all off-ramps in Florida are partial diamond, only 3.1% of all the off-ramps potentially associated with WWD crashes were found to be partial diamond. On the other hand, while only 11.5% of all off-ramps in Florida are parclo loop, a relatively high 20.8% of all the off-ramps potentially associated with WWD crashes were found to be parclo loop.

Table 4-13: WWD Crashes on Freeways and Type of Off-ramp

Type	1st Upstream Off-ramp	2nd Upstream Off-ramp	3rd Upstream Off-ramp	Total	% of Off-ramps Potentially Associated with WWD Crashes	% of Off-ramps in the State
Diamond	103	91	96	290	47.1%	48.1%
Partial Diamond	4	8	7	19	3.1%	16.5%
Parclo Loop	52	40	36	128	**20.8%**	11.5%
Trumpet	21	14	10	45	**7.3%**	7.2%
Other	55	44	35	134	**21.8%**	16.7%
All	**235**	**197**	**184**	**616**	**100.0%**	**100.0%**

Previous research has determined that drivers often get confused and enter the freeway from an off-ramp when the on-ramps and off-ramps are in close proximity. Table 4-14 provides the relation between WWD crashes and the proximity of on-ramps and off-ramps. As can be observed from the table, about 25% of the instances where the on-ramps and off-ramps are in close proximity were found to be associated with WWD crashes. Nonetheless, close proximity of on-ramps and off-ramps could be one of the factors contributing to WWD incidents.

Table 4-14: WWD Crashes on Freeways and Proximity of On-ramps and Off-ramps

Proximity of On- and Off-ramps	1st Upstream Off-ramp	2nd Upstream Off-ramp	3rd Upstream Off-ramp	Total	%
Near/Close	66	44	43	153	24.8%
Not Close	169	153	141	463	75.2%
All	**235**	**197**	**184**	**616**	**100.0%**

4.4.3 Analysis of WWD Crashes on Off-ramps

Table 4-15 provides the statistics of the types of off-ramps that were associated with WWD crashes on freeway off-ramps. Of the 31 WWD crashes that occurred on freeway off-ramps, a relatively high 48.4% occurred on parclo loops, while only 11.5% of all off-ramps in Florida are parclo loop. Similarly, 16.1% all WWD crashes on off-ramps occurred on trumpets, while only 7.2% of all off-ramps are trumpets. Although 64.6% of all off-ramps in Florida are either diamond or partial diamond, only 16.1% of all the WWD crashes that occurred on freeway off-ramps were found to have occurred on diamond or partial diamond off-ramps. From the table, it could be concluded that parclo loops and trumpets tend to be associated with a greater proportion of WWD crashes.

Table 4-15: WWD Crashes on Freeway Off-ramps and Type of Off-ramp

Type	Number of Off-ramps Potentially Associated with WWD Crashes	Percent of Off-ramps Potentially Associated with WWD Crashes	Percent of Off-ramps in the State
Diamond	5	16.1%	48.1%
Partial Diamond	0	0.0%	16.5%
Parclo Loop	15	**48.4%**	11.5%
Trumpet	5	**16.1%**	7.2%
Other	6	**19.4%**	16.7%
All	**31**	**100.0%**	**100.0%**

Table 4-16 provides the relation between WWD crashes on freeway off-ramps and the proximity of on-ramps and off-ramps. As can be observed from the table, about 38.7% of the instances where the on-ramps and off-ramps are in close proximity were found to be associated with WWD crashes on off-ramps. Close proximity of on-ramps and off-ramps could be one of the factors contributing to WWD incidents.

Table 4-16: WWD Crashes on Freeway Off-ramps and Proximity of On-ramps and Off-ramps

Proximity of On- and Off-ramps	Number of Off-ramps Associated with WWD Crashes	Percent
Near/Close	12	38.7%
Not Close	19	61.3%
All	**31**	**100.0%**

4.4.4 Analysis of WWD Crashes on the Turnpike System

From 2011-2015, the Turnpike System experienced a total of 43 WWD crashes. As can be observed from Table 4-17, of the 43 WWD crashes that occurred on the Turnpike System, 35 crashes originated from off-ramps, 5 occurred on off-ramps; while in the remaining 3 WWD crashes that occurred on the freeway mainline, the wrong-way driver did not enter the freeway from an off-ramp. Note that the analysis of WWD crashes on the Turnpike System just focused on the 40 WWD crashes that either occurred on the off-ramps, or involved wrong-way driver who entered the freeway from an off-ramp.

Table 4-17: WWD Crashes on Florida Turnpike

WWD Crash Type	Number
WWD crashes originated from off-ramps	35
WWD crashes that occurred on off-ramps	5
WWD crashes where wrong-way driver did not enter the freeway from an off-ramp	3
Total WWD Crashes on Freeways	**43**

Table 4-18 provides the statistics of the types of off-ramps that could potentially be associated with WWD crashes on the Turnpike System. Similar to the results provided in Table 4-13, a relatively higher proportion of WWD crashes were found to be associated with parclo loop and trumpets. Table 4-19 provides the relation between WWD crashes on the Turnpike System and the proximity of on-ramps and off-ramps. As can be observed from the table, 48.1% of the instances where the on-ramps and off-ramps are in close proximity were found to be associated with WWD crashes.

Table 4-18: WWD Crashes on the Florida Turnpike System and Type of Off-ramp

Type	1st Upstream Off-ramp	2nd Upstream Off-ramp	3rd Upstream Off-ramp	Total	% of Off-ramps Potentially Associated with WWD Crashes	% of Off-ramps in the State
Diamond	9	8	7	24	25.5%	48.1%
Partial Diamond	0	1	1	2	2.1%	16.5%
Parclo Loop	6	5	8	19	**20.2%**	11.5%
Trumpet	16	9	6	31	**33.0%**	7.2%
Other	7	8	3	18	**19.1%**	16.7%
All	**38**	**31**	**25**	**94**	**100.0%**	**100.0%**

Table 4-19: WWD Crashes on Florida Turnpike and Proximity of On-ramps and Off-ramps

Proximity of On- and Off-ramps	1st Upstream Off-ramp	2nd Upstream Off-ramp	3rd Upstream Off-ramp	Total	%
Near/Close	18	12	16	46	48.9%
Not Close	20	19	9	48	51.1%
All	**38**	**31**	**25**	**94**	**100.0%**

4.5 Summary

A novel approach using spatial analysis tools in ArcGIS was developed to identify and rank WWD hotspots in each FDOT District. This analysis was based on WWD crash data. When available, WWD citation data also provides valuable information on WWD incidents. As such, the WWD arrests data obtained from Hillsborough County were used to identify WWD hotspots. Information on WWD arrests was found to provide greater insights on WWD incident locations; hotspots based on WWD crash data and WWD arrests data were found to be similar. In addition to WWD crash data, it is recommended to use WWD citation data, when available, to identify WWD hotspots for implementing WWD countermeasures.

Furthermore, WWD crashes on limited access facilities were analyzed separately to identify specific type of off-ramps that could be more prone to WWD incidents. Some of the specific conclusions include:

- About 50% of all WWD crashes could potentially be associated with diamond and partial diamond ramps. However, these interchanges are most common in Florida.
- A greater proportion of Parclo loop and trumpets could potentially be associated with WWD crashes.
- Close proximity of on-ramps and off-ramps could be one of the factors contributing to WWD incidents.

CHAPTER 5
WRONG-WAY DRIVING CRASH MITIGATION APPROACH

This chapter provides a comprehensive and holistic approach to mitigate WWD crashes. The approach focused on determining the relation between the demographic and land-use variables identified in Chapter 3 and the WWD crashes that occurred at the WWD crash hotspots identified in Chapter 4. This chapter is divided into three major sections. Section 5.1 focuses on the WWD crash data. It discusses the crash data preparation efforts and the crash data analysis approach. Section 5.2 discusses the methodology used to determine the relation between the demographic and land-use variables and the WWD crashes. Finally, Section 5.3 presents the analysis results.

5.1 Crash Data

5.1.1 Crash Data Preparation

The analysis was based on crash data for the years 2011-2015. The analysis primarily focused on crashes involving *drivers aged 65 years and older*, *tourists*, and *impaired drivers*. Table 5-1 provides descriptive statistics of the crash data used in this study. The table provides the number of WWD crashes that occurred within the WWD hotspots, the total number of WWD crashes in Florida, and the total number of crashes in Florida that occurred from 2011-2015.

Table 5-1: Descriptive Statistics of Crash Data (2011-2015)

Category	WWD Crashes in Hotspots	WWD Crashes in Florida	Total Crashes in Florida
Crashes Involving Drivers Aged 65 Years and Older	251	950	190,864
Crashes Involving Impaired Drivers	456	2,168	87,104
Crashes Involving Tourists	247	1,031	252,599
All Crashes	1,717	6,880	1,898,753

Crashes involving *drivers aged 65 years and older* were extracted and included in the analysis. Similarly, crashes involving *impaired drivers* were also extracted and analyzed. Identifying crashes involving *tourists* was found to be difficult as none of the fields in the crash database explicitly state whether or not the crash involved tourists. The zip code of the driver (Variable code: DR_ZIPCODE9) and the crash location were compared to identify crashes involving *tourists*. The following rules were adopted to identify crashes involving *tourists*:

1. Crashes involving drivers with zip codes within the county where the crash occurred were considered as those involving the local population (i.e., not tourists).
2. Crashes involving drivers with zip codes within the counties surrounded by the county where the crash occurred were also considered as those involving local people (i.e., not tourists).
3. Crashes involving drivers with all the remaining zip codes were considered as crashes involving tourists.

The aforementioned rules are explained using Figure 5-1. For a crash (ID: 819943520) that occurred in Seminole County, the driver's zip code (in the field "DR_ZIPCODE9") was extracted. If the driver's zip code belonged to the zip codes within Seminole County (identified with purple color in the figure) or the zip codes within the surrounding counties (i.e., Volusia, Lake, Orange, Brevard) (identified with pink color in the figure), the crash was categorized as non-tourist-related (i.e., crashes involving local drivers). If the driver's zip code was from the counties not immediately surrounded by the Seminole County (identified with cyan color in the figure), the crash was identified as a crash involving *tourists*.

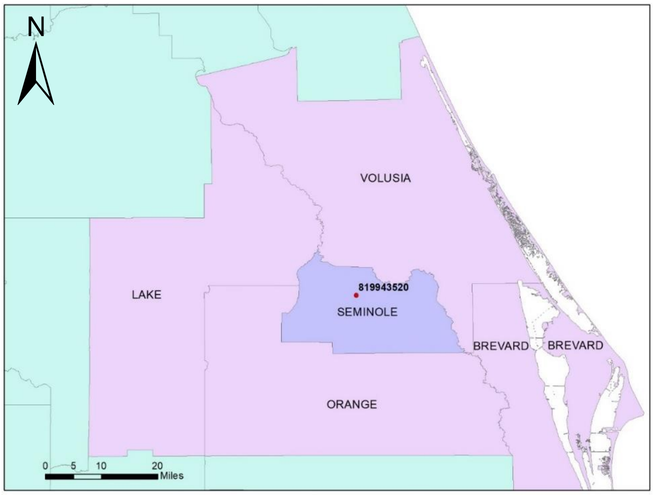


Figure 5-1: Logic Adopted to Identify Crashes Involving Tourists

5.1.2 Crash Data Analysis

Based on the previous studies discussed in Section 3.1 and a preliminary review of the reported WWD crashes during the five-year study period, three categories of drivers involved in WWD incidents were considered in this analysis: *drivers aged 65 years and older*, *tourists*, and *impaired drivers*. *Drivers aged 65 years and older* may have poor vision or become confused by the roadway geometry. Tourists and visitors may be unfamiliar with the roadway network, and the diminished decision-making ability of drivers impaired by alcohol and/or drugs may result in wrong-way driving.

Of the 6,880 WWD crashes that occurred during the five-year analysis period, nearly half occurred in the identified WWD hotspots, statewide. The crash dataset was further reduced to contain only incidents involving *drivers aged 65 years and older*, *tourists*, and *impaired drivers*. Crash reports with missing data, such as missing driver age, driver zip code, etc., were excluded from the analysis.

To determine the proportion of WWD crashes involving *drivers aged 65 years and older*, *tourists*, and *impaired drivers* relative to statewide totals of WWD crashes in each identified hotspot, the relative density of each WWD crash category ($R_i^{Drivers\ 65+}$, $R_i^{Tourists}$, and $R_i^{Impaired\ Drivers}$) was computed. The following equations were used to calculate the relative density of WWD crashes involving *drivers aged 65 years and older* ($R_i^{Drivers\ 65+}$):

$$R_i^{Drivers\ 65+} = \frac{CR_i^{Drivers\ 65+} - Ave\ CR_i^{Drivers\ 65+}}{Ave\ CR_i^{Drivers\ 65+}}$$

$$CR_i^{Drivers\ 65+} = \frac{Total\ WWD\ Crashes\ Involving\ Drivers\ Aged\ 65\ Years\ and\ Older_i}{Total\ WWD\ Crashes_i}$$

$$Ave\ CR_i^{Drivers\ 65+} = \frac{Total\ Crashes\ Involving\ Drivers\ Aged\ 65\ Years\ and\ Older_{Florida}}{Total\ Crashes_{\ Florida}}$$

where,

$R_i^{Drivers\ 65+}$	=	relative density of WWD crashes involving *drivers aged 65 years and older* at WWD hotspot *i,*
$CR_i^{Drivers\ 65+}$	=	ratio of WWD crashes involving *drivers aged 65 years and older* to total WWD crashes within the WWD hotspot *i*, and
$Ave\ CR_i^{Drivers\ 65+}$	=	proportion of crashes involving *drivers aged 65 years and older* in the entire state of Florida from 2011-2015.

Similarly, the relative density of WWD crashes involving *tourists* ($R_i^{Tourists}$) was calculated using the following equations.

$$R_i^{Tourists} = \frac{CR_i^{Tourists} - Ave\ CR_i^{Tourists}}{Ave\ CR_i^{Tourists}}$$

$$CR_i^{Tourists} = \frac{Total\ WWD\ Crashes\ Involving\ Tourists_i}{Total\ WWD\ Crashes_i}$$

$$Ave\ CR_i^{Tourists} = \frac{Total\ Crashes\ Involving\ Tourists_{Florida}}{Total\ Crashes_{\ Florida}}$$

where,

$R_i^{Tourists}$	=	relative density of WWD crashes involving *tourists* at WWD hotspot *i,*
$CR_i^{Tourists}$	=	ratio of WWD crashes involving *tourists* to total WWD crashes within the WWD hotspot *i*, and
$Ave\ CR_i^{Tourist}$	=	proportion of crashes involving *tourists* in the entire state of Florida from 2011-2015.

Finally, the relative density of WWD crashes involving *impaired drivers* ($R_i^{Impaired\ Drivers}$) was calculated using the following equations.

$$R_i^{Impaired\ Drivers} = \frac{CR_i^{Impaired\ Drivers} - Ave\ CR_i^{Impaired\ Drivers}}{Ave\ CR_i^{Impaired\ Drivers}}$$

$$CR_i^{Impaired\ Drivers} = \frac{Total\ WWD\ Crashes\ Involving\ Impaired\ Drivers_i}{Total\ WWD\ Crashes_i}$$

$$Ave\ CR_i^{Impaired\ Drivers} = \frac{Total\ Crashes\ Involving\ Impaired\ Drivers_{Florida}}{Total\ Crashes_{\ Florida}}$$

where,

$R_i^{Impaired\ Drivers}$	=	relative density of WWD crashes involving *impaired drivers* at WWD hotspot *i,*
$CR_i^{Impaired\ Drivers}$	=	ratio of WWD crashes involving *impaired drivers* to total WWD crashes within the WWD hotspot *i*, and
$Ave\ CR_i^{Impaired\ Drivers}$	=	proportion of crashes involving *impaired drivers* in the entire state of Florida from 2011-2015.

Table 5-2 provides the crash data analysis results. The proportion of WWD crashes involving *impaired drivers* at WWD hotspots (26.56%) was found to be *six* times greater than the average proportion of crashes involving *impaired drivers* in the entire state of Florida (4.59%). The proportion of WWD crashes involving *drivers aged 65 years and older* at WWD hotspots (14.62%) was found to be *50% more* than the average proportion of crashes involving this age group in Florida (10.05%). However, the proportion of WWD crashes involving *tourists* at WWD hotspots (14.94%) was found to be *comparable* to the statewide average proportion (14.51%).

Table 5-2: WWD Crashes in Hotspots Compared to Total Crashes in Florida

Category	WWD Crashes in Hotspots			Total Crashes in Florida		
	WWD Crashes by Category	**Total WWD Crashes**	**Percentage**	**Total Crashes by Category**	**Total Crashes**	**Percentage**
Impaired Drivers	456	1,717	**26.56%**	87,104	1,898,753	**4.59%**
Drivers Aged 65 Years and Older	251		**14.62%**	190,864		**10.05%**
Tourists	247	1,653[a]	**14.94%**	252,599	1,741,294[a]	**14.51%**

[a] Crashes with missing information on driver zip code were not included in this category.

Figure 5-2 provides an example of the crash analysis for WWD hotpots in FDOT District 7 (D7). The relative density of each WWD crash category is illustrated for each hotspot location. Values above zero indicate crash densities greater than the statewide proportion for a particular WWD crash category (*drivers aged 65 years and older*, *tourists*, and *impaired drivers*). Alternatively, negative values represent hotspot densities lower than the statewide densities. For example, for WWD Hotspot No. 1, the relative density of *drivers aged 65 years and older* is 0.87, or the proportion of *drivers aged 65 years and older* at WWD Hotspot No. 1 is 1.87 times (calculated as 0.87+1) greater than the statewide proportion of WWD crashes involving *drivers aged 65 years and older*. Similarly, the relative density of *impaired drivers* in WWD Hotspot No. 1 is 3.63, or the proportion of impaired drivers at WWD Hotspot No. 1 is 4.63 times (calculated as 3.63+1) greater than the statewide proportion of WWD crashes involving *impaired drivers*. The relative density of *tourists* (-0.58), however, is 0.42 times (calculated as -0.58+1) the density of WWD crashes involving *tourists* in the entire state.

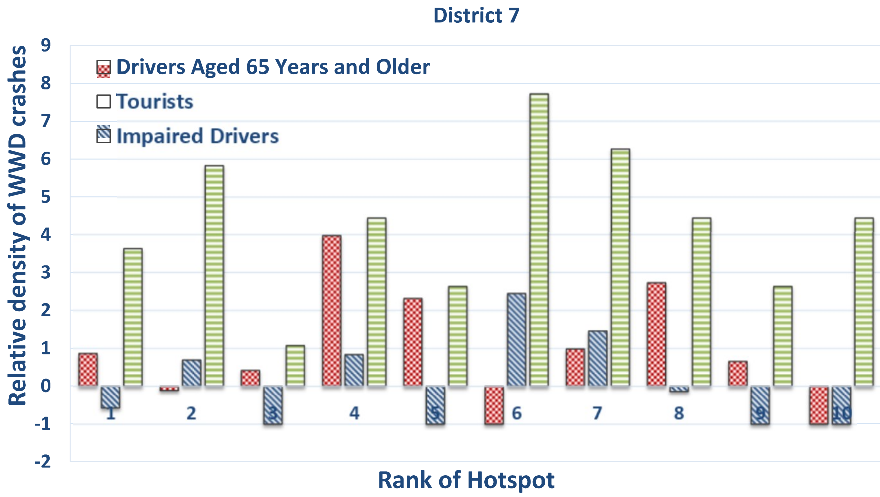


Figure 5-2: WWD Crash Category Relative Densities for FDOT District 7 WWD Hotspots

Figure 5-3 provides the relative densities of the WWD crashes involving *drivers aged 65 years and older*, *tourists*, and *impaired drivers* in the top WWD hotspots (i.e., average of the top hotspots) identified in each of the seven districts. Since different parameters are used based on the density of road network, the relative densities of WWD crashes across districts are not comparable. The following observations could be made from the figure:

- The proportion of WWD crashes involving *impaired drivers* in the WWD hotspots in all districts is much higher compared to the average proportion of crashes involving *impaired drivers* in the state.

- The proportion of WWD crashes involving *drivers aged 65 years and older* in the WWD hotspots in all districts is slightly higher compared to the average proportion of crashes involving *drivers aged 65 years and older* in the state.

- The proportion of WWD crashes involving *tourists* in the WWD hotspots in all districts is similar to the average proportion of crashes involving *tourists* in the state.

- The proportion of WWD crashes involving *tourists* in D1, D2, D3 and D7 is slightly higher compared to the average proportion in the state, while the proportion in D4, D5, and D6 is lower than the average proportion in the state.

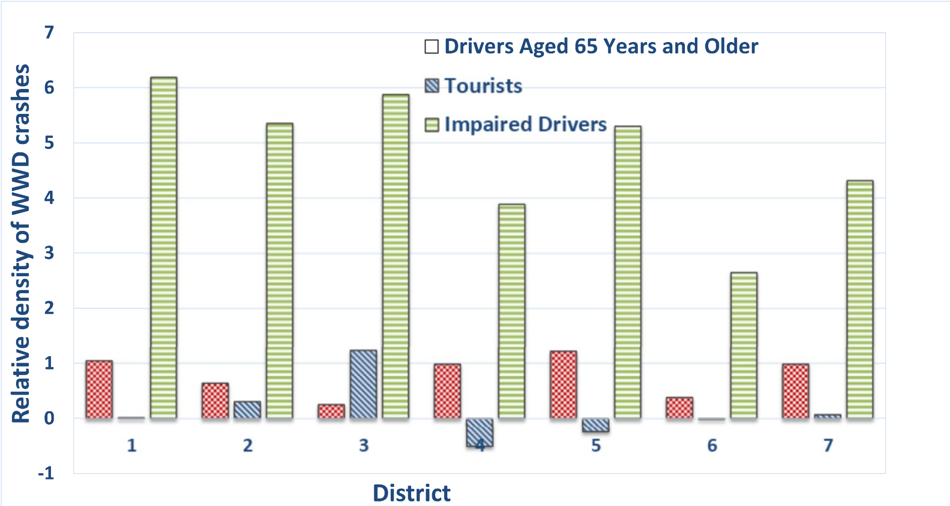


Figure 5-3: Relative Densities of Different WWD Crash Categories in Each District

5.2 Spatial Analysis of Crash Hotspots

5.2.1 Variables of Interest

Based on extensive literature review and preliminary analysis of WWD crashes in Florida, WWD incidents were found to potentially involve:

- Drivers aged 65 years and older who may have poor vision, and could get confused by the roadway geometry
- Tourists and visitors who are unfamiliar with the roadways
- Drivers who are under the influence of alcohol and/or drugs

The following demographic and land-use variables were considered in the analysis.

- *Drivers Aged 65 Years and Older*
  - Percent of population aged 65 years and older
  - Health facilities

- *Tourists and Visitors*
  - Shopping centers
  - Transportation terminals
  - Parks and recreational facilities
  - Hotels
  - Theaters and auditoriums
  - Bowling alleys, race tracks, skating rinks, and enclosed arenas
  - Restaurants and cafeterias

- *Impaired drivers*
  - Restaurants and cafeterias
  - Bowling alleys, race tracks, skating rinks, and enclosed arenas
  - Night clubs, bars, and cocktail lounges

Table 5-3 lists all the variables considered in this study. The table also includes the specific attributes of interest, and their corresponding data source, attribute unit, and attribute feature type. All the land-use attributes were extracted from the *2015 Florida Parcel Land-use* dataset, and their standard unit is square miles, and the features are polygons. Information on the *percent of population aged 65 years and older* was obtained from the *2015 Census Block Groups* dataset, population is its standard unit, and it is a polygon feature as well. Finally, information on *transportation terminals* was obtained from *2015 NavStreets* shapefile. Number of terminals (and not area of terminals) was used in the analysis.

Table 5-3: Variables of Interest

Cat.	Variable	Attribute	Source	Unit	Feature Type
Drivers Aged 65 Years and Older	Percent of Population Aged 65 Years and Older	AGE_65_UP	2015 Census Block Groups	Population	Polygon
	Health Facilities	Hospitals, clinics, outpatient care centers, and specialized care centers	2015 Florida Parcel Land-use	Square Miles	
Tourists	Shopping Centers	Supermarket			
		Regional Shopping Malls			
		Community Shopping Centers			
	Transportation Terminals	Airports, Marinas, Bus Terminals, and Piers	2015 NAVSTREETS	Number	Point
	Entertainment Facilities	Drive-in Theaters, Open Stadiums	2015 Florida Parcel Land-use	Square Miles	Polygon
		Enclosed Theaters, Auditorium			
		Bowling Alleys, Skating Rinks, Sport Arenas			
		Race Horse, Auto, and Dog Tracks			
	Hotels	Hotels, Motels			
	Recreation Facilities	Tourist Attractions			
		Camps			
		Outdoor Recreational Facilities			
Impaired Drivers	Alcohol Sales Establishments	Restaurants, Cafeterias			
		Drive-in Restaurants			
		Night Clubs, Bars, and Cocktail Lounges			
	Entertainment Facilities	Sport Arenas			

5.2.2 Analysis Framework

Spatial analysis was conducted for each hotspot for the three WWD crash categories (*drivers aged 65 years and older*, *tourists*, and *impaired drivers*) to examine the relationship between WWD crash category and facilities associated with WWD incidents. Figure 5-4 describes the methodology used to conduct the spatial analysis for the variables listed in Table 5-3, using the *drivers aged 65 years and older* WWD crash category as an example. The process was repeated for each WWD hotspot in each FDOT District for each of the three WWD crash categories.

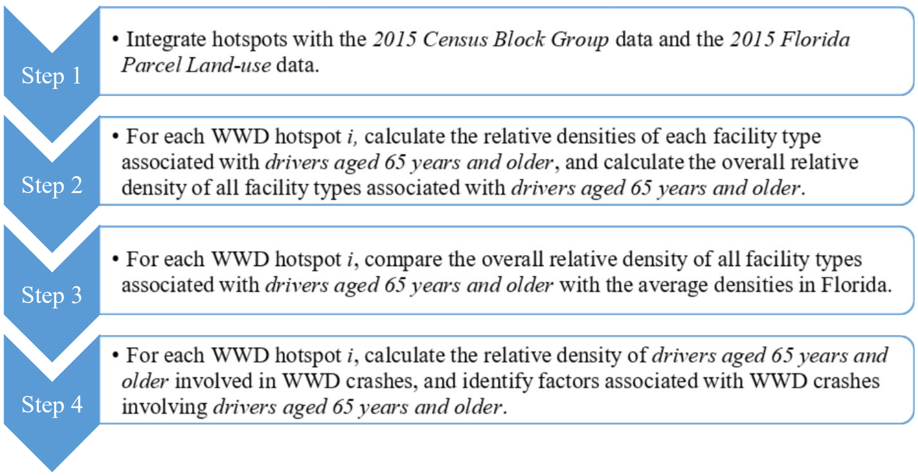


Figure 5-4: Methodology to Identify Factors Associated with WWD Crashes Involving Drivers Aged 65 Years and Older

R, the overall relative density of facilities for each WWD crash category (i.e., *drivers aged 65 years and older*, *tourists*, and *impaired drivers*), was calculated using the following equation:

$$\boldsymbol{R} = \frac{\sum_{j=1}^{n} r_j}{n}$$

where,

r_j = relative density of each facility type *j* (e.g., shopping malls, hotels, etc.),
n = total number of facilities included in each WWD crash category, and
j = facility type.

For each WWD hotspot *i* in each district, the overall relative density of each WWD crash category was calculated as follows:

$$R_i^{Drivers\ 65+} = \frac{r_i^{Population\ 65+} + r_i^{Health\ Facilities}}{2}$$

$$R_i^{Tourists} = \frac{r_i^{Recreation} + r_i^{Shopping} + r_i^{Hotel} + r_i^{Theatre} + r_i^{Sport\ Arena} + r_i^{Restaurant} + r_i^{Terminal}}{7}$$

$$R_i^{Impaired\ Drivers} = \frac{r_i^{Bar} + r_i^{Restaurant} + r_i^{Sport\ Arena}}{3}$$

In the above equations, r represents the relative density of each facility, calculated as the ratio of the density of the facility within each WWD hotspot *i* to the density of the facility in the entire state of Florida.

The proportion of facility *j* in the entire state of Florida, $P_j^{Florida}$, is a fixed value for each facility

j (provided in Table 5-4), and calculated as follows:

$$P_j^{Florida} = \frac{\sum_{l=1}^{n} A_{jl}}{A_{Florida}}$$

where,

$P_j^{Florida}$	=	proportion of facility j in the entire state of Florida (see Table 5-4),
$\sum_{l=1}^{n} A_{jl}$	=	total area of all facilities j within Florida,
n	=	total number of each facility j within Florida, and
$A_{Florida}$	=	area of the state of Florida in sq. miles calculated as the sum of the areas of the census block groups in 2015 with population > 0.

Table 5-4: Proportion of Different Facility Types in Florida

Category	Facility	Total Area	Unit	Percentage
Impaired Drivers	Bars	2.31	Sq. miles	0.0040%
	Restaurants	12.32	Sq. miles	0.0211%
	Sports Arenas	10.99	Sq. miles	0.0188%
Drivers Aged 65 Years and Older	Population Aged 65 Years & Older	3,650,991[a]	Number	18.580%
	Health Facilities	31.06	Sq. miles	0.0533%
Tourists	Recreation Facilities	223.70	Sq. miles	0.3838%
	Shopping Centers	72.58	Sq. miles	0.1245%
	Hotels	34.51	Sq. miles	0.0592%
	Theaters	2.61	Sq. miles	0.0045%
	Sports Arenas	10.99	Sq. miles	0.0188%
	Restaurants	12.32	Sq. miles	0.0211%
	Transportation Terminals	1,389[b]	Number	2.3830%
Total Florida Area		58,288.59	Sq. miles	
Total Florida Population		19,645,772[a]	Number	

[a] Population is based on numbers.
[b] Number of transportation terminals (and not area of transportation terminals) was considered in the analysis.

All land-use variables listed in Table 5-3 have units of *square miles*. The following equation was used to compute the relative density r_{ij} of each facility j in each WWD hotspot i:

$$r_{ij} = \frac{\frac{\sum_{k=1}^{n} A_{jk}}{A_i} - P_j^{Florida}}{P_j^{Florida}}$$

where,

$P_j^{Florida}$	=	proportion of facility j in the entire state of Florida (see Table 5-4),
$\sum_{k=1}^{n} A_{jk}$	=	total area of all facilities j within 0.5-mile buffer of WWD hotspot *i,*
n	=	total number of each facility j within 0.5-mile buffer of WWD hotspot *i,* and
A_i	=	area of WWD hotspot i in sq. miles.

The following interpretations can be made from the aforementioned equations:

- r_{ij} = -1 when P_{ij} = 0 implies that none of the facilities *j* are in WWD hotspot *i.*
- $r_{ij} < 0$ when $P_{ij} < P_j^{Florida}$ implies that the density of facility *j* in WWD hotspot *i* is lower than the average density of facility *j* in the entire state of Florida.
- $r_{ij} = 0$ when $P_{ij} = P_j^{Florida}$ implies that the density of facility *j* in WWD hotspot *i* is equal to the average density of facility *j* in the entire state of Florida.
- $r_{ij} > 0$ when $P_{ij} > P_j^{Florida}$ implies that the density of facility *j* in WWD hotspot *i* is higher than the average density of facility *j* in the entire state of Florida.

Since the unit for the *Transportation Terminals* variable is *numbers*, the relative density of transportation terminals was calculated using the following equations:

$$r_i^{Terminal} = \frac{\frac{N_i}{A_i} - P_{Florida}{}^{Terminal}}{P_{Florida}{}^{Terminal}}$$

$$P_{Florida}{}^{Terminal} = \frac{N_{Florida}}{A_{Florida}}$$

where,

$r_i^{Terminal}$	=	relative density of transportation terminals in WWD hotspot *i,*
N_i	=	total number of transportation terminals within 0.5-mile buffer of WWD hotspot *i,*
A_i	=	area of WWD hotspot *i* in sq. miles,
$P_{Florida}{}^{Terminal}$	=	proportion of transportation terminals in Florida (see Table 5-4),
$N_{Florida}$	=	total number of transportation terminals in Florida, and
$A_{Florida}$	=	area of the state of Florida in sq. miles calculated as the sum of the areas of the census block groups in 2015 with population > 0.

Information for the *Percent of Population Aged 65 Years and Older* variable was extracted from the *2015 Census Block Groups* dataset, and therefore calculated based on population. The relative density of the population aged 65 years and older ($r_i^{Population\ 65+}$) was determined using the following equations:

$$r_i^{Population\ 65+} = \frac{P_i^{Population\ 65+} - P_{Florida}{}^{Population\ 65+}}{P_{Florida}{}^{Population\ 65+}}$$

$$P_i^{Population\ 65+} = \frac{\sum_{k=1}^{n} Pop_k{}^{Population\ 65+}}{\sum_{k=1}^{n} Pop_k{}^{Total}}$$

where,

$P_i^{Population\ 65+}$	=	proportion of population aged 65 years and older within WWD hotspot *i,*
$\sum_{k=1}^{n} Pop_k{}^{Total}$	=	total population in WWD hotspot *i*,
n	=	number of census block groups that intersect with WWD hotspot *i*,

$\sum_{k=1}^{n} Pop_k^{Population\ 65+}$ = total population aged 65 years and older in WWD hotspot i,

$P_{Florida}^{Population\ 65+}$ = proportion of population aged 65 years and older in Florida, and

$r_i^{Population\ 65+}$ = relative density of population aged 65 years and older in WWD hotspot i.

5.2.3 Analysis Example

Figure 5-5 illustrates the results from the spatial analysis conducted on hotspots in FDOT District 7 for the following facility types: senior population and health facilities, tourist facilities, and alcohol sales establishments. Positive values indicate facility densities greater than the statewide average for a particular facility type. Alternatively, negative values represent hotspot densities lower than the statewide averages. For example, for WWD Hotspot No. 1 in Figure 5-5, the overall relative density for senior population and health facilities is 9.87, revealing that the density of these facilities in this hotspot region is 10.87 times (calculated as 9.87+1) greater than the density of these facilities in the entire state. Similarly, the density of tourist facilities and alcohol sales establishments in this hotspot region is 8.75 (calculated as 7.75+1) and 8.01 (calculated as 7.01+1) times greater, respectively, than the statewide density. On the other hand, the overall relative density value for senior population and health facilities in WWD Hotspot No. 5 is -0.11, indicating that the density of senior population and health facilities is 0.89 times (calculated as -0.11+1) the average density of these facilities in the state.

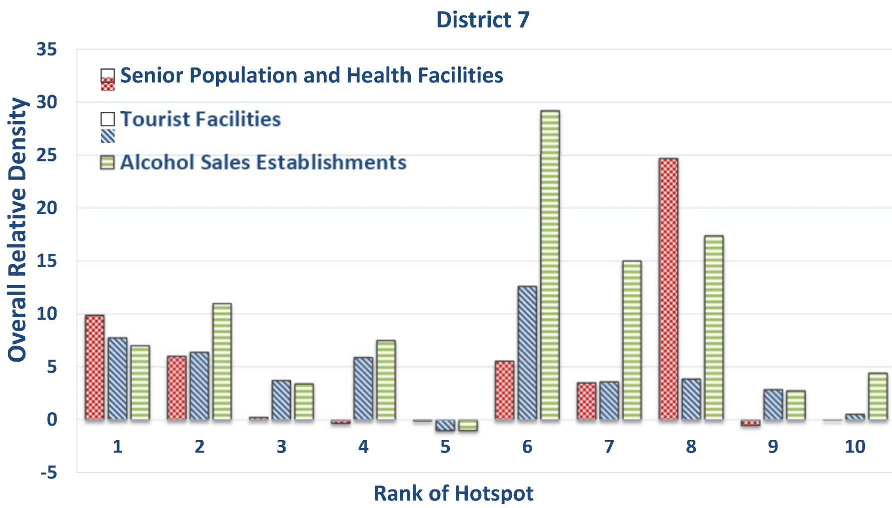


Figure 5-5: Relative Densities of Facilities in FDOT District 7 WWD Hotspots

When findings demonstrated in Figure 5-5 are compared to the relative density of WWD crashes involving *drivers aged 65 years and older*, *tourists*, and *impaired drivers* (Figure 5-2) at FDOT D7 hotspots, the higher densities of facility types appear to correlate with a higher number of WWD crashes involving *drivers aged 65 years and older* and *impaired drivers*. For example, WWD Hotspots No. 6, 7, and 8 indicate a higher number of WWD crashes involving *impaired drivers* compared to the statewide proportion. The densities of alcohol sales establishments are also considerably higher than the statewide averages at these locations. Similar comparisons can be observed with *drivers aged 65 years and older* and senior population and health facilities, yet to a lesser extent. *Tourist drivers* and tourist facilities results are inconsistent at hotspots in this district.

Figure 5-6 provides the relative densities of the facilities for seniors, tourist facilities, and alcohol sales establishments in the top WWD hotspots (i.e., average of the top hotspots) identified in each of the seven districts.

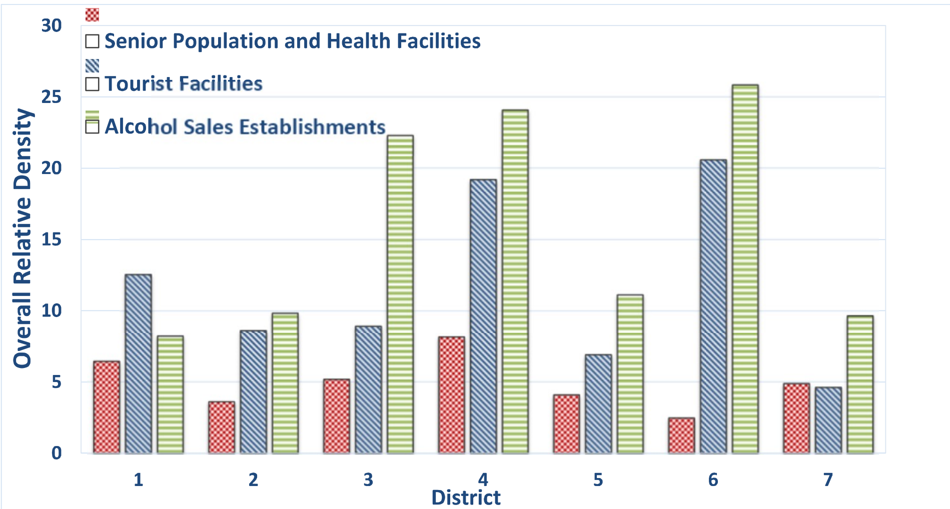


Figure 5-6: Relative Densities of Different Facility Types in Each District

Since different parameters are used based on the density of road network, the relative densities of WWD crashes across districts are not comparable. The following observations could be made from the figure:

- The densities of all facilities in the WWD hotspots in all districts are higher than the average densities in Florida.
- Compared to other districts, D3, D4, and D6 have a higher density of alcohol sales establishments.
- Compared to other districts, D1 and D4 have a higher density of the facilities for seniors.
- Compared to other districts, D1, D4, and D6 have a higher density of tourist facilities.

Table 5-5 provides the relative densities of different categories (facilities for seniors, tourist facilities, and alcohol sales establishments) and their associated WWD crashes for each WWD hotspot in each district. Note that the numbers (i.e., relative densities) in the table could be interpreted using the following logic:

- Relative density > 0 implies that the density at the hotspot is greater than the average density in Florida.
- Relative density < 0 implies that the density at the hotspot is lower than the average density in Florida.
- Relative density = 0 implies that the density at the hotspot is equal to the average density in Florida.
- Relative density = -1 implies that there are no related facilities (or associated crashes) at the hotspot.

Table 5-5: Relative Densities of Different Categories and their Associated WWD Crashes

Rank	Facilities For Seniors	WWD Crashes Involving Drivers Aged 65 Years and Older	Tourist Facilities	WWD Crashes Involving Tourists	Alcohol Sales Establishments	WWD Crashes Involving Impaired Drivers
District 1						
1	5.00	0.66	5.54	-0.62	8.73	4.45
2	1.39	0.73	6.21	-0.69	4.63	5.63
3	5.16	0.17	12.46	-1.00	10.09	9.26
4	15.17	1.21	9.61	-1.00	6.96	3.84
5	8.19	1.21	11.26	-0.23	8.33	8.69
6	-0.02	0.42	23.74	0.97	11.65	11.46
7	2.52	-0.01	7.21	0.53	10.37	1.18
8	1.25	2.98	2.45	1.95	7.18	3.36
9	23.44	0.11	18.96	-0.14	12.87	6.27
10	2.27	2.98	28.13	0.38	1.16	7.72
District 2						
1	3.82	0.23	14.01	0.66	8.04	5.52
2	1.49	-0.48	7.46	-0.23	11.21	3.59
3	11.75	-0.01	14.26	-0.64	18.90	13.17
4	9.70	-0.55	12.80	1.51	5.96	9.90
5	-0.78	0.66	5.42	0.15	6.78	9.90
6	3.33	1.30	9.53	0.38	8.24	4.03
7	-0.43	2.32	8.85	1.30	12.46	-1.00
8	-0.75	-1.00	12.25	1.30	10.21	-1.00
9	13.84	-1.00	7.52	0.72	5.89	12.62
10	-0.82	-1.00	4.50	1.30	1.61	-1.00

Table 5-5 (Cont'd): Relative Densities of Different Categories and their Associated WWD Crashes

Rank	Facilities For Seniors	WWD Crashes Involving Drivers Aged 65 Years and Older	Tourist Facilities	WWD Crashes Involving Tourists	Alcohol Sales Establishments	WWD Crashes Involving Impaired Drivers
District 3						
1	5.01	0.71	10.44	0.51	18.25	7.72
2	1.45	-0.60	7.32	0.75	9.03	5.48
3	5.81	0.76	9.62	0.97	14.95	8.62
4	0.56	-0.01	12.70	-0.23	31.99	7.72
5	-0.51	-1.00	11.74	3.14	15.33	9.90
6	-0.21	-1.00	2.29	0.97	8.97	8.69
7	-0.45	3.26	-0.42	3.14	-0.54	2.11
8	-0.26	-1.00	22.45	3.14	104.76	-1.00
9	-0.40	0.99	4.58	-1.00	5.32	1.18
10	40.81	0.42	8.56	0.97	15.06	8.34
District 4						
1	6.92	-0.35	14.24	-0.64	2.87	5.08
2	39.42	-0.25	20.91	-0.29	5.04	7.17
3	0.49	-0.01	5.86	-1.00	3.14	5.54
4	0.37	-0.17	22.57	-0.37	32.28	0.82
5	-0.29	1.71	8.21	-1.00	31.35	2.96
6	0.32	1.30	4.23	-1.00	7.91	7.38
7	0.45	3.59	66.92	0.06	133.91	0.68
8	0.04	1.30	6.40	0.20	7.40	3.19
9	5.62	2.32	6.76	-1.00	6.05	0.82
10	28.08	0.42	35.67	-0.02	10.89	5.23
District 5						
1	1.21	0.33	9.04	0.33	10.32	3.72
2	3.05	0.66	11.33	-0.37	19.04	8.08
3	8.83	0.66	5.96	-0.02	25.84	3.84
4	1.06	2.83	2.59	0.20	2.13	5.71
5	3.63	0.31	2.88	-0.46	4.08	5.31
6	1.46	0.42	4.41	-0.02	7.50	6.27
7	0.27	2.62	11.14	-0.37	5.73	2.96
8	-0.19	3.42	11.67	-1.00	10.74	1.42
9	10.69	-0.56	5.44	-0.16	10.71	5.78
10	10.84	1.49	4.45	-0.54	15.21	9.90

Table 5-5 (Cont'd): Relative Densities of Different Categories and their Associated WWD Crashes

Rank	Facilities For Seniors	WWD Crashes Involving Drivers Aged 65 Years and Older	Tourist Facilities	WWD Crashes Involving Tourists	Alcohol Sales Establishments	WWD Crashes Involving Impaired Drivers
District 6						
1	3.01	0.12	15.54	-0.26	11.44	1.36
2	0.23	-0.48	20.68	1.43	20.28	7.03
3	-0.47	-0.34	9.77	-1.00	19.86	1.91
4	-0.35	1.30	35.25	0.15	22.14	4.03
5	7.97	0.24	6.22	-1.00	4.05	-1.00
6	-0.60	1.09	1.81	0.81	3.33	0.15
7	0.33	-0.72	16.33	0.78	6.09	3.24
8	0.24	1.09	24.75	-0.59	8.20	5.88
9	12.92	0.87	9.59	-0.57	20.11	3.09
10	1.49	0.66	65.67	0.15	142.72	0.82
District 7						
1	9.87	0.87	7.75	-0.58	7.01	3.63
2	5.99	-0.11	6.38	0.70	10.97	5.83
3	0.22	0.42	3.71	-1.00	3.40	1.08
4	-0.32	3.97	5.87	0.84	7.49	4.45
5	-0.11	2.32	-1.00	-1.00	-1.00	2.63
6	5.55	-1.00	12.60	2.45	29.19	7.72
7	3.49	0.99	3.59	1.46	15.01	6.27
8	24.67	2.73	3.85	-0.14	17.39	4.45
9	-0.51	0.66	2.86	-1.00	2.73	2.63
10	-0.03	-1.00	0.52	-1.00	4.41	4.45

5.3 Discussion of Results

This section presents the relation between demographic and land-use variables and the three WWD crash categories (i.e., *impaired drivers*, *drivers aged 65 years and older*, and *tourists*).

5.3.1 Impaired Drivers

WWD crashes involving *impaired drivers* were found to have a strong positive association with the density of alcohol sales establishments. The higher the overall relative density of alcohol sales establishments, the higher the relative density of WWD crashes involving *impaired drivers*. As an example, Figure 5-7 provides the relationship between the density of alcohol sales establishments and WWD crashes involving *impaired drivers* at WWD hotspots in D1. The overall relative densities of all the hotspots in D1 are greater than the average density of alcohol sales establishments in Florida. Similar trends were also observed in all the districts.

As can be observed from Figure 5-7, Hotspots No. 3 and 6 have a high density of alcohol sales establishments and a high density of WWD crashes involving *impaired drivers*. Hotspot No. 7 has very high density of alcohol sales establishments, but very low density of WWD crashes involving *impaired drivers*. This observation suggests that this location may already have some WWD countermeasures in place, and/or drivers perceive this location as unsafe and are cautious while driving in this region. Hotspot No. 10, on the other hand, has very low density of alcohol sales establishments, but a very high density of WWD crashes involving *impaired drivers*. Other factors that are not considered in this study may have contributed to crashes involving *impaired drivers* at this location.

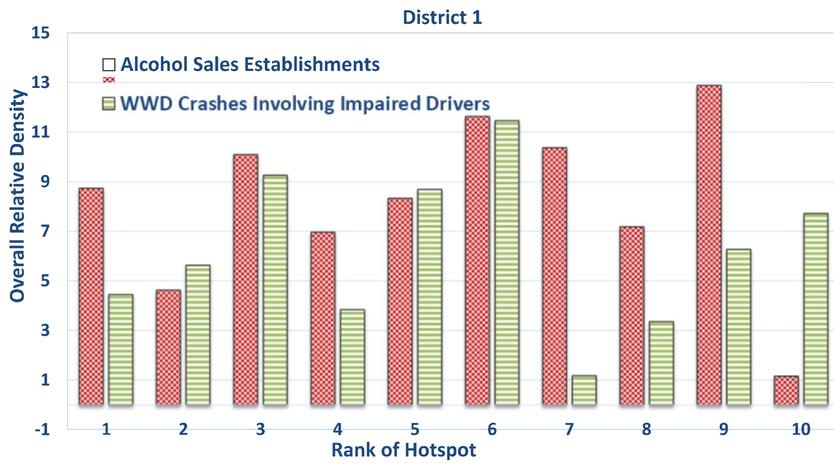


Figure 5-7: Relationship between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers in FDOT District 1

Strategies (i.e., countermeasures) to mitigate WWD crashes involving *impaired drivers* may consider the following three scenarios:

- **Scenario A:** Hotspots have *high* density of alcohol sales establishments and *high* density of WWD crashes involving *impaired drivers*.

- **Scenario B:** Hotspots have *high* density of alcohol sales establishments, but *low* density of WWD crashes involving *impaired drivers*.

- **Scenario C:** Hotspots have *low* density of alcohol sales establishments, but *high* density of WWD crashes involving *impaired drivers*.

5.3.2 Drivers Aged 65 Years and Older

WWD crashes involving *drivers aged 65 years and older* were found to *not* have a strong positive association with the densities of senior population and health facilities. Most of the WWD hotspots have very high relative density of senior population and health facilities, but, relatively low density of WWD crashes involving *drivers aged 65 years and older*. As an example, Figure 5-8 provides the relationship between the density of senior population and health facilities and WWD crashes involving *drivers aged 65 years and older* at WWD hotspots in D1. As can be observed, there is no strong association between these facilities and WWD crashes involving *drivers aged 65 years and older*.

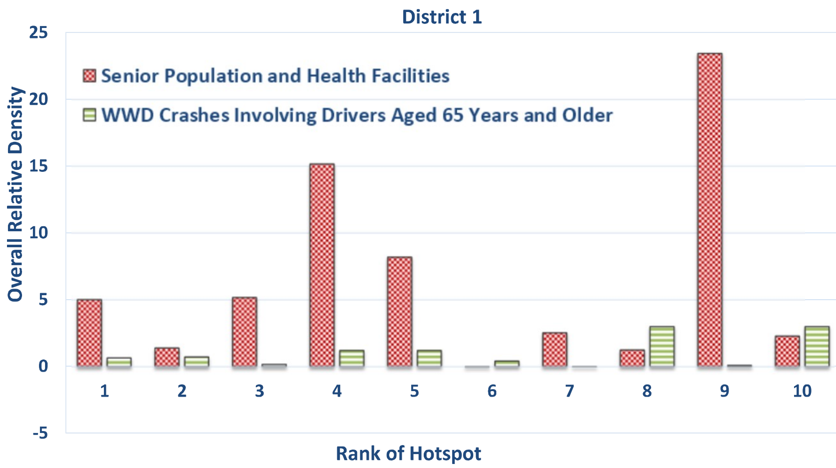


Figure 5-8: Relationship between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older in FDOT District 1

The relationship between the facilities that attract *drivers aged 65 years and older* and the WWD crashes involving *drivers aged 65 years and older* was not prominent. Strategies (i.e., countermeasures) to mitigate WWD crashes involving *drivers aged 65 years and older* may consider the following two scenarios:

- **Scenario D:** Hotspots where the relative density of WWD crashes involving *drivers aged 65 years and older* is *greater* than the state average.
- **Scenario E:** Hotspots where the overall relative density of senior population and health facilities is *greater* than the state average AND the relative density of WWD crashes involving *drivers aged 65 years and older* is *at least double* the state average.

5.3.3 Tourists

Unlike WWD crashes involving *impaired drivers* and *drivers aged 65 years and older*, no association was found between WWD crashes involving *tourists* and the density of tourist facilities. As an example, Figure 5-9 provides the relationship between the density of tourist facilities and WWD crashes involving *tourists* at WWD hotspots in D1. No apparent association between the tourist facilities and WWD crashes involving *tourists* is evident. In fact, some hotspots have very high relative density of tourist facilities, but the density of WWD crashes involving *tourists* is lower than the average density in the state.

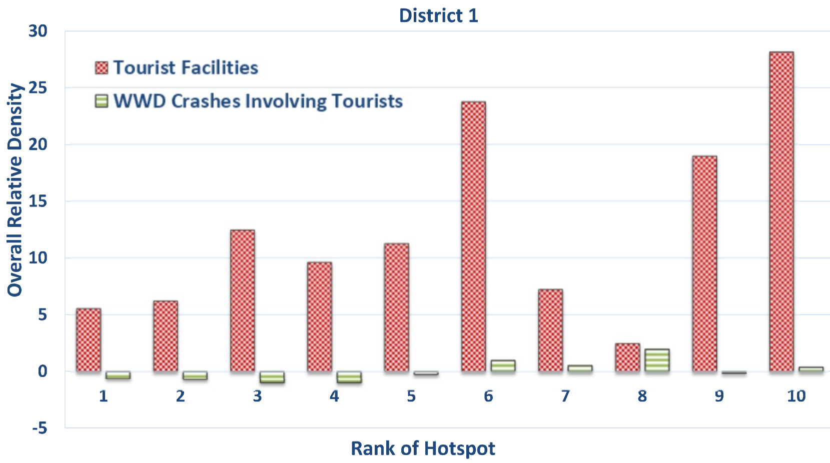


Figure 5-9: Relationship between Density of Tourist Facilities and WWD Crashes Involving Tourists in FDOT District 1

Overall, no direct relation was found between the density of tourist facilities and WWD crashes involving *tourists*. However, detailed site-specific analysis of WWD hotspots in each district resulted in some positive associations between the facilities and crashes. Countermeasures to mitigate WWD crashes involving *tourists* may consider the following two scenarios:

- **Scenario F:** Hotspots where the relative density of WWD crashes involving *tourists* is *greater* than the state average.

- **Scenario G:** Hotspots where the overall relative density of tourist facilities is *greater* than the state average AND the relative density of WWD crashes involving *tourists* is *at least double* the state average.

Table 5-6 provides a matrix of suggested scenarios to mitigate WWD crashes pertaining to the three WWD crash categories analyzed at each of the 10 WWD hotspots identified in each of the seven FDOT Districts. The results in Table 5-6 could be interpreted as follows: for Hotspot No. 1 in D1, the countermeasures should address *impaired drivers* and *drivers aged 65 years and older*, while the countermeasures at Hotspot No. 7 in D1 should address *impaired drivers* and *tourists*.

Table 5-6: Scenarios Pertaining to Specific WWD Crash Categories at Each WWD Hotspot

Rank							
District 1							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
District 2							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
District 3							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
District 4							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Table 5-6 (cont'd): Scenarios Pertaining to Specific WWD Crash Categories at Each WWD Hotspot

Rank							
District 5							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
District 6							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
District 7							
1							
2							
3							
4	Y			Y	Y	Y	
5		Y		Y	Y		
6		Y				Y	Y
7	Y			Y		Y	Y
8		Y		Y	Y		
9	Y			Y			
10	Y						

Appendices A and B provide the relative densities of different facility types and WWD crash categories at WWD hotspots in each district, respectively. Appendices C through E provide the relation between the density of different facility types and their associated WWD crashes at WWD hotspots in each district.

5.4 Summary

This chapter discussed a demographics-based methodology to identify regions that possess a combination of *pre-conditions* for increased likelihood of WWD incidents. WWD crash hotspots were identified for each of the seven FDOT Districts in Florida, and the impact of demographic and land-use factors at each hotspot was examined using spatial analysis.

To explore WWD incidents in Florida, hotspots were identified using the 6,880 reported WWD crashes that occurred from 2011-2015. Three WWD crash categories were analyzed: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*. The methodology focused on identifying the relationship between the facilities associated with the three WWD crash categories and the WWD crashes within the WWD hotspots. The density of alcohol sales establishments was found to be highly associated with the WWD crashes involving *impaired drivers*. The relationship between the facilities that attract *drivers aged 65 years and older* and the WWD crashes involving *drivers aged 65 years and older* was somewhat associative. No observable relationship was found between the density of tourist facilities and WWD crashes involving *tourists*.

CHAPTER 6
WRONG-WAY DRIVING COUNTERMEASURES IMPLEMENTATION PLAN

This chapter focuses on the approach used to proactively identify the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each off-ramp in Florida. This chapter is divided into two major sections. Section 6.1 presents the comprehensive approach that has been adopted by FDOT to address the WWD issue. Section 6.2 discusses the WWD Countermeasures Implementation Plan which identifies the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each of the 1,642 off-ramps in Florida. The supplemental documents include an excel file with the WWD Countermeasures Implementation Plan.

6.1 FDOT's Approach

FDOT has been a pioneer in addressing the WWD issue. In the past few years, FDOT has made tremendous strides in mitigating WWD incidents in Florida. The dedication and commitment of the FDOT Central Office, the District Safety Engineers (DSEs), the District Traffic Operations Engineers (DTOEs), the Florida Highway Patrol (FHP), the law enforcement and first responders, and the Florida Universities is clearly evident as FDOT has begun to see a reduction in the frequency and severity of WWD incidents. FDOT's approach is data-driven, cross-jurisdictional, multi-disciplinary, replicable, and sustainable. It has focused on developing a policy-specific framework emphasizing on continual consultation, coordination, and communication. FDOT has also developed a strategic and coordinated research efforts tackling all the issues with WWD incidents and assisting the agencies with developing an implementation strategy to mitigate WWD incidents.

6.1.1 Policy-oriented Strategy

Ponnaluri (2016a) presented a "policy-oriented framework toward addressing WWD incidents in a systematic manner and suggested a systemic discipline for transforming policy objectives to actionable outcomes". Figure 6-1 presents this framework with the backdrop of leadership-supported institutionalization to strategize road safety improvements.

As illustrated in the figure, the holistic approach taken by the FDOT leadership included:

- implementing pilot projects;
- conducting a statewide study with crash evaluation and field reviews, identifying interchange types, and developing countermeasures;
- evaluating and deploying experimental devices specifically approved by the Federal Highway Administration (FHWA);
- conducting a human factors study;
- transforming recommendations to design guidance;
- discussing with planners on interchange types susceptible to WWD incidents;
- retrofitting exit ramps with the recommended countermeasures; and
- leveraging the media to promote awareness and to educate the public about the dangers of driving under the influence.

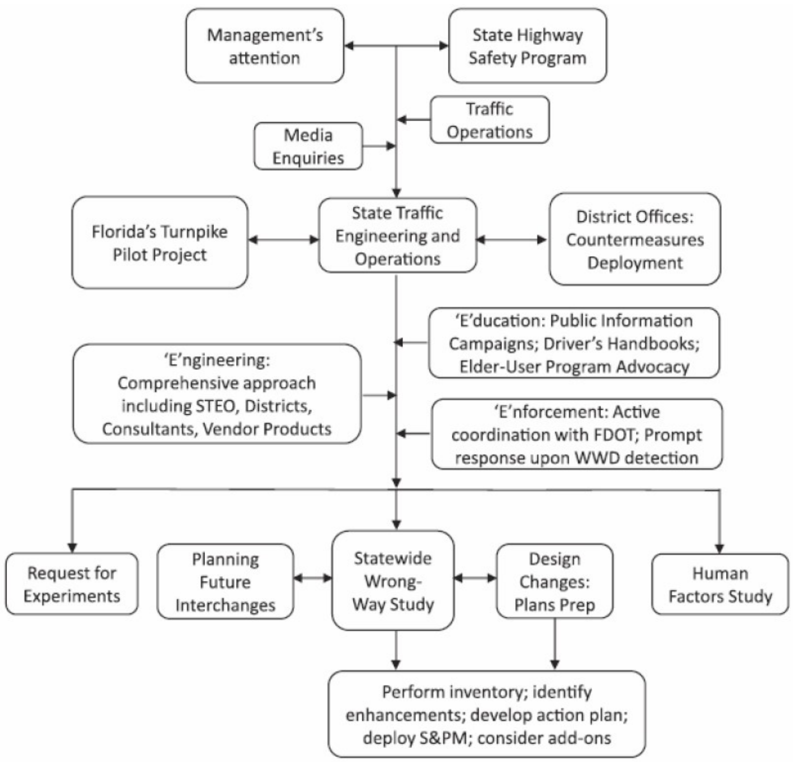


Figure 6-1: Mitigating WWD Incidents through FDOT Framework (Ponnaluri, 2016a)

6.1.2 Statewide WWD Crash Study

Kittelson and Associates (2015) conducted a detailed statewide study of WWD crashes in Florida focusing on analyzing trends and contributing factors associated with WWD incidents on limited access facilities. Some of the most relevant statistics are:

- From 2009-2013, approximately 280 WWD crashes occurred on Florida's freeways and expressways resulting in more than 400 injuries and 75 fatalities.
- Weekends and early morning hours (12 AM - 6 AM) were found to be more susceptible to WWD crashes.
- Impaired drivers were involved in 45% of WWD crashes.
- About 71% of WWD crashes occurred in dark conditions.
- Approximately 75% of WWD crashes occurred in urban areas.
- The majority of WWD movements were entering the freeway from an exit ramp.
- Diamond/partial diamond, partial cloverleaf, and trumpet interchange types experienced the highest number of WWD crashes, while the full cloverleaf interchange type

experienced the lowest number of WWD crashes. However, this information was not normalized by the level of exposure.

6.1.3 Human Factors Study

A human factors study was conducted to understand the role of human cognition in driver decision-making process. Boot et al. (2015) focused primarily on nighttime crashes involving impaired drivers and daytime crashes involving older drivers. The authors concluded that a combination of cues help drivers pursue safe driving options; not one particular sign or a lane marking, but a combination of cues provide sensory inputs to drivers for making decisions. Based on extensive literature review, the authors developed the decision-making process related to wrong-way entries and crashes (see Figure 6-2). One specific recommendation from this study was that WWD crashes could be reduced at problematic interchanges by increasing the number and diversity of countermeasures.

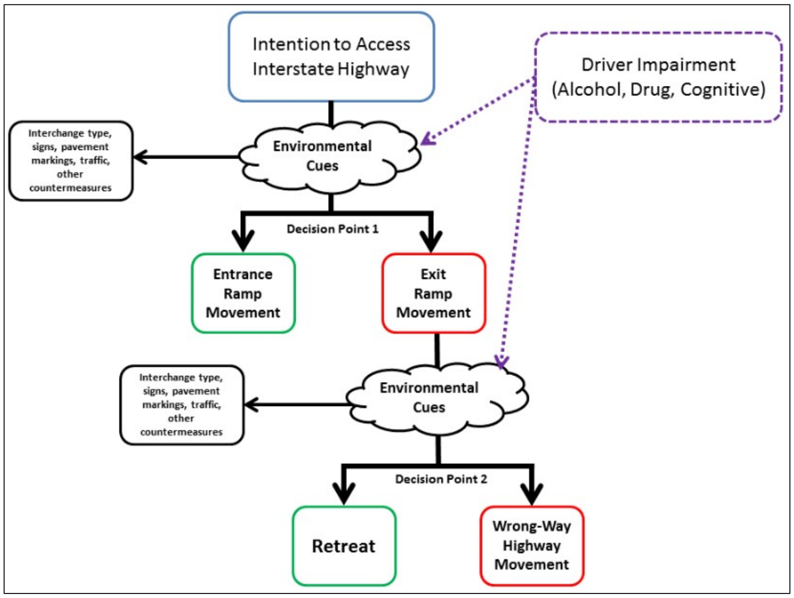


Figure 6-2: Decision-making Process Related to Wrong-way Entries and Crashes Based on Literature (Source: Boot et al., 2015)

6.1.4 Pilot Projects across Florida

FDOT has been conducting pilot studies and Request for Experiments (RFEs) to evaluate the following seven innovative countermeasures:

1. Newly-developed Signing and Pavement Marking (S&PM) standards (FDOT's Plans Preparation Manual, Figures 7.2.1. and 7.2.2)
2. Red-RRFBs

3. Red flush-mount iiRPMs
4. Detection-triggered LED lights around "WRONG WAY" signs
5. Detection-triggered blank-out signs that flash "WRONG WAY"
6. Delineators along off-ramps
7. Wigwag flashing beacons

Most recently, Lin et al. (2017) compared these seven pilot countermeasures that were installed on exit ramps and adjacent arterials across Florida for mitigating wrong-way entries onto limited-access facilities. The authors recommended a combination of countermeasures for future deployment consideration. The authors provided recommendations based on field evaluations and focus group surveys. The study conclusions can be found in Lin et al. (2017).

6.1.5 Education- and Enforcement-related Efforts

In addition to the *Engineering* countermeasures, FDOT has also focused on the other 3*E's*, i.e., *Education*, *Enforcement*, and *Emergency Medical Services*. For example, FDOT considers July as *WWD Awareness Month*, and works on educating the public regarding tips to follow to avoid being involved in WWD crashes. The Florida Department of Highway Safety and Motor Vehicles (DHSMV) has been leading extensive education efforts to reduce WWD incidents. DHSMV is using #*StayRightatNight* to urge drivers to "Stay Right at Night" and avoid a crash while driving the wrong way. This campaign has generated significant interest in the social media. On its website and through several avenues, the Florida DHSMV offers the following safety tips to avoid WWD crashes (DHSMV, 2016):

- Stay Right at Night to avoid crashes with wrong-way drivers.
- Call 911 immediately to report wrong-way drivers. If you see a wrong-way driver approaching, immediately reduce your speed and pull off the roadway.
- Learn and obey all traffic signs. If you drive past a Wrong Way sign, turn around as soon as it is safe to do so.
- Look for FDOT dynamic messaging signs for wrong-way driver alerts.
- When you see a posted red sign, think: "Stop." "Do Not Enter." "Wrong Way."
- Stay alert - do not drive distracted or impaired.

6.1.6 Freeway WWD Detection Systems

FDOT is currently spearheading a research effort focusing on real-time strategies to mitigate WWD incidents on freeways. The WWD countermeasures generally provide cues to the wrong-way drivers to prevent them from entering the freeway from the off-ramp. If the wrong-way driver misses all these cues on the arterial and the off-ramp, and enters the freeway from the off-ramp, the last and the final resort would be to alert the traffic on the freeway and the police to prevent a crash on the freeway. As can be observed from Figure 6-3, this procedure involves the following typical stages:

- Detect the vehicle traveling in the wrong direction.
- Record the video.

- Send the video to the Transportation Management Center (TMC) to verify that the incident is indeed a WWD incident.
- Once confirmed, alert the public about the potential wrong-way driver through a message on DMS (see Figure 6-4) and the Highway Advisory Radio (HAR).
- Coordinate with the FHP and dispatch personnel to the location.

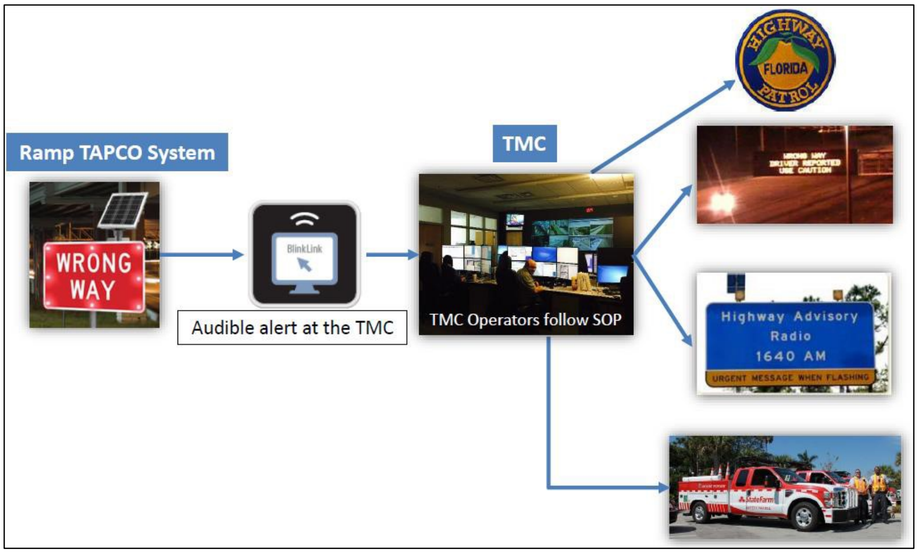


Figure 6-3: Typical WWD Detection Notification Process
(Source: Gordin, E., and Kinney, K., 2016)

Figure 6-4: Wrong-way Driver Alerts on Dynamic Message Signs in Florida
(Source: DHSMV, 2016)

FDOT is currently conducting a research project to test and evaluate selected freeway WWD detection systems currently in the market for their capabilities related to wrong-way vehicle detection using existing cameras in real-time and TMC notification. This is a joint research and development effort by the FDOT Research Center, the Center for Urban Transportation Research Center (CUTR) at the University of South Florida (USF), and selected vendors. This project (Project BDV25 977-40), once completed, will support FDOT in future implementation of WWD detection systems on limited-access facilities in Florida.

6.2 WWD Countermeasure Implementation Plan

The WWD Countermeasure Implementation Plan identifies the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each of the 1,642 off-ramps in Florida. The analysis was based on 2011-2015 WWD crash data and demographic and land-use variables. A combination of crash data analysis and spatial analysis, as described in Chapters 3 through 5, was used to identify one of the following as the most predominant factor at each of the 1,642 off-ramps:

- impaired drivers,
- drivers aged 65 years and older, and
- tourist drivers.

Overall, the most predominant factor was identified based on the following analyses:

1. analysis of WWD hotspots,
2. analysis of WWD crashes on freeways, and
3. analysis of demographic and land-use factors in the vicinity of off-ramps.

6.2.1 Analysis of WWD Hotspots

The WWD hotspot analysis combined both demographic and land-use factors and the WWD crashes that occurred on the public road network in Florida from 2011-2015. Chapter 5 provides more details about the analysis approach. A total of ten hotspots were identified in each of the seven districts. The hotspots were regions and not specific off-ramps. Hence, the specific off-ramps within each of these regions were identified. Note that some hotspots might not have any off-ramps while some hotspots might have multiple off-ramps.

The factors contributing to WWD crashes within each of the hotspots were identified. For each hotspot, one or more of the following factors were identified: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*. Of the 1,642 off-ramps, 187 off-ramps (i.e., 11.4%) were found to be located within the 70 hotspot regions.

In general, the density of alcohol sales establishments was found to be highly associated with the WWD crashes involving *impaired drivers*. The relationship between the facilities that attract *drivers aged 65 years and older* and the WWD crashes involving *drivers aged 65 years and older* was somewhat associative. No observable relationship was found between the density of tourist facilities and WWD crashes involving *tourists*.

6.2.2 Analysis of WWD Crashes on Freeways

The WWD crashes that occurred on freeways were analyzed to identify factors that could be associated with the off-ramps. Up to three off-ramps upstream of each of the WWD crash on a freeway that could have potentially been associated with WWD crashes were first identified and analyzed. Again, the factors contributing to WWD crashes were identified. For each off-ramp associated with a WWD crash on a freeway, one or more of the following factors were identified:

impaired drivers, *drivers aged 65 years and older*, and *tourists*. Of the 1,642 off-ramps, 350 off-ramps (i.e., 21.3%) were found to be associated with WWD crashes on freeways.

6.2.3 Analysis of Demographic and Land-use Factors

All the off-ramps that were not flagged in the analysis of WWD hotspots and the analysis of WWD crashes on freeways were analyzed to determine if these locations possess a combination of *pre-conditions* or *factors* for increased likelihood of WWD incidents. Demographic and land-use factors in the vicinity of these off-ramps were analyzed to identify if the locations have a higher density of alcohol sales establishments, senior population and health facilities, and/or tourist attractions that could potentially result in an increased likelihood of WWD incidents. Note that this analysis was not based on WWD crashes as there were no WWD crashes in the vicinity of these off-ramps. This analysis identified the most predominant factor for 873 off-ramps (i.e., 53.2% of 1,642 off-ramps).

6.2.4 Potential Countermeasures for Consideration

The results from the three analyses (i.e., analysis of WWD hotspots, analysis of WWD crashes on freeways, and analysis of demographic and land-use factors in the vicinity of off-ramps) were combined to obtain the final predominant factors at each of the 1,642 off-ramps. The predominant factors were identified based on a conservative approach. If *alcohol* was identified as a predominant factor in any of the three analyses, it was considered to be the predominant factor to be addressed. Similarly, if *drivers aged 65 years and older* were identified as a predominant factor in any of the three analyses, then *drivers aged 65 years and older* were considered to be the predominant factor to be addressed. Again, if *tourist drivers* were identified as a predominant factor in any of the three analyses, then *tourists* were considered to be the predominant factor to be addressed. Finally, the most predominant factor was identified in the following order: *impaired drivers*, *drivers aged 65 years and older*, and *tourist drivers*.

A combination of Red-RRFBs and iiRPMs could be considered to address the issue of *impaired drivers*. A combination of LED lights surrounding the Wrong Way signs and iiRPMs could be considered to accommodate the *drivers aged 65 years and older*. Finally, either Red-RRFBs or LED lights surrounding the Wrong Way signs could assist *tourist* drivers. In addition to the aforementioned countermeasures, new S&PM standards could be considered at all the off-ramps.

CHAPTER 7
SUMMARY AND CONCLUSIONS

A wrong-way driving (WWD) crash is one in which a vehicle traveling in a direction opposing the legal flow of traffic on a high-speed divided highway or access ramp collides with a vehicle traveling on the same roadway in the proper direction (NTSB, 2012). Wrong-way drivers pose a serious risk to the safety of themselves and other motorists. On average, WWD crashes result in about 355 fatalities each year. WWD mitigation has therefore been on the national front, with states tackling this issue from several avenues, focusing on the 4*E's*, i.e., *Engineering*, *Education, Enforcement*, and *Emergency Medical Services*; policy-oriented changes; and adopting state-of-the-art technology to detect, verify, and respond to WWD incidents in real-time. Several states including Arizona, California, Illinois, and Texas have made great strides in reducing the frequency and severity of WWD incidents.

Understanding the seriousness of WWD incidents, the Florida Department of Transportation (FDOT) has endeavored to continually explore ways to strategically draft, design, and deploy countermeasures while proactively identifying areas that can help mitigate these incidents. FDOT's strategy has included policy-oriented changes to create actionable WWD initiatives; extensive research on understanding the underlying WWD crash patterns and causes, and driver behavior while intoxicated; and motivation to implement and compare several pilot countermeasures. FDOT has always been on the forefront in investigating and deploying innovative methods and Intelligent Transportation Systems (ITS) applications to mitigate WWD incidents.

Since WWD crashes are rare and random, a system-wide deployment of countermeasures requires careful consideration. FDOT needs an actionable and implementable plan to systemically and strategically deploy WWD countermeasures at all the 1,642 off-ramp locations across the state. It is therefore critical to identify the most suitable countermeasures at each of these off-ramps such that they yield the maximum benefit.

The traditional approach to selecting the most suitable countermeasures has been based on crashes and crash contributing factors. However, WWD crashes being random and relatively rare, do not lend themselves to the traditional approaches. Other data sources such as traffic citations thus become an important input element and could be used to supplement the crash data to better understand WWD incidents. Nonetheless, this approach of using crash and citation data is *reactive* and is based on responding to events after they had happened. An effective approach is to be *proactive* and identify the most suitable locations for deploying countermeasures based on the *pre-conditions* of the region.

The objective of this research was to develop a demographics-based methodology to identify regions that possess a combination of *pre-conditions* for increased likelihood of WWD incidents, and to proactively identify the most predominant factor that could potentially contribute to the occurrence of WWD incidents at each off-ramp in Florida.

Descriptive analysis of WWD crashes and spatial analysis of demographic and land-use factors were conducted to identify the most predominant factor that could potentially contribute to WWD incidents at each of the 1,642 off-ramps. More specifically, the following three factors were analyzed:

- impaired drivers,
- drivers aged 65 years and older, and
- tourists.

The analysis was based on 6,880 WWD crashes that occurred in Florida from 2011-2015, demographic data obtained from the *2015 Census Block Groups* dataset, and land-use data obtained from the *2015 Florida Parcel Land-use* dataset.

The most predominant factor that could potentially contribute to WWD incidents was identified based on the following analyses: (a) *analysis of WWD hotspots*; (b) *analysis of WWD crashes on freeways*; and (c) *analysis of demographic and land-use factors*.

The WWD hotspot analysis combined both demographic and land-use factors and the WWD crashes that occurred on the public road network in Florida from 2011-2015. A total of ten hotspots were identified for each of the seven FDOT districts. The factors contributing to WWD crashes within each of the hotspots were identified. For each hotspot, one or more of the following factors were identified: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*.

In general, the density of alcohol sales establishments was found to be highly associated with the WWD crashes involving *impaired drivers*. The relationship between the facilities that attract *drivers aged 65 years and older* and the WWD crashes involving *drivers aged 65 years and older* was somewhat associative. No observable relationship was found between the density of tourist facilities and WWD crashes involving *tourists*.

The WWD crashes that occurred on freeways were analyzed to identify factors that could be associated with the off-ramps. Up to three off-ramps upstream of each of the WWD crash on a freeway that could have potentially been associated with WWD crashes were first identified and analyzed. Again, the factors contributing to WWD crashes were identified. For each off-ramp associated with a WWD crash on a freeway, one or more of the following factors were identified: *impaired drivers*, *drivers aged 65 years and older*, and *tourists*.

Finally, all the off-ramps that were not flagged in the analysis of WWD hotspots and the analysis of WWD crashes on freeways were analyzed to determine if these locations possess a combination of *pre-conditions* or *factors* for increased likelihood of WWD incidents. Demographic and land-use factors in the vicinity of these off-ramps were analyzed to identify if the locations have a higher density of alcohol sales establishments, senior population and health facilities, and/or tourist attractions that could potentially result in an increased likelihood of WWD incidents.

The results from the three analyses were combined to obtain the final predominant factor at each of the 1,642 off-ramps. The predominant factors were identified based on a conservative approach. If *impaired drivers* was identified as a predominant factor in any of the three analyses, it was considered to be the predominant factor to be addressed. Similarly, if *drivers aged 65 years and* *older* (or, *tourists*) were identified as a predominant factor in any of the three analyses, then *drivers aged 65 years and older* (or, *tourists*) was considered to be the predominant factor to be addressed. Finally, the most predominant factor was identified in the following order: *impaired drivers*, *drivers aged 65 years and older*, and *tourist drivers*.

A combination of red rectangular rapid flashing beacons (Red-RRFBs) and internally illuminated raised pavement markers (iiRPMs) could be considered to address the issue of *impaired drivers*. A combination of Light Emitting Diode (LED) lights surrounding the Wrong Way signs and iiRPMs could be considered to accommodate the *drivers aged 65 years and older*. Finally, either Red-RRFBs or LED lights surrounding the Wrong Way signs could assist *tourist* drivers. In addition to the aforementioned countermeasures, new signing and pavement markings (S&PM) could be considered at all the off-ramps. Table 7-1 provides a summary of potential countermeasures that could be considered for deployment at all the off-ramps in Florida.

Table 7-1: Summary of Potential WWD Countermeasures for Consideration by Jurisdiction

Factor Being Addressed	Potential WWD Countermeasures for Deployment Consideration	D1	D2	D3	D4	D5	D6	D7	TPK[1]	CFX[2]	OCX[3]	Total
Impaired Drivers	Red-RRFB + iiRPM	56	164	40	60	88	104	86	84	23		**705**
Drivers Aged 65 & Older	LED + iiRPM	31	44	14	114	54	81	58	158	41	5	**600**
Tourists	Red-RRFB or LED	5	22	7	10	19	14	9	14	5		**105**
No Specific Factor	New S&PM	15	38	15	34	38	9	19	41	21	2	**232**
Total		**107**	**268**	**76**	**218**	**199**	**208**	**172**	**297**	**90**	**7**	**1,642**

[1] Florida Turnpike Authority; [2] Central Florida Expressway Authority; [3] Osceola County Expressway Authority.

Findings from this study provide guidance on a proactive approach for identifying locations that are prone to WWD incidents, and the WWD incident categories to be addressed at these locations. In addition to implementing engineering countermeasures that target specific WWD incident categories, knowing at-risk locations can assist law enforcement agencies and advocacy groups in identifying where to focus their efforts to deploy resources such that their efforts can be most effective.

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APPENDIX A: RELATIVE DENSITIES OF DIFFERENT FACILITY TYPES AT WRONG-WAY DRIVING HOTSPOTS IN EACH DISTRICT

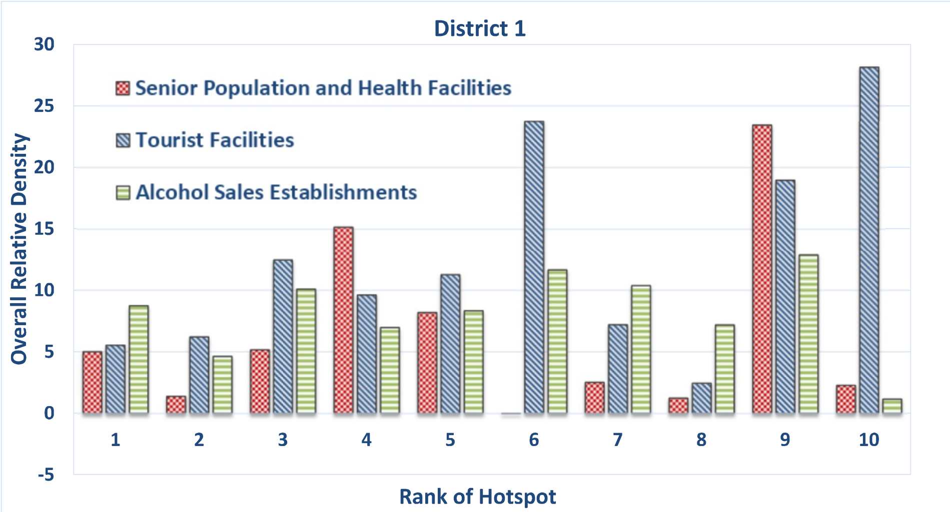

Figure A-1: Relative Densities of Different Facility Types at WWD Hotspots in D1

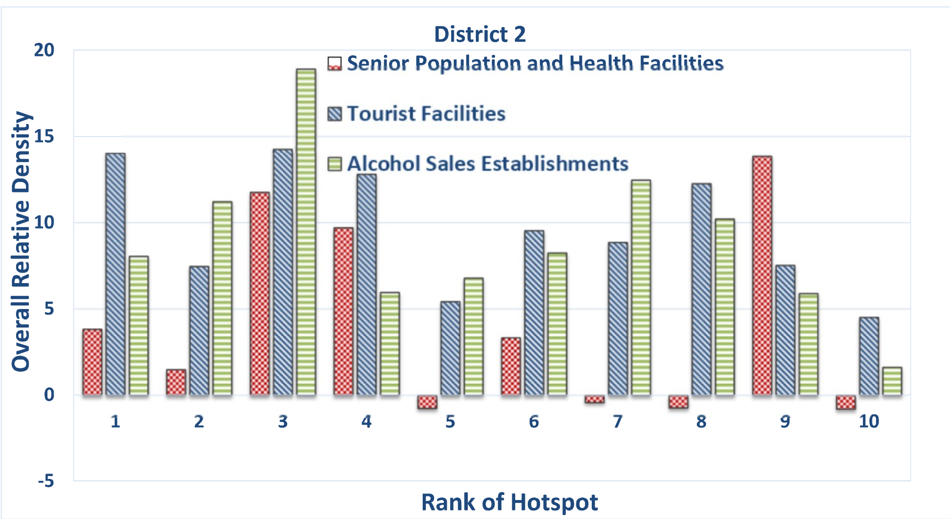

Figure A-2: Relative Densities of Different Facility Types at WWD Hotspots in D2

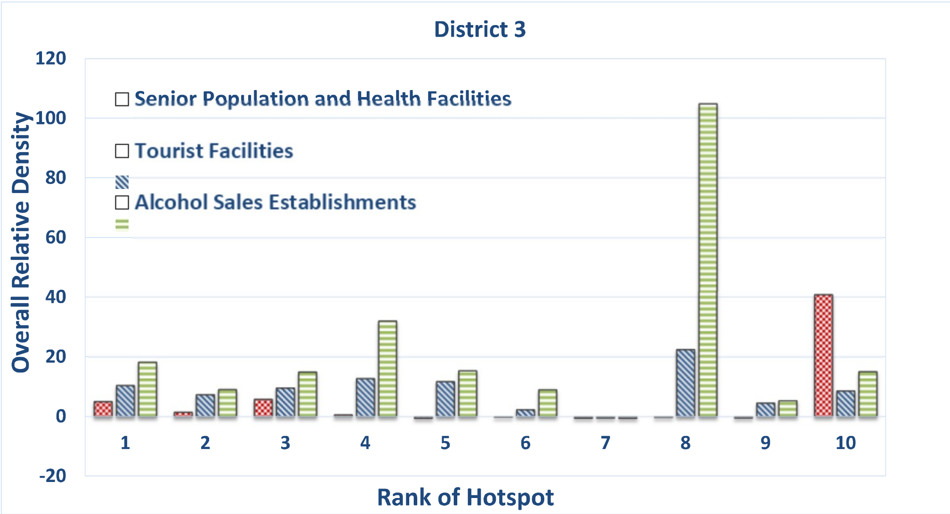

Figure A-3: Relative Densities of Different Facility Types at WWD Hotspots in D3

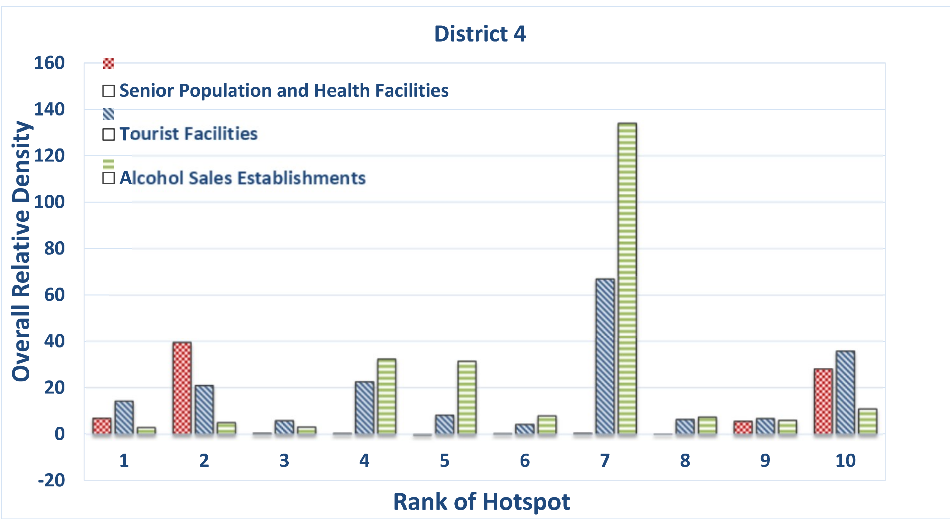

Figure A-4: Relative Densities of Different Facility Types at WWD Hotspots in D4

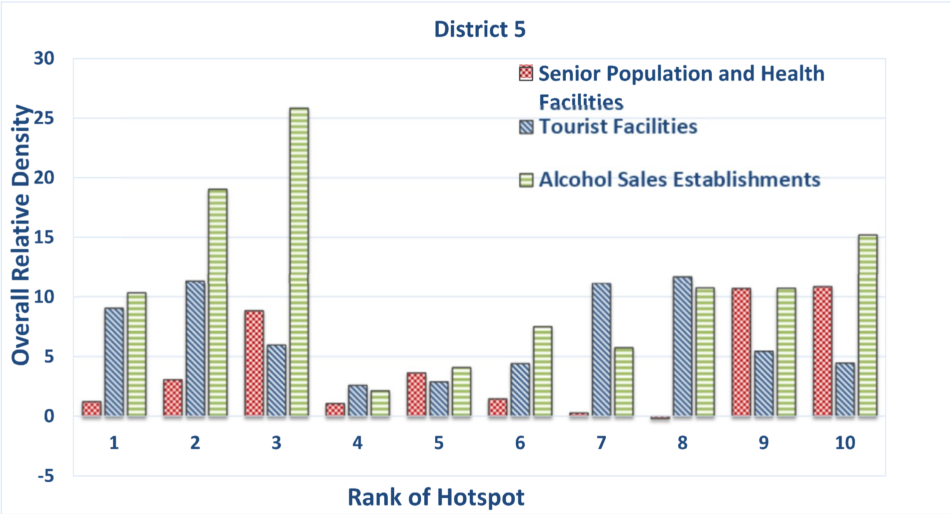

Figure A-5: Relative Densities of Different Facility Types at WWD Hotspots in D5

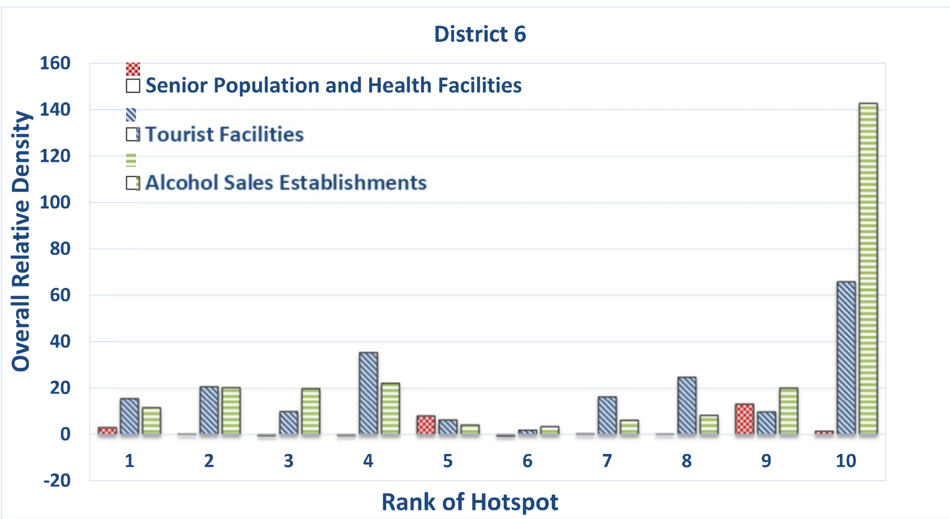

Figure A-6: Relative Densities of Different Facility Types at WWD Hotspots in D6

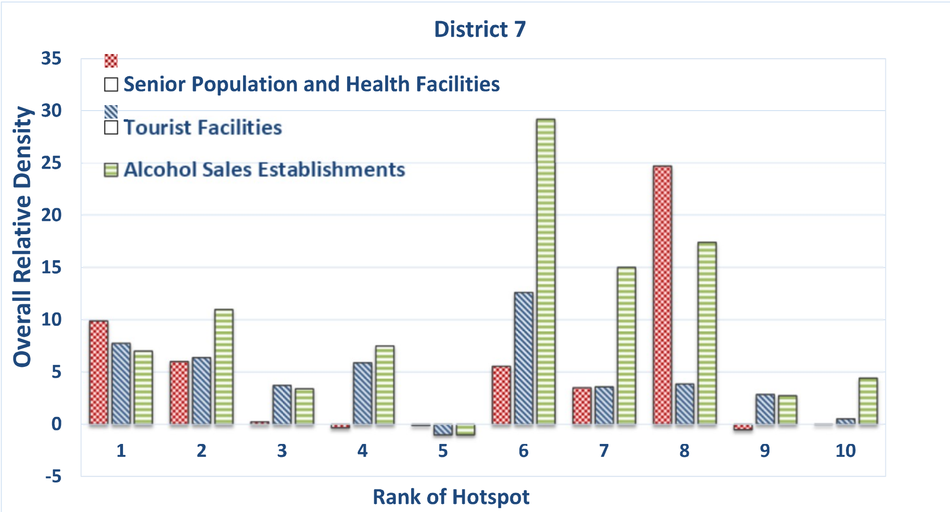

Figure A-7: Relative Densities of Different Facility Types at WWD Hotspots in D7

APPENDIX B: RELATIVE DENSITIES OF DIFFERENT WRONG-WAY DRIVING CRASH CATEGORIES AT WRONG-WAY DRIVING HOTSPOTS IN EACH DISTRICT

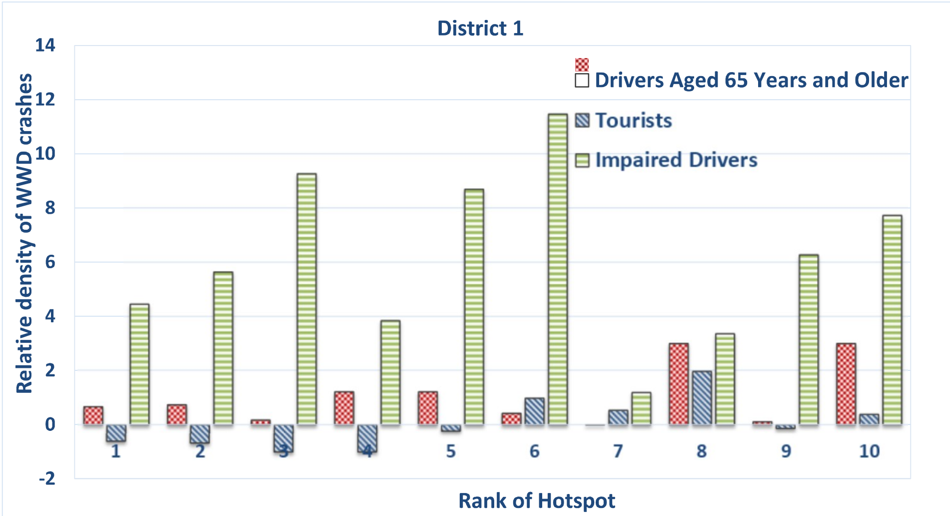

Figure B-1: Relative Densities of Different WWD Crash Categories at Hotspots in D1

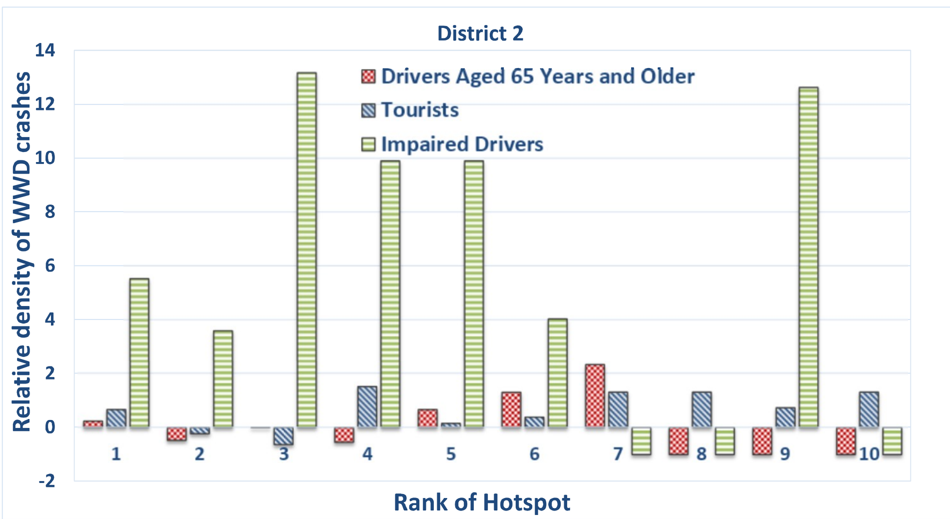

Figure B-2: Relative Densities of Different WWD Crash Categories at Hotspots in D2

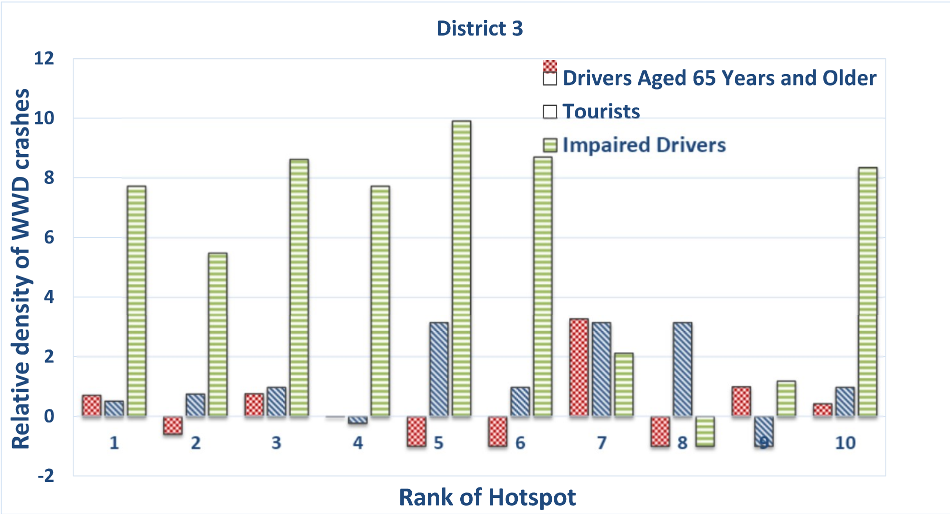

Figure B-3: Relative Densities of Different WWD Crash Categories at Hotspots in D3

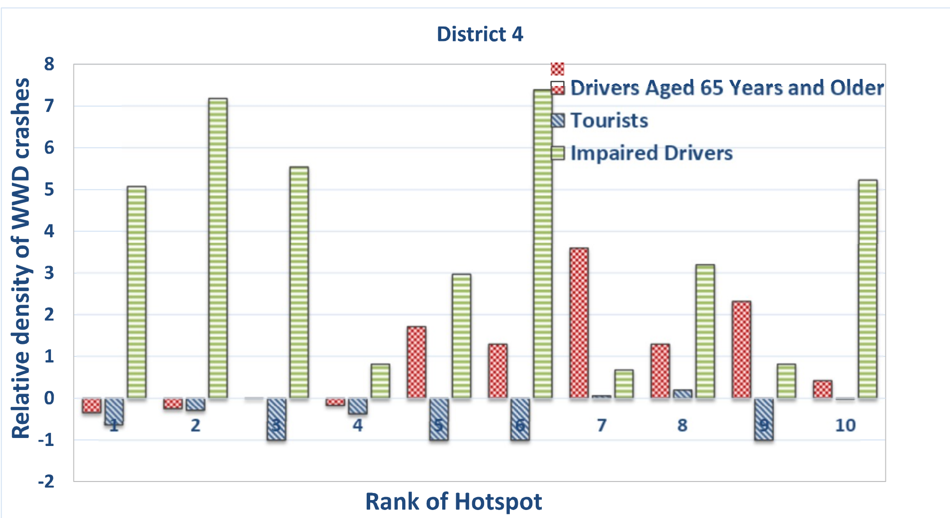

Figure B-4: Relative Densities of Different WWD Crash Categories at Hotspots in D4

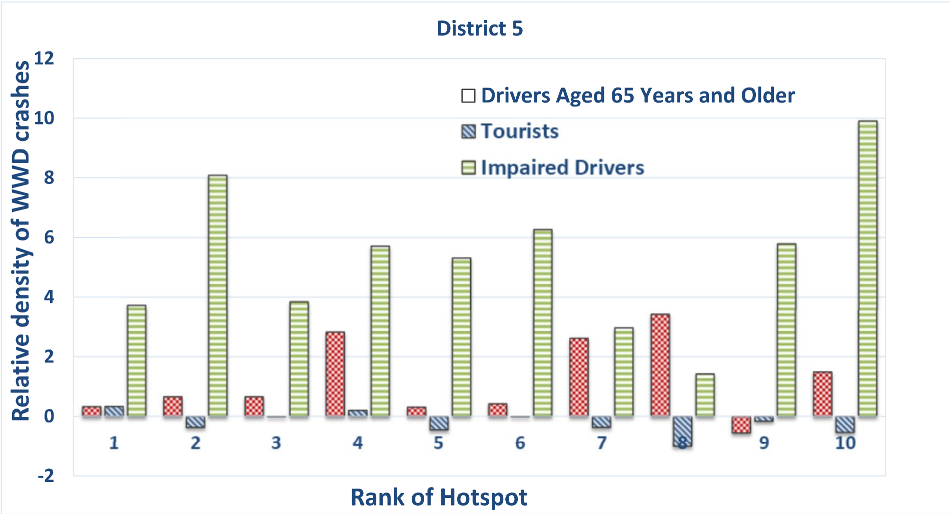

Figure B-5: Relative Densities of Different WWD Crash Categories at Hotspots in D5

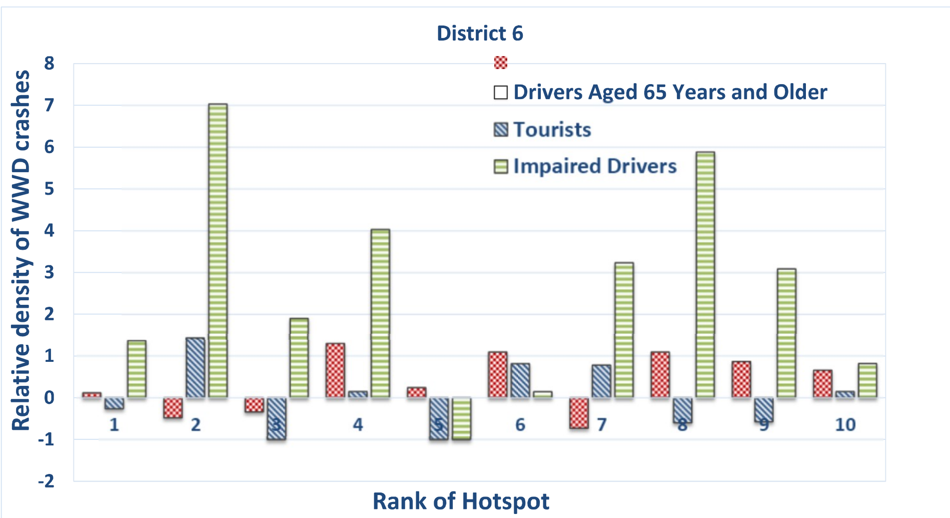

Figure B-6: Relative Densities of Different WWD Crash Categories at Hotspots in D6

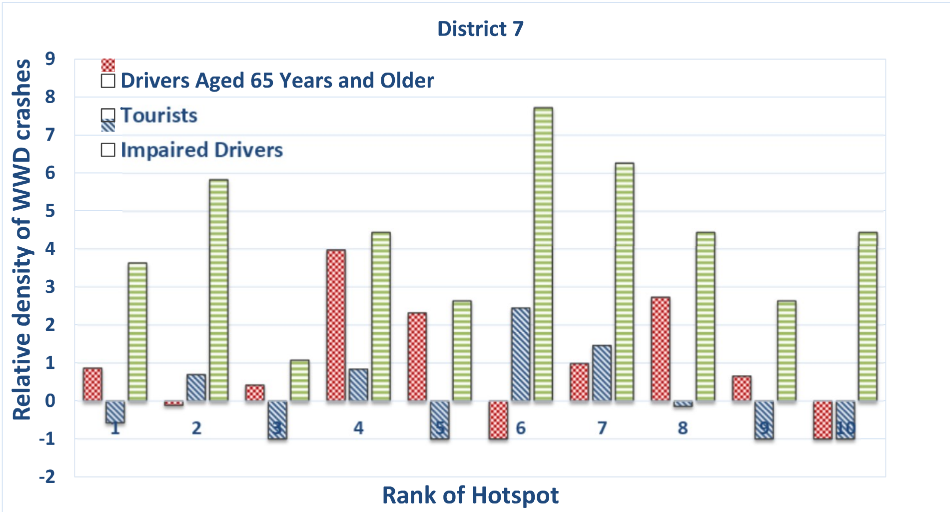

Figure B-7: Relative Densities of Different WWD Crash Categories at Hotspots in D7

APPENDIX C: RELATION BETWEEN DENSITY OF ALCOHOL SALES ESTABLISHMENTS AND WRONG-WAY DRIVING CRASHES INVOLVING IMPAIRED DRIVERS AT WRONG-WAY DRIVING HOTSPOTS IN EACH DISTRICT

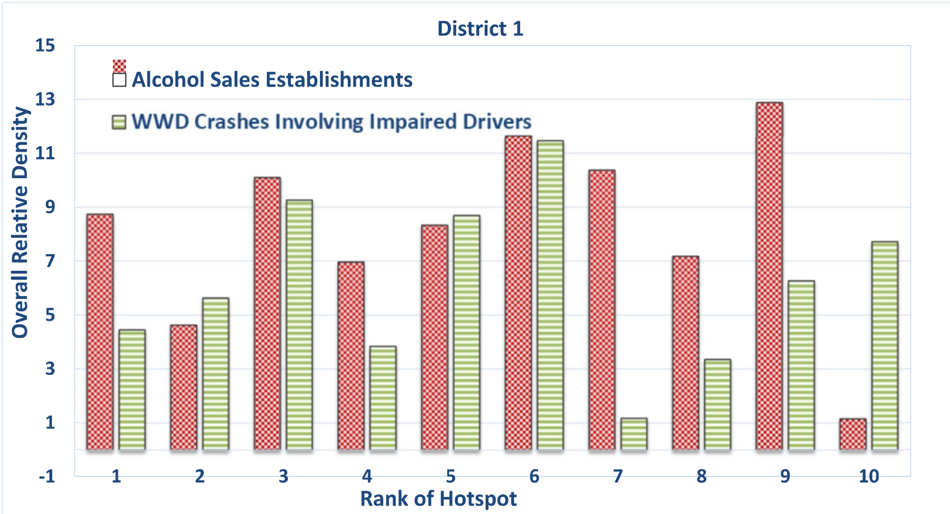

Figure C-1: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D1

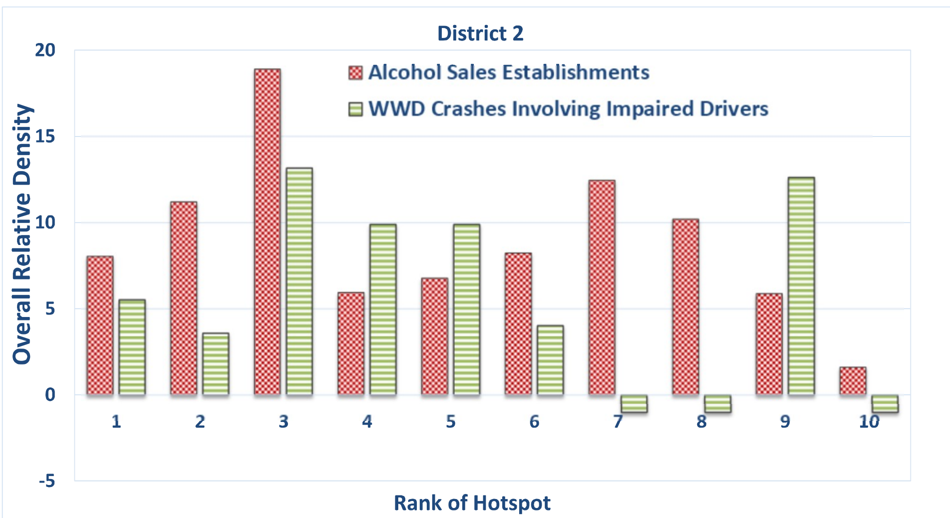

Figure C-2: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D2

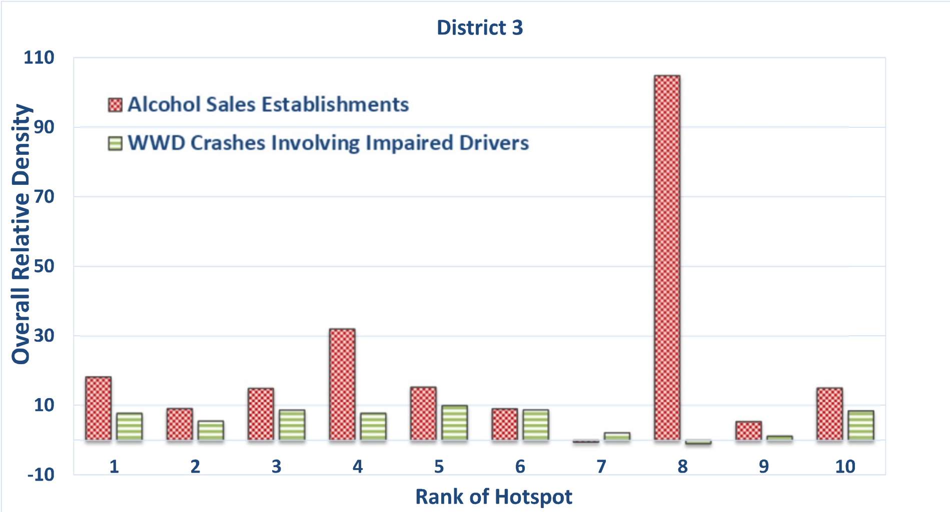

Figure C-3: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D3

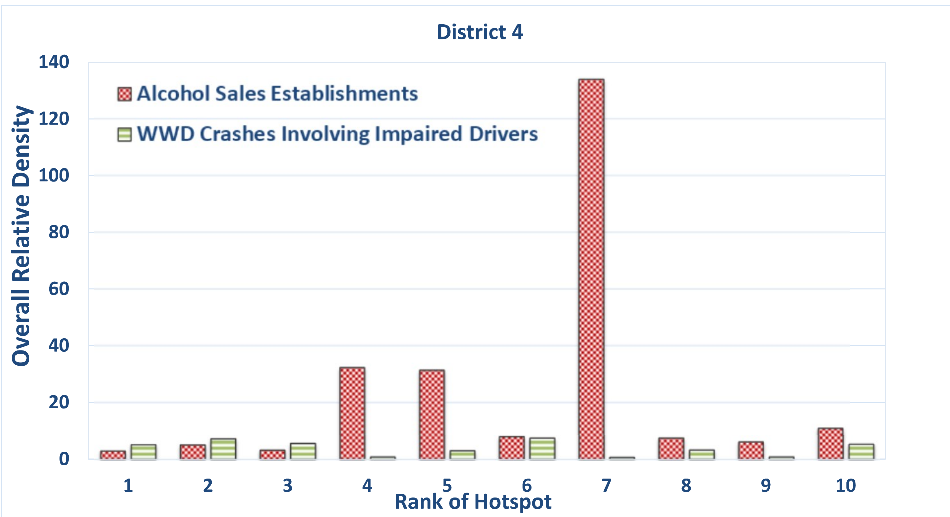

Figure C-4: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D4

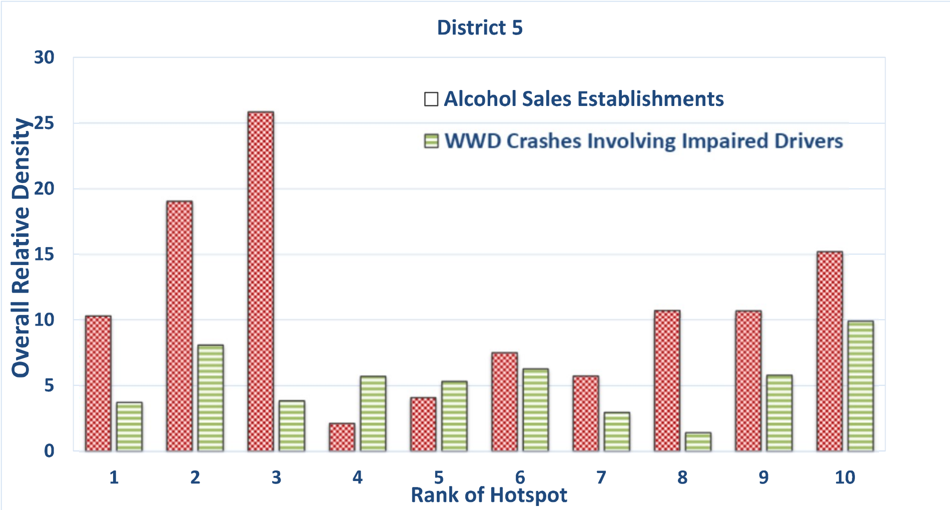

Figure C-5: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D5

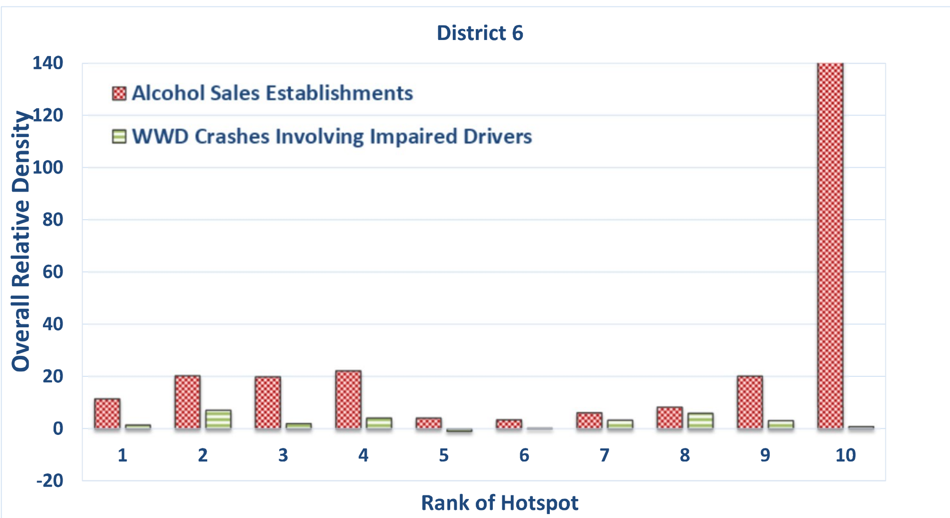

Figure C-6: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D6

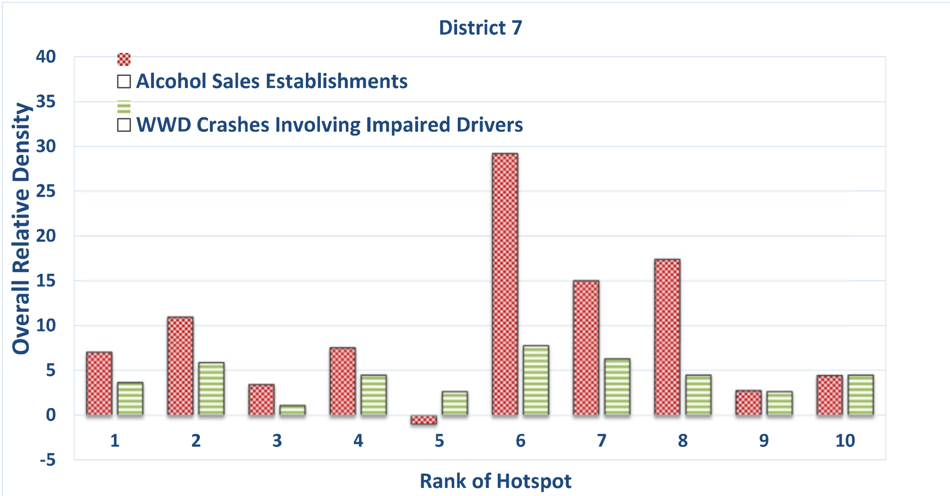

Figure C-7: Relation between Density of Alcohol Sales Establishments and WWD Crashes Involving Impaired Drivers at WWD Hotspots in D7

APPENDIX D: RELATION BETWEEN DENSITY OF SENIOR POPULATION AND HEALTH FACILITIES AND WRONG-WAY DRIVING CRASHES INVOLVING DRIVERS AGED 65 YEARS AND OLDER AT WRONG-WAY DRIVING HOTSPOTS IN EACH DISTRICT

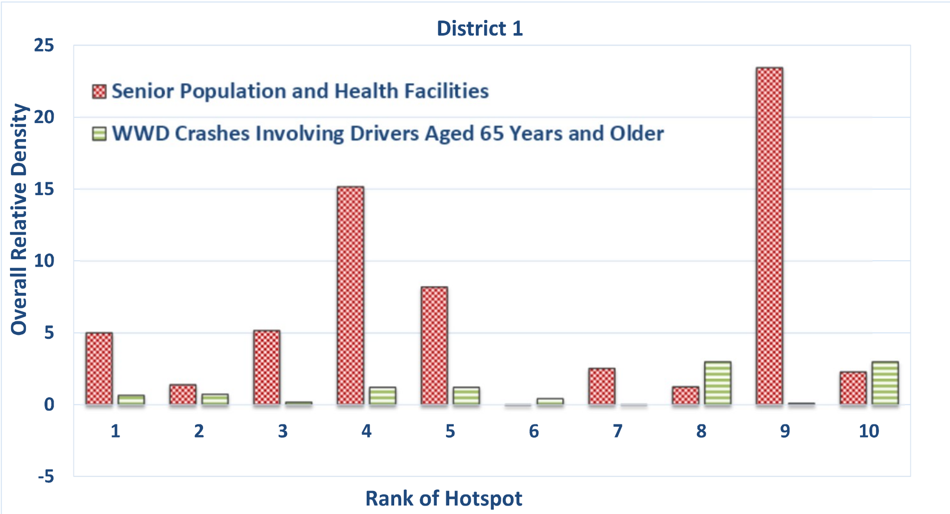

Figure D-1: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D1

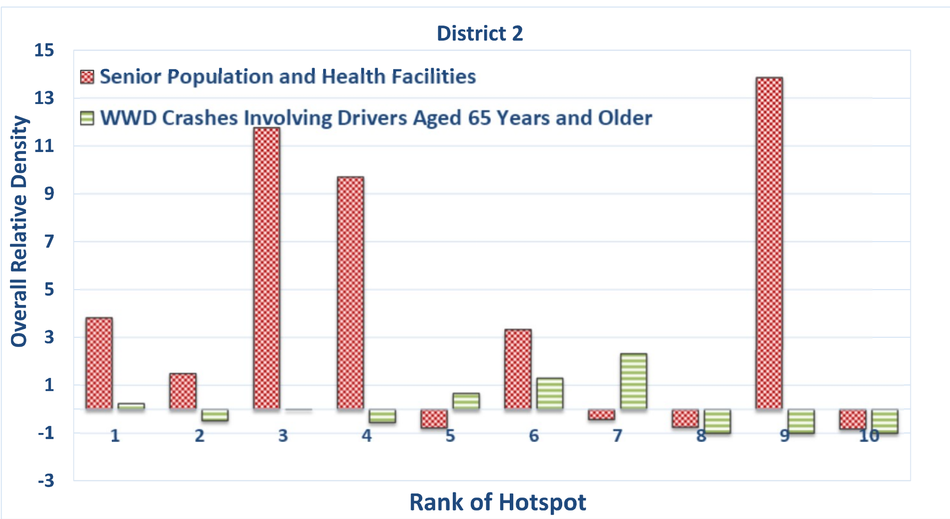

Figure D-2: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D2

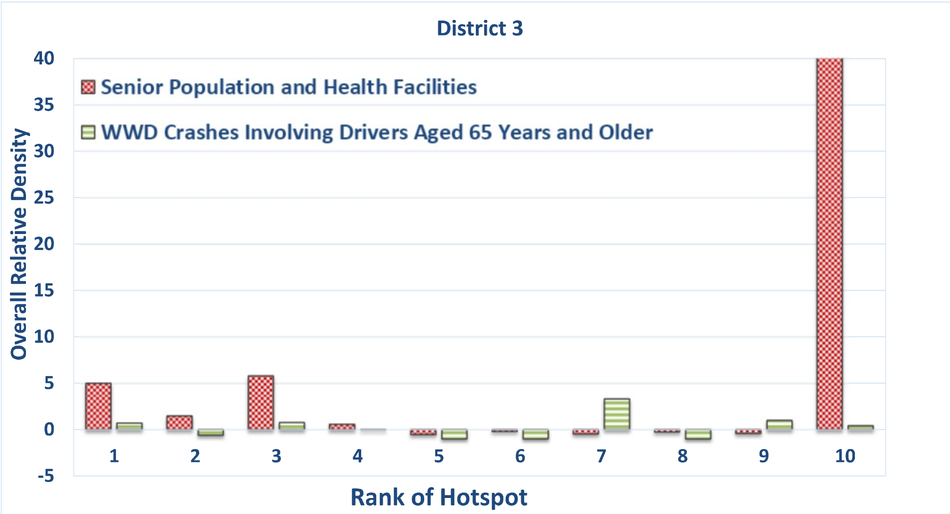

Figure D-3: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D3

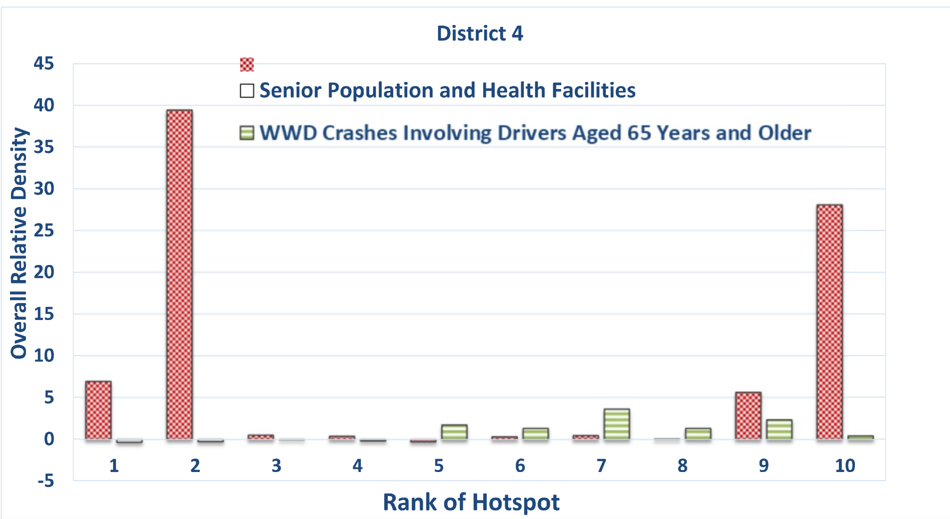

Figure D-4: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D4

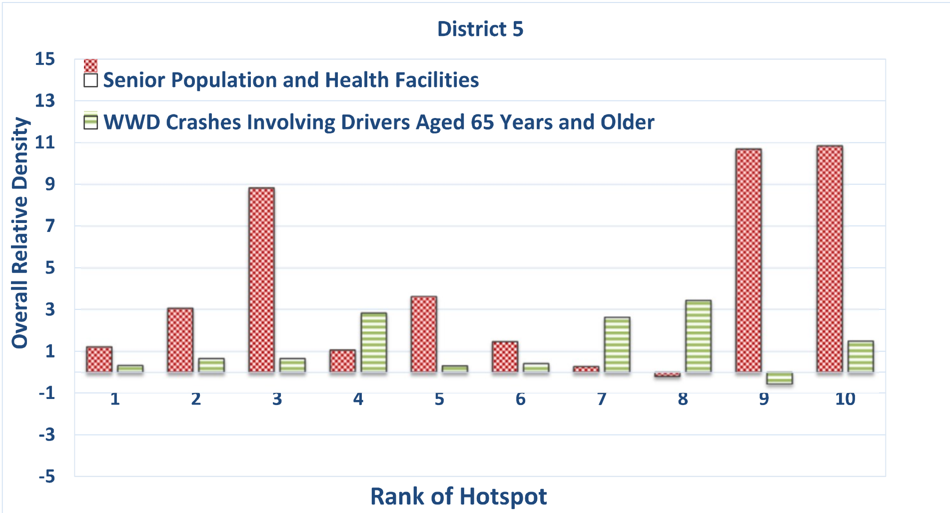

Figure D-5: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D5

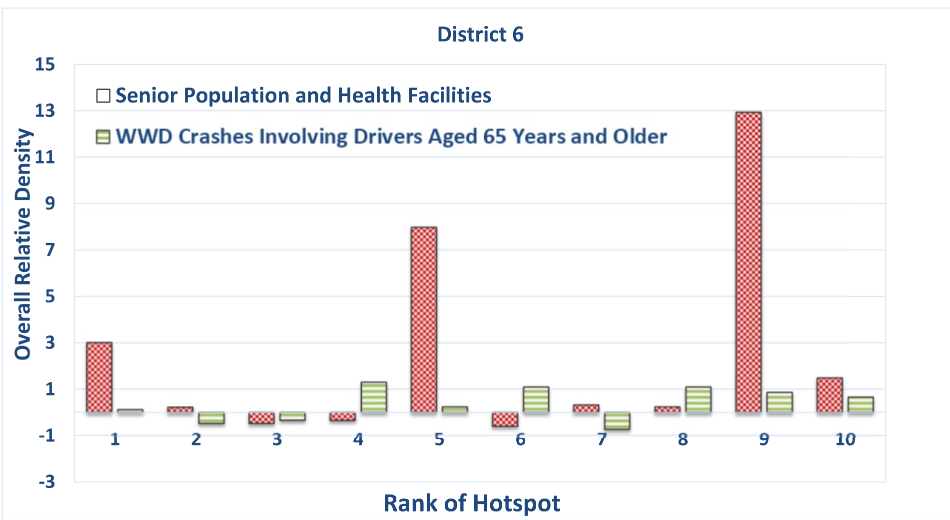

Figure D-6: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D6

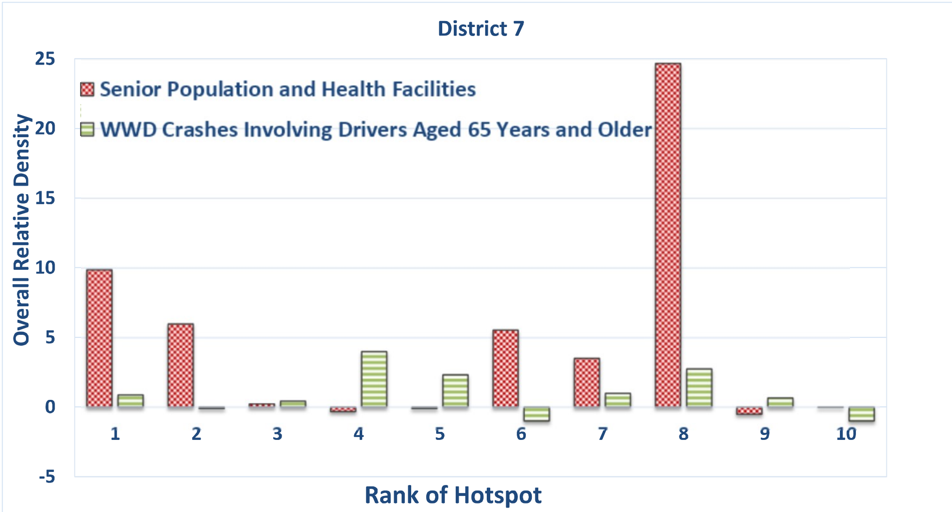

Figure D-7: Relation between Density of Senior Population and Health Facilities and WWD Crashes Involving Drivers Aged 65 Years and Older at WWD Hotspots in D7

APPENDIX E: RELATION BETWEEN DENSITY OF TOURIST FACILITIES AND WRONG-WAY DRIVING CRASHES INVOLVING TOURISTS AT WRONG-WAY DRIVING HOTSPOTS IN EACH DISTRICT

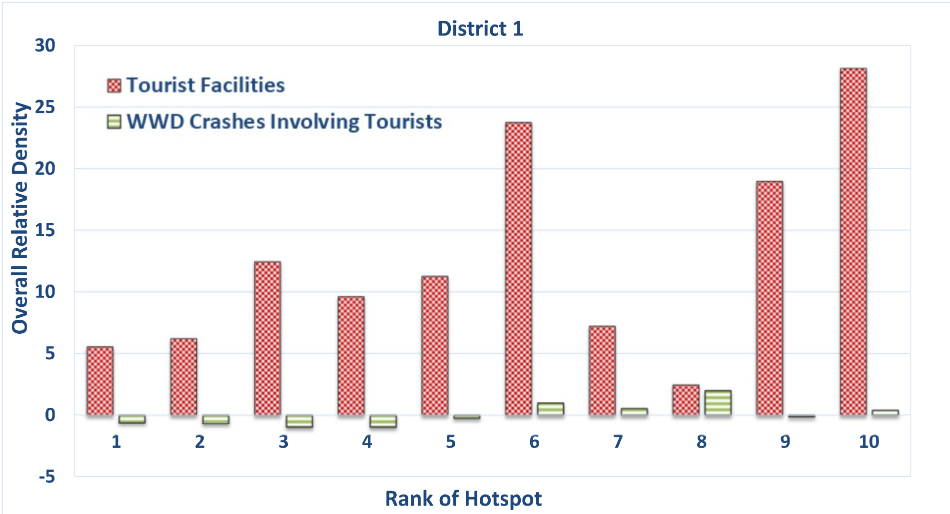

Figure E-1: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D1

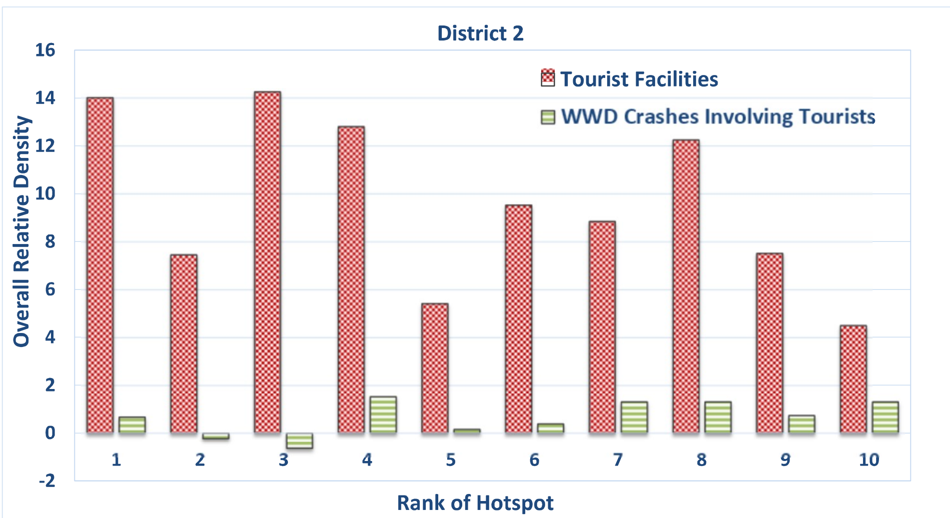

Figure E-2: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D2

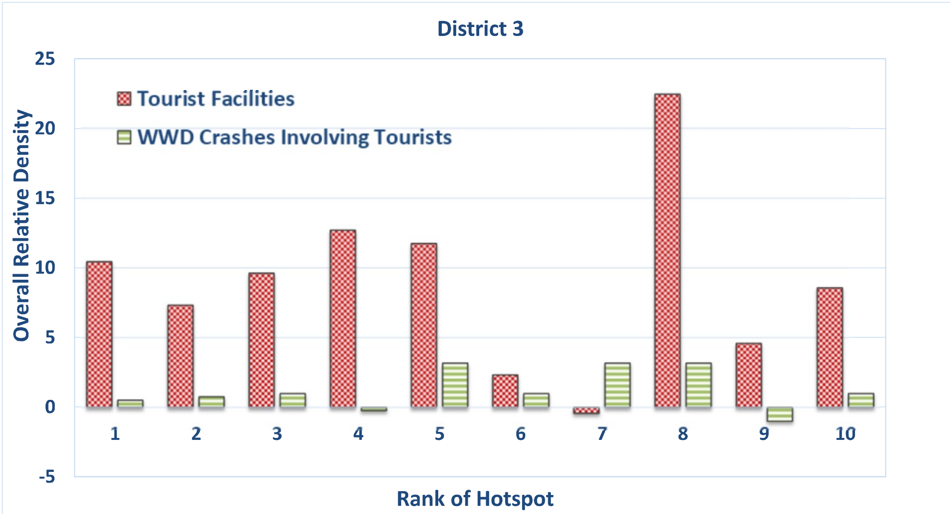

Figure E-3: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D3

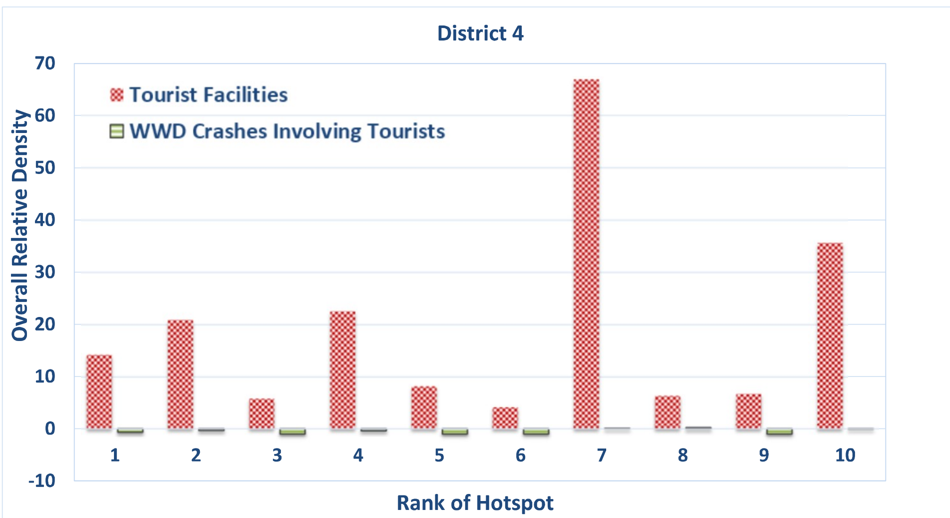

Figure E-4: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D4

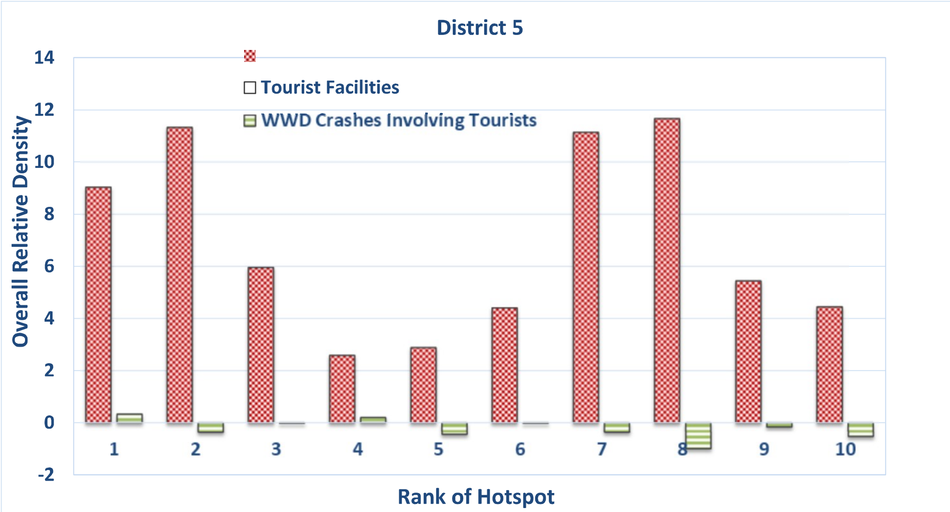

Figure E-5: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D5

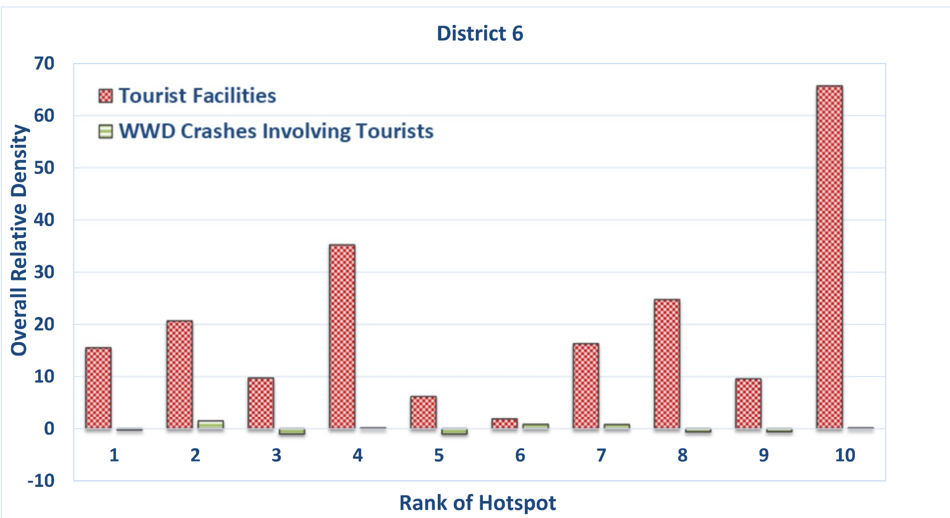

Figure E-6: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D6

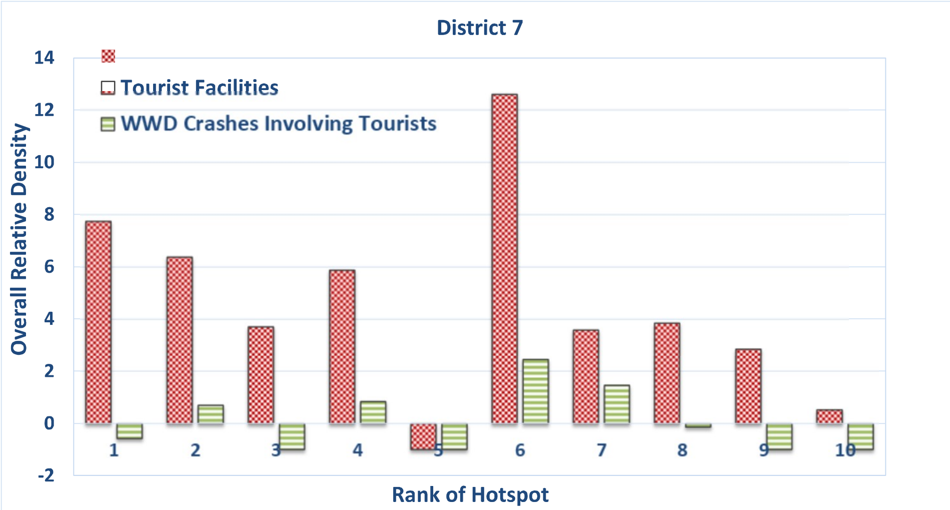

Figure E-7: Relation between Density of Tourist Facilities and WWD Crashes Involving Tourists at WWD Hotspots in D7