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Investigating the Extent of Wrong-Way Driving Events and Identifying Wrong-Way Driving Hotspot Roadway Segments and Lone Wolf Exits with High Wrong-Way Driving Risk on Idaho High-Speed Roadways

RP 306

By

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16. Abstract This project investigated the extent and characteristics of wrong-way driving (WWD) on Idaho limited access roadways. WWD crash (WWC) counts have been increasing in recent years, especially on I-84 and I-90. A model was developed to identify WWD hotspot segments by predicting WWCs based on non-crash WWD citations, exit design characteristics, traffic volumes, and area type. An optimization algorithm was then utilized to identify specific exits within and outside of the hotspots for optimal deployment of WWD countermeasures. The optimization algorithm identified the 81 optimal exit ramps for countermeasure deployment and was shown to improve WWD reduction by 60% compared to only deploying countermeasures in the hotspot segments. Based on the findings from this project, it is recommended for the Idaho Transportation Department to prioritize deployment of WWD countermeasures at these 81 optimal ramps, consider lighting and signage improvements at exit ramp terminals and crossing streets, install treatments at crossing roads to reduce left-turning WWD vehicles where possible, increase law enforcement presence on I-90 and at nighttime if possible to reduce WWCs, standardize the reporting practices for WWCs and WWD citations, collect WWD dispatch reports throughout the state, and conduct additional research on mainline and construction crossover WWCs.		
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Each research project is overseen by a Technical Advisory Committee (TAC), which is led by an ITD project sponsor and project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

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List of Abbreviations and Acronyms

2L	two-leg directional
3L	three-leg directional
AADT	annual average daily traffic
CFX	Central Florida Expressway Authority
DNE	Do Not Enter
DOT	Department of Transportation
EB	eastbound
FD	full diamond
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FTE	Florida's Turnpike Enterprise
GAMS	General Algebraic Modeling System
GEE	generalized estimating equation
GIS	Geographic Information Systems
ISP	Idaho State Police
ITD	Idaho Transportation Department
ITS	intelligent transportation system
LED	light-emitting diode
MAE	mean absolute error
MUTCD	Manual on Uniform Traffic Control Devices
NB	northbound
NCHRP	National Cooperative Highway Research Program
NTSB	National Transportation Safety Board
OD	other diamond
PC	partial cloverleaf
PD	partial diamond
QIC	quasi-likelihood information criterion

RA.....rest area

RFB.....rectangular flashing beacon

RMSE.....root mean squared error

SB.....southbound

SD.....split diamond

SR.....slip ramp

St. d.....standard deviation

SWAAI.....Statewide Asset Attribute Inventory

TAC.....Technical Advisory Committee

TMC.....traffic management center

UCF.....University of Central Florida

UI.....unsignalized intersection

US.....United States

WB.....westbound

WW.....wrong way

WWC .....wrong-way crash

WWCR.....wrong-way crash risk

WWD .....wrong-way driving

Executive Summary

Wrong-way driving (WWD) is a dangerous behavior that can result in severe crashes if not properly treated. On limited access roadways, WWD can originate from exit ramps, mainline crossovers, or other types of maneuvers that result in drivers going against traffic. All of these behaviors can result in WWD crashes (WWCs), but they require different treatments. WWCs which definitely or likely originate from exit ramps are typically the most common, so they were the main focus of this project. Professor Haitham Al-Deek, Ph.D., P.E., and his University of Central Florida (UCF) research team have studied WWD for many years and developed an innovative WWD hotspots modeling and optimization approach to help agencies understand WWD and identify locations with high WWC risk (WWCR). This approach has been applied successfully to multiple Florida limited access roadway networks. In this project, the UCF approach was utilized to identify WWD hotspots and high-risk locations on Idaho limited access roadways. The results of this project can help the Idaho Transportation Department (ITD) understand the influencing factors for WWD and identify appropriate WWD countermeasures and data collection practices to better monitor and reduce WWD in the future.

A thorough literature review of previous WWD research showed that driving under the influence of alcohol/drugs, nighttime conditions (especially with little or no lighting), and older drivers are common factors that increase WWD behavior. WWC and non-crash WWD data, traffic volumes, area characteristics, and design factors all need to be considered in a holistic approach to fully understand and effectively combat WWD since WWCs are rare. Non-crash WWD events (such as law enforcement citations, 911 calls, and traffic management center reports) are often more frequent than WWCs, so they can help identify high-risk locations. Existing and planned WWD countermeasure deployments throughout the United States were also reviewed. Many states have developed their own guidelines for the deployment of intelligent transportation system (ITS) WWD countermeasures at high-risk locations. Wrong Way (WW) signs equipped with rectangular flashing beacons (RFBs) or light-emitting diodes (LEDs) have been proven to be especially effective at causing WW drivers to turn around before reaching the mainline. Lessons can also be learned from WWD countermeasure deployments in states near Idaho (Oregon, Nevada, Utah, and Arizona).

To apply the WWD hotspots and modeling approach to Idaho, detailed roadway data and WWD event data were collected. Six limited access roadways were studied (I-90, I-84, I-184, I-86, I-15, and the portion of US 20 from I-15 to Cottonwood Drive), with each direction of these roadways considered separately. Macroscopic, microscopic, and WWD countermeasure data were collected for all exits on these roadways. Macroscopic data included exit location, crossing roads, area type, interchange design, number of exit ramps, and traffic volumes. Microscopic data included various exit ramp, crossing street, and entrance ramp design characteristics (lighting, number of lanes, median presence, relative locations of the exit and entrance ramps, etc.). The WWD countermeasure data included the types, quantities, and locations of signage and pavement markings which could reduce WWD on the exit ramps and crossing streets. These data showed that diamond interchanges were most common, many exit ramps did not have sufficient lighting, crossing roads often did not have medians to stop drivers from making

WW left turns onto exit ramps, and WW signage was limited on crossing roads. Making improvements to lighting, median design, and WW signage could help reduce WWD.

The WWD event data consisted of WWCs, citations issued to WW drivers by Idaho State Police (ISP), and ISP WWD dispatch reports for I-90 in ITD District 1. Over 6,000 potential WWCs in Idaho from 2009-2023 were collected, with this number reduced to 202 limited access WWCs after filtering. Only 55% of these crashes were reported as WWCs in the crash reports, indicating the need for more consistent reporting practices in the future. The number of WWCs has substantially increased since 2019, agreeing with Idaho's large population growth in recent years. Compared to Florida data from 2018-2023, Idaho had higher WWC rates per million people and million licensed drivers, indicating the need for WWD treatments in Idaho. Most WWCs occurred on I-84 and I-90, during evening and nighttime hours, and in winter months. Approximately 45% of the WWCs started on the mainline or in a construction crossover (with many being caused by snowy or icy conditions). Further research on mainline and construction WWD is needed to fully understand these events and effective treatments. Almost half of the WWCs had fatal or serious injuries, showcasing the devastating impacts these crashes can have. I-84 and I-15 had many unknown origin WWCs, so WWD detection devices could be beneficial to better understand WWD on these roadways.

ITD provided the UCF research team with statewide ISP citations and WWD complaint reports from District 1. The citation data contained 2,335 citations from April 2018 through January 2024 for six Idaho statutes potentially related to WWD; this count was reduced to 102 limited access WWD citations after filtering. These non-crash WWD citations were issued for three different Idaho statutes (49-630, 49-636, and 49-645) and did not contain latitude or longitude coordinates, so it is recommended to improve the reporting of these citations to make the data more consistent and easier to locate. Analyses suggested that increased law enforcement presence could help reduce WWCs, especially on I-90 and at nighttime. Most citations had exit ramp or unknown origins, but 27% were caused by drivers turning WW on the mainline to avoid congestion. I-84 WB Exit 168 at Golf Course Rd. had multiple WWCs and WWD citations. For the ISP WWD dispatch data, there were 32 reports from January 2019 through September 2023 after filtering. There were many reports in 2023, which could be due to increased WWD or better reporting of WWD events. It is recommended to collect similar reports for all ITD Districts and limited access roadways to obtain a comprehensive understanding of WWD in Idaho.

Using the collected roadway and WWD event data, the UCF WWD hotspots modeling and optimization approach was applied to Idaho's limited access roadways. First, a WWD hotspots model was developed to predict the number of WWCs on multi-exit roadway segments based on statistically significant non-crash WWD events, traffic volumes, area type, and exit design characteristics. Only exit ramp and unknown origin WWCs and WWD citations from 2018-2022 were considered for this model. Each ITD limited access roadway direction was split into multi-exit overlapping roadway segments for modeling to help account for the uncertainty in WWD origins. Generalized estimating equations were used to develop Poisson and negative binomial models to predict WWC frequency for a five-year period on each segment, as these equations can account for the correlation between overlapping roadway segments since the overlapping caused segments to be correlated. The final model results indicated that a

negative binomial model with 6-exit segments was the most accurate based on various performance measures.

This WWD hotspots model showed that segments with higher crossing street volumes, a higher number of exit ramps with right angles between the ramp and the crossing street, at least one WWD citation, at least one split diamond interchange, and which were located in primarily rural areas were predicted to have more WWCs. Segments with a higher number of exit ramps which merged directly onto the crossing street rather than meeting the crossing street at an intersection, at least one other diamond interchange, at least one exit where the crossing street had a grass median for potential left-turning WW vehicles, and at least one exit ramp with an associated entrance ramp not located directly adjacent to or across from it were predicted to have fewer WWCs. The actual and predicted WWC counts for each segment were added together to obtain WWCR values, which were used to identify 36 WWD hotspot segments with 80 unique Idaho exits (85 exit ramps).

Next, the WWCR reduction lone wolf optimization algorithm was used to identify specific high-risk exits, including hotspot exits and lone wolf exits outside of the hotspots. WWD events with unknown origins were distributed to the nearest possible WWD entry points based on the distances traveled by WW drivers in Idaho to estimate the proportion of WWD in each roadway segment due to each exit. These proportions and the segment WWCR values were used by the optimization algorithm to estimate the annual potential WWCR reduction for all modeled Idaho exit ramps. Comparing the 85 ramps with the highest WWCR reduction potential to the 85 hotspot ramps showed that the optimization algorithm identified 37 lone wolf exits (potential to improve resource utilization by 43.5%) and improved WWCR reduction by 60%. Deploying WWD treatments at 81 exit ramps would provide the largest difference between the percentage of maximum possible WWCR reduction (82.22%) and percentage of ramps selected (24.11%), indicating that 81 ramps is the optimal number of ramps for additional WWD countermeasure deployment. Life-cycle benefit-cost evaluations were also conducted on advanced RFB and LED WWD countermeasures using data from implementations in Florida to estimate their potential benefits for Idaho. Deploying two sets of RFBs had an estimated life-cycle benefit-cost ratio of 65.85 when deployed at the 81 optimal exit ramps compared to an estimated life-cycle benefit-cost ratio of 33.12 for deploying one set of LEDs at the same 81 optimal exit ramps. However, the actual results could vary for Idaho due to differences in costs and effectiveness between Florida and Idaho.

Overall, the results and recommendations from this project can help ITD best reduce WWD on limited access roadways in the future. Understanding the characteristics which most influence WWC frequency can help ITD determine appropriate treatments and design practices for the future. Making improvements to existing low-cost WWD countermeasures, modifying exit ramp and crossing design features, and deploying multiple sets of RFB ITS WWD countermeasures at the high-risk exits identified by the optimization algorithm are all effective methods to treat WWD. ITD should revisit the WWD hotspots model and optimization algorithm every few years using the most recent data to best plan WWD countermeasure deployments. This will ensure that ITD is proactive and cost-effective in combatting the dangerous WWD problem to reduce traffic delays and save lives for Idaho travelers.

1. Introduction

Driving the wrong way (WW) on limited access roadways is one of the most dangerous actions drivers can make. While crashes due to WW driving (WWD) are rare, they often result in serious injuries or fatalities. The National Transportation Safety Board (NTSB) (2012, 1) reported that WW crashes (WWCs) only make up about 3% of highway crashes. However, WWCs result in around 500 fatalities per year in the United States (US) (Federal Highway Administration [FHWA] 2020). Identifying the factors that increase WWC frequency and determining locations with high WWC risk (WWCR) is important to effectively deploy WWD detection and countermeasure systems.

The Idaho Transportation Department (ITD) has been concerned about the extent of WWD on Idaho limited access roadways in recent years. To address these concerns and better understand WWD in Idaho, ITD hired Professor Haitham Al-Deek, Ph.D., P.E., and his research team at the University of Central Florida (UCF) to investigate and analyze WWD events on Idaho limited access roadways. This final report represents the culmination of these research efforts.

The main goal of this research project was to help ITD determine the extent of the WWD problem, understand potential contributing causes, identify locations with high WWCR, and provide recommendations for improved WWD data collection and mitigation on Idaho limited access roadways. The results and findings from this research will help ITD better understand WWD and cost-effectively deploy WWD countermeasures to reduce WWD in the future. To achieve this goal, the following research objectives were met:

- Review previous studies to identify the methods used for analysis and modeling of WWD events, approaches used to determine WWD hotspot locations, and results of WWD countermeasure deployments throughout the US.
- Collect and analyze roadway and WWD event data to identify common trends and characteristics of WWD on Idaho limited access roadways.
- Review existing WWD signage and pavement markings at Idaho limited access exit ramps to identify potential low-cost improvements.
- Develop a WWD hotspots model to predict WWCs on multi-exit roadway segments based on statistically significant factors, including non-crash WWD events, interchange designs, traffic volumes, area type, and microscopic exit ramp characteristics.
- Identify WWD hotspot segments with high WWCR using the results of the WWD hotspots model.
- Develop a WWCR reduction lone wolf optimization algorithm to identify individual exits with high WWCR for priority treatment.

- Evaluate the potential benefits and costs of deploying advanced WWD countermeasures at Idaho limited access exit ramps.
- Recommend effective treatments and improved data collection practices to help ITD better monitor and mitigate WWD in the future.

This report discusses the methods, procedures, and results utilized and obtained by the UCF research team to achieve these objectives. Chapter 2 contains a detailed literature review of WWD studies and countermeasure deployments throughout the US, including prior successful applications of the innovative WWD modeling and optimization approach developed by Professor Al-Deek and his UCF research team. Chapter 3 discusses the collected roadway data, including a review of existing signage and pavement markings which could help reduce WWD on Idaho limited access exit ramps. In Chapter 4, the methods used to collect WWC and non-crash WWD events data are discussed, along with detailed analyses of these data. Chapter 5 discusses the procedures and results of the WWD hotspots model and the WWCR reduction lone wolf optimization algorithm, including evaluations of rectangular flashing beacon (RFB) and light-emitting diode (LED) WWD countermeasures. Chapter 6 summarizes the major findings from this project and contains a list of recommendations to help ITD effectively combat WWD in the future. Lastly, Chapter 7 contains all the references cited in this report. Additionally, supplementary data files and programming code for the WWD hotspots model and WWCR reduction lone wolf optimization algorithm were submitted to ITD along with this report.

Before discussing the details of this project, it is important to have a clear definition of WWD. In this project, an event (crash, citation, or dispatch report) was considered to be a WWD event if it involved any driver actions which resulted in a driver going the WW on a limited access roadway. These actions included, but were not limited to, the following: drivers turning WW onto an exit ramp, drivers crossing over the median to go WW on the mainline, drivers going left of center in a limited access construction zone where both travel directions are on the same side of the roadway, and drivers turning WW on the mainline after missing an exit. Different deterrent and treatment strategies are needed for different types of WWD behavior. This project was focused on WWD at exit ramps, so WWD events which were definitely or likely caused by drivers turning WW onto exit ramps were the primary consideration. Other types of WWD events (such as mainline and construction crossovers) were considered when analyzing WWD events as a whole (with some separate analyses of these events), but they were not considered in the modeling and optimization efforts. These types of WWD events require separate research to fully understand their characteristics and potential treatments.

It is also important to define some general terminology that is used throughout this report to avoid potential confusion. In this report, the term “interchange” refers to the entire set of on-ramps and/or off-ramps that lead to or from the same crossing roadways for both directions of a limited access roadway. The term “exit” refers to all exit ramps for the same direction of the limited access facility at a particular interchange, while the term “exit ramp” refers to a specific off-ramp from the limited access mainline which drivers use to reach arterials or other roadways at an interchange and the term “exit ramp terminal” refers to the location where the exit ramp meets the crossing roadway. Similarly, the

term “entrance ramp” refers to a specific on-ramp connecting a roadway to the limited access mainline which drivers use to reach the mainline and the term “entrance ramp opening” refers to the location where the entrance ramp meets the crossing roadway and drivers can enter the entrance ramp. Additionally, corresponding exit and entrance ramps refer to ramps that lead drivers away from or towards the same limited access facility direction. For example, Figure 1.1 shows the interchange at I-90 and W. Pointe Parkway. This interchange contains an exit for I-90 eastbound (EB) and an exit for I-90 westbound (WB). Both the I-90 EB and I-90 WB exits each contain one exit ramp (circled in red in Figure 1.1) and one entrance ramp (circled in yellow in Figure 1.1). Figure 1.2 shows the exit ramp terminals (circled in red) and entrance openings (circled in yellow) for each of these ramps.

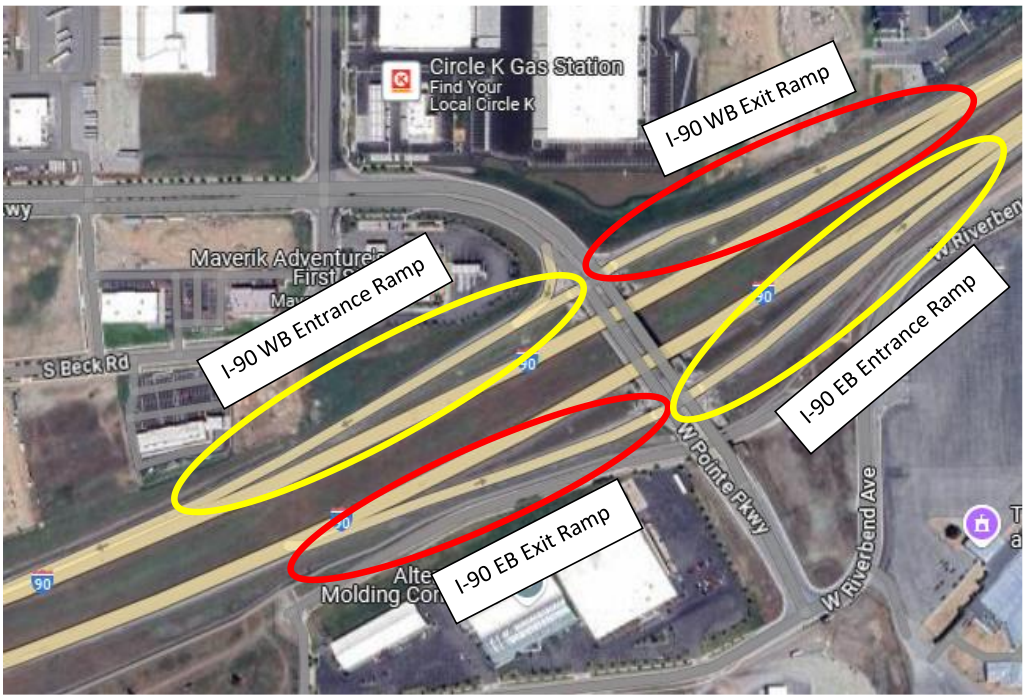

Figure 1.1 Example interchange, entrance ramps, and exit ramps at I-90 and W Pointe Parkway

Figure 1.2 Example exit ramp terminals and entrance ramp openings at I-90 and W Pointe Parkway

2. Literature Review

Understanding the state of the art and practice regarding WWD analysis, modeling, and countermeasure deployment was important to meet the objectives of this project. The methods and results from previous WWD research were used to shape the data collection methods, modeling and optimization procedures, and recommendations discussed in this report. This chapter discusses the thorough literature review that the UCF research team conducted on WWD event analysis, WWD hotspot identification, applicable statistical and optimization methods, WWD countermeasure guidelines and effectiveness, and ongoing WWD research projects and countermeasure deployments throughout the US. The findings from this literature review helped the UCF research team understand what research has been done (including strengths and weaknesses of past research) and what other states and agencies are doing to combat the WWD problem to ensure that this project's methods were comprehensive, accurate, and appropriate for Idaho's available WWD data and limited access roadway characteristics.

WWD Event Analysis, Modeling, and Identification of WWD Hotspots and Lone Wolf Exits

To effectively reduce WWD, it is first important to understand the extent of the problem and common factors which impact WWD frequency and severity. The rarity of WWCs means that they should not be relied on as the only measure of WWD activity. A holistic approach which incorporates WWCs, non-crash WWD events (law enforcement citations, 911 calls, traffic management center [TMC] logs, WWD detection data, or other sources of WWD activity as shown in Sandt et al. 2015, 100), interchange and ramp design characteristics, traffic volumes, and regional factors (area type, interchange density, etc.) will allow for the most comprehensive understanding of WWD. Analyzing and modeling these holistic data rather than only one or two types of data (such as only WWCs and ramp design) will help agencies better identify locations with high WWCR and cost-effectively deploy WWD countermeasures. This section first discusses various analyses of WWCs and non-crash WWD events conducted in different states for various potential influencing factors (such as driver characteristics, temporal factors, roadway design elements). Then, previous modeling approaches used to identify WWD hotspots in the US and internationally are discussed, with a focus on the WWCR modeling and optimization approach developed by Professor Al-Deek and his UCF research team. This approach has been successfully applied to multiple limited access roadway networks in Florida. Lastly, modeling and optimization approaches used in non-WWD related studies are discussed to show how these methods helped shape the modeling and optimization approach utilized in this project. The studies referenced in this chapter are mainly ones conducted within the last ten years to help ensure that the design practices and driver characteristics from these studies are consistent with present day conditions.

WWC analyses

Many studies have analyzed limited access WWCs in a specific state to determine common characteristics. An analysis of WWD on freeways in Michigan found that 60% of 101 WW drivers were intoxicated with alcohol, drugs, or both. For WWCs, 54 of 60 happened at night, with 57% of all WWCs and 71% of fatal and severe WWCs occurring between 11 p.m. and 6 a.m. (Morena and Leix 2012). An evaluation of one million crash records in Florida from 2003-2010 found that more WWCs involved male WW drivers than female WW drivers and the weekend had a higher chance of WWCs (total and fatal only) compared to weekdays (Ponnaluri 2016b, 107). In Alabama, an analysis of 93 WWCs on freeways and multilane divided highways from 2009-2013 was conducted using Haddon matrices. The results showed that male drivers, drivers who were impaired or under the influence of alcohol or drugs, and drivers aged 65 years and older were more likely to cause a WWC, especially during nighttime or evening hours. (Alabama Department of Transportation [DOT] 2018, 67-69). A driver simulator study in Japan also showed that diminished mental capabilities in older drivers was an important factor in WWD behavior (Nihei et al. 2022, 70). In Kansas, an analysis of 372 WWCs from 2005-2015 on divided highways showed that driver intoxication, absence of lighting at nighttime, the use of safety devices like seatbelts, and driver age being from 46-55 or over 74 years old were all significant factors which increased WWC severity (Fitzsimmons et al. 2019, 239-240).

Some studies have also been done using WWC data from multiple states and for both limited access and non-limited access facilities. A National Cooperative Highway Research Program (NCHRP) study analyzed and compared WWD crashes on high-speed divided highways in California (66 WWCs from 2008-2011), Texas (201 WWCs from 2012-2014), and Florida (160 WWCs from 2010-2013). The Texas and Florida datasets were similar in that 57% or more of the studied WWCs resulted in a serious injury or fatality. However, only 32% of the studied WWCs in California resulted in a serious injury or fatality. Overall, 53% of WWCs on high-speed divided highways occurred on Friday, Saturday, and Sunday (NCHRP 2018, 8-9). A study of 398 WWCs in Alabama and Illinois showed that WWCs in rural areas resulted in more severe injuries compared to WWCs in urban areas, with time of day, driver and vehicle age, driver condition, roadway surface conditions, type of crash and vehicle, lighting conditions, airbag status, and seatbelt use all associated with WWC severity (Jalayer et al. 2018, 133-134). Since Idaho is primarily rural, it is especially important to properly analyze and model WWD events on Idaho limited access roadways so these severe WWCs can be reduced. Rural areas were also found to have more fatal WWCs than urban areas in a study by Ponnaluri (2018) which compared fatal and non-fatal WWCs between arterials and freeways. This study examined approximately 3,800 WWCs and found that WWCs were more likely to involve male drivers and drivers aged 21-40 years old, with higher blood alcohol concentration levels more likely to result in WWCs and fatalities for both arterials and freeways. Most WWCs occurred between 6 PM and 6 AM, with the presence of street lightning and rainy weather decreasing the likelihood of a WWC occurring (Ponnaluri 2018, 15-16). Another study applied an Eclat association rule learning algorithm to identify the relationship between different factors which influenced WWCs on freeway exit ramps and low-speed roadways for five years of WWC data in Louisiana containing 1419 WWCs. A data mining approach utilizing a random forest algorithm and simple convex optimization

method was used to identify significant factors. The most significant factor among 20 identified rules was driver impairment, with other significant characteristics that increased WWC frequency being signalized intersections in business areas; two-way roadways with no physical separation; higher speed limits; and improper markings, signs, or alert systems on exit ramps (Das et al. 2018, 118-122).

Research has also been done on the impacts of ramp design on WWCs. However, this research has typically focused on specific interchange types (full diamond [FD] and partial cloverleaf [PC]), making the studied WWC sample sizes small and providing weak results that would likely be different for states outside the area of study. In one study, 172 PC exit ramps with parallel entrance ramps in Alabama and Illinois were analyzed. There were 65 WWCs from 2004-2013 at these ramps, with 118 ramps having no WWCs, 43 ramps having one WWC, and 11 ramps having two WWCs during this ten-year period (Alabama DOT 2018, 27). A binary logistic regression model was used to identify significant design factors and it found that ramps with an exit ramp corner radius of more than 80 feet, the presence of traversable medians on the crossing road, and median widths of less than 30 feet between parallel entrance and exit ramps at the studied PC interchanges were more likely to have WWCs. The model had a very low pseudo-R^2 value of 0.131, indicating that it did not fit the data well (likely due to the low WWC sample size). Additionally, there were contradictions between the reported modeling results and the interpretation of these results, suggesting a lack of confidence in the results. For instance, the model showed that the presence of a traversable median on the crossing road had a positive coefficient (i.e., a higher probability of a WWC) compared to the presence of non-traversable medians, but the authors stated that WWCs were more likely at ramps with a non-traversable median on the crossroad (Alabama DOT 2018, 28). The low sample size used in this study was likely a main reason for these contradictions, which makes it difficult to obtain any meaningful insights.

Another study compared WWC frequency at FD and PC interchanges in Alabama and Illinois for five years (2009-2013) to investigate why the Alabama interchanges had more WWD entries than the Illinois interchanges. The WWC sample size was larger in this study (130 WWCs) compared to the previous study (65 WWCs), but this increase was due to the number of exit ramps being higher (708 exit ramps compared to 172 exit ramps in the previous study). Therefore, the ratio of WWCs to the number of ramps was still low. Chi-square tests were used to determine if various design factors and traffic control device characteristics differed between the two states (Atiquzzaman and Zhou 2020, 427-433). A major issue with these comparisons was that they were done for all FD and PC interchanges within each state and not to compare interchanges with and without WWCs. This made it nearly impossible to understand what factors actually impacted WWD. For instance, it was found that Alabama had statistically more traversable channelizing islands at FD ramps than Illinois (Atiquzzaman and Zhou 2020, 430). However, since it was unknown what types of channelizing islands were present at ramps which experienced WWCs, it was wrong to state that these islands were a reason for the higher WWC frequency in Alabama. These two studies show the challenges with focusing solely on design characteristics when studying WWCs, namely small sample sizes and difficulty in interpreting results. Therefore, it is not recommended to only consider design elements when analyzing WWCs.

UCF research on WWCs and non-crash WWD events

One major limitation of the studies discussed so far is that they only focused on WWCs. While WWCs are the most severe outcome of WWD events, it is important to look at non-crash WWD events to obtain a full picture of the WWD problem. These non-crash WWD events, which can include law enforcement citations, 911 calls, TMC logs, and detections from advanced WWD countermeasures, are often more frequent than WWCs. Sandt et al. (2021. 256) identified 265 WWCs and 3,684 non-crash WWD events (citations and 911 calls) on Florida limited access roadways from 2011 to 2016. Additionally, Sandt et al. (2022, 438) found that only 1 of 726 WWD detections at 36 exit ramps from 2016 to 2020 resulted in a WWC. These studies show that including non-crash WWD events in analyses can drastically increase the sample size compared to only studying WWCs, which can result in more accurate and trustworthy insights. It can also be difficult to know exactly where a WW vehicle involved in a WWC entered the highway, but non-crash WWD data can provide insight into the most likely entry points. Additionally, if left untreated, non-crash WWD events could eventually result in WWCs. Professor Al-Deek and his UCF research team have done many thorough studies analyzing and modeling non-crash WWD data. These studies are discussed in this section and the next section. They include studies on the relationship between WWCs and non-crash WWD events, regional WWD behavior, factors which influence WWD entries at exit ramps, and applications of the UCF WWCR modeling and optimization approach.

The first study done by the UCF research team on non-crash WWD data used WWC data, WWD citation data, and WWD 911 call data for all Florida limited access roadways from 2011-2012, as these were the only two years with data available for all three datasets. After filtering and removing overlap, there were 90 WWC events, 123 WWD citation events, and 804 WWD 911 call events. Analysis of these events found that longer roadways typically had higher WWD event counts, while shorter roadways tended to have higher WWD event densities (events per mile) (Rogers et al. 2015, 121). A model was then developed to predict WWC frequency for each hour of the day based on the WWD citation and 911 call frequencies. Using this model, the non-crash WWD events were converted to an equivalent crash frequency and added to the WWC frequency to obtain WWD risk values. These risk values were obtained for the 17 Florida counties with the most WWD events and each unique limited access roadway segment within these counties. Based on these WWD risk values, Miami-Dade and Broward Counties in South Florida were identified as the most problematic areas (Rogers et al. 2015, 124-127). This study shows the importance of considering the length of the roadway when analyzing WWD frequency and developing models, especially for long roadways like I-84, I-90, and I-15 in Idaho.

The next WWD study by the UCF research team focused on the regional nature of the WWD problem in Florida. WWCs, WWD citations, and WWD 911 calls from 2011-2015 for all Florida limited access roadways were analyzed to find how many counties and roadways the WW drivers traveled between the first and last known data point for WWD events with multiple data points. This regional WWD analysis showed that 10.5% of the 564 multi-data point WWD events included data points in multiple counties and 29.1%. of the 248 multi-data point WWD events in counties with interchanges between two limited access facilities operated by different agencies occurred near these interchanges.

Additionally, 30.4% of the single-data point WWD events happened at or near these interchanges between limited access facilities, which increases the likelihood of a WW vehicle traveling from one limited access facility to another. Negative binomial models were also developed to predict WWC and WWD citation frequencies by county over the studied five-year period based on driver demographics, vehicle miles traveled, and area type. These models showed that counties with more WWD 911 calls, more vehicle miles traveled, and higher percentages of elderly drivers and Hispanic population were expected to have significantly more WWD crashes and citations. Additionally, counties with fewer WWD citations, urban counties, and counties with higher percentages of drivers under 30 years old were expected to have significantly more WWCs (Faruk et al. 2018, 109-113). The negative relationship between WWCs and WWD citations indicates the importance of law enforcement in reducing WWCs by apprehending WW drivers before they cause a crash.

Two more studies done by the UCF research team focused on design factors which could influence all WWD events, not just WWCs. In the first study, a model was developed to predict the number of WWD entries (non-crash WWD 911 calls and citations) at exit ramp locations in Florida and determine the roadway and traffic features which affect WWD behavior. First, WWC data from 2011-2015 and WWD entry data from January 2011 through March 2018 were analyzed and filtered for all Florida limited access roadways to remove any overlap within and between the datasets, resulting in 256 unique WWCs, 1199 unique WWD citations and 3925 unique WWD 911 calls. Comparing the WWC and non-crash data showed that locations with higher WWC frequencies also had higher WWD entry frequencies, with approximately 68% of WWCs having associated WWD entries. These results showed that non-crash WWD events were a valid surrogate for WWCs. Next, a negative binomial model was developed to predict the number of WWD entries at 1157 exit ramps. Exit ramps which met the crossing road at an obtuse angle had a higher probability of WWD entries compared to exit ramps which met the crossing road at an acute angle, while urban areas had a lower chance of WWD entries compared to rural areas. Additionally, higher annual average daily traffic (AADT) volumes on the exit ramp or mainline typically resulted in more WWD entries (Kayes, Sandt, et al. 2019, 570-573). The second study analyzed and modeled WWD detection data from 48 Central Florida toll road exit ramps with active WWD detection technologies from June 2017 through December 2020. The model results showed that the predicted number of WWD detections increased when exit ramps had more lanes, a toll booth was present on the exit ramp, and crossing street volumes were higher. Conversely, having more lanes on the opposing approach to the exit ramp was predicted to reduce the number of WWD detections. WWD detection data from five of these exit ramps were analyzed further to understand factors that might have caused drivers to make left-turn or right-turn WWD entries. These analyses indicated that extending the median on the crossing road could potentially reduce left-turn WWD entries at locations with parallel exit and entrance ramps, while the presence of channelizing islands for right-turning vehicles on the exit ramp could potentially confuse drivers and cause them to make right-turn WWD entries onto the exit ramp more frequently (Sandt et al. 2022, 437-440).

Development and application of UCF holistic WWCR modeling and optimization approach

The studies discussed in the previous section illustrated many benefits of including non-crash WWD data when studying WWD behavior. However, the main benefit of non-crash WWD data in previous studies by the UCF research team was to help identify WWD hotspots and high-risk exits on limited access roadways. Professor Al-Deek and his UCF research team developed an innovative and successful WWCR modeling and optimization approach. In this approach, a WWD hotspots model was developed to predict WWCs on multi-exit limited access roadway segments. This model utilized non-crash WWD event data, interchange design, traffic volumes, and other pertinent roadway factors. Combining the model predictions with the actual WWC counts resulted in WWCR values which considered both actual WWCs (since these have major negative impacts such as fatalities injuries, road closures, and media attention) and potential WWCs due to the significant factors in the model. Roadway segments were then ranked by WWCR to identify WWD hotspots. The WWCR values were also used in an optimization algorithm to identify specific exits with high WWCR. These included exits within the identified hotspot segments (known as hotspot exits) and exits outside of the identified hotspot segments (known as lone wolf exits). Deploying WWD countermeasures at the combination of hotspot exits and lone wolf exits selected by the algorithm would provide more WWCR reduction and help agencies better utilize their resources compared to only deploying WWD countermeasures at hotspot exits. This section discusses the multiple iterations, applications, and benefits of the UCF WWCR modeling and optimization approach.

The first study to identify WWD hotspots in Florida focused on developing WWC prediction models for interstates and toll roads in Miami-Dade and Broward Counties, as these counties had the most WWD. Four years of WWC, WWD 911 call, and WWD citation data from 2011-2014 were used to develop two models: one to predict the yearly WWC frequency for each limited access roadway within these two counties and one to predict the four-year WWC frequency for seven-interchange roadway segments on each of these limited access roadways. The findings showed that the highest WWCR occurred on I-95 and State Road 821, with high-WWCR segments located on State Road 821 from Exit 20 to Exit 39 and I-95 from Exit 0 to Exit 6B and Exit 7 to Exit 14. Segments with more WWD 911 calls, more major directional interchanges per mile, and more 2-leg directional (2L) and 3-leg directional (3L) interchanges per mile were predicted to have more WWCs, while segments with more WWD citations and higher crossing road volumes were predicted to have fewer WWCs. For the second model, each seven-interchange segment was obtained by moving one interchange along the roadway from the previous segment. As an example, the first segment on State Road 821 contained the seven interchanges from Exit 0 to Exit 11 and the second segment contained the seven interchanges from Exit 1 to Exit 12 (Rogers et al. 2016, 172-174). This use of overlapping segments provided multiple advantages compared to modeling individual exits, such as an increased sample size and the ability to account for the uncertainty in knowing exact WWD entry points, making it an integral part of all future applications of the UCF WWCR modeling and optimization approach. Improvements were made in these future applications to handle the correlation between roadway segments due to the overlapping and model each direction of

a roadway separately. Additionally, an optimization algorithm was eventually developed and incorporated into this approach to identify individual exits with high WWCR.

Next, the UCF research team expanded this South Florida research to Central Florida. WWD hotspot segments on Central Florida limited access highways were identified using two approaches. In the first approach, a Poisson regression model was developed to predict WWD crashes and obtain WWCR values for five-interchange segments based on WWD citations, WWD 911 calls, traffic volumes, and interchange designs. By using smaller-sized segments compared to the South Florida application, a more balanced sample was obtained (i.e., a similar number of segments had zero WWCs and at least one WWC), which made the model more accurate. For the second approach, WWD event durations were estimated for each five-interchange segment based on WWD TMC logs; this approach can be used as an alternative to the first approach if precise WWD citation and 911 call data are not available. The findings showed that both approaches had similar results, with State Road 91 and I-4 in Orange County and I-95 in northern Brevard and southern Volusia Counties classified as the top WWD hotspots. From the developed model, it was found that segments with more 911 calls, trumpet interchanges, and higher crossing AADT were expected to have more WWCs, while segments with more citations, partial diamond (PD) interchanges, and major directional interchanges were predicted to have less WWCs. (Sandt, Al-Deek, and Rogers 2017, 63-67).

In the next study, a WWCR reduction approach was developed to identify priority locations on the Central Florida Expressway Authority (CFX) toll road network where WWD countermeasures should be installed based on WWD event history, geometric design, traffic volumes, and countermeasure cost. This study was the first inclusion of an optimization algorithm to supplement the WWCR segment model developed by Sandt, Al-Deek, and Rogers (2017). Using this algorithm, the optimal number of ramps to equip with RFB WWD countermeasures was determined based on the percentage gain (the difference between the percentage of the maximum WWCR reduction and the percentage of CFX exit ramps equipped). Deploying RFB countermeasures at these 18 optimal ramps was estimated to provide cost savings of 57% compared with equipping entire hotspot segments and 83% compared with equipping all interchanges on State Road 408, State Road 417, and State Road 528. A second hypothetical scenario was also used to illustrate the flexibility of the optimization algorithm by adding constraints to represent different real-world scenarios (Sandt and Al-Deek 2018, 87-93).

An improved and extended version of the UCF WWCR modeling and optimization approach was then applied to the CFX toll road network to identify the optimal locations for deployment of RFB WWD countermeasures. For the first time, directional roadway segments were used, allowing the WWCR model to predict different WWCR values for segments in each direction of a roadway rather than considering both directions in the same segment. This made the model more accurate and improved the ability of the optimization algorithm to identify the most high-risk exits. Six-exit roadway segments were modeled, with the model results indicating that segments with more WWD citations and 911 calls, trumpet interchanges, and higher mainline AADT were expected to have more WWCs, while segments with 2-leg or 3-leg interchanges were expected to have less WWCs. The optimization algorithm was also improved by distributing WWD events to multiple nearest exits rather than just assuming they came

from the nearest exit. This distribution was obtained by analyzing WWD events with multiple WWD 911 calls to determine how many exits the WW vehicles traveled. Distributing WWD events in this manner made the optimization algorithm more accurate in identifying the expected WWCR reduction for individual exits. Utilizing these new improvements, two optimization algorithms were applied to identify the high-risk exits and mainline sections. The results showed that there were estimated cost savings ranging from 9% to 28% when deploying RFBs at the locations identified from the optimization algorithm compared to deploying them at all exits in the 15 identified WWD hotspot segments. It was also found that State Road 408, State Road 417, and State Road 528 had mainline sections with high WWCR (Sandt, Al-Deek, and Kayes 2019, 40-47).

The UCF WWCR modeling and optimization approach was then expanded further by applying it to the Florida's Turnpike Enterprise (FTE) toll road network, which contains limited access roadways throughout the entire state of Florida. Like the previous study, a WWCR model was used to predict the number of WWCs in six-exit segments for each direction of FTE roadways based on non-crash WWD events, interchange designs, and traffic volumes. Then, the model outputs were used in the WWD countermeasures optimization algorithm to identify the most effective exits for countermeasure deployment. The major improvement to the WWCR model in this study was the use of generalized estimating equations (GEEs) to account for the correlation between segments and make the model results more accurate. This improved WWCR model showed that segments with more WWD 911 calls, PD interchanges and service plazas were likely to have more WWCs, while fewer WWCs typically occurred in segments with more WWD citations and 3L exits. Three optimization scenarios were applied under different constraints, with the results showing that equipping the optimal 20% of FTE ramps (39 out of 196 possible ramps) could provide 41% of the maximum possible WWCR reduction. These optimal ramps included ones within and outside of the 24 identified hotspots, showing that only deploying countermeasures at hotspot exits was not the most effective approach (Sandt and Al-Deek 2020, 50-52).

The final application of the UCF WWCR modeling and optimization approach was to all Florida limited access facilities. Five years of WWD event data from 2012-2016 were used and different WWD hotspot models were tested, with the selected Poisson model using GEEs. Segments with more non-crash WWD events, higher crossing road traffic volumes, and rest areas had increased WWCR, while segments with trumpet interchanges and slip ramps had decreased WWCR. The optimization algorithm was then used to select the optimal 169 exit ramps for WWD countermeasure deployment (same number of ramps as in the 63 identified WWD hotspot segments). These optimal ramps contained 96 ramps not in the hotspots and improved the WWCR reduction by almost 38% compared to deploying countermeasures at only the hotspot exits (Sandt et al. 2021, 262). Overall, the previous studies by the UCF research team showcased the transferability of the WWCR modeling and optimization approach to various network sizes, ranging from relatively small networks like the CFX network to the large Florida statewide limited access roadway network. Therefore, it was decided to use a similar approach for Idaho limited access roadways, with modifications and improvements to make the approach appropriate for the available data in Idaho.

Other WWD modeling studies

While the WWCR modeling and optimization approach developed by Professor Al-Deek and his UCF research team was the most extensively utilized in the literature, there have been other studies which utilized modeling to predict WWD. A study by Osman et al. (2022) in Minnesota applied several models (Poisson model, Poisson mixed effect model, negative binomial model, and negative binomial mixed effect model) to estimate WWC frequency and determine the significant roadway features of high-risk segments for all roadway types, not just limited access roadways. The results showed that the negative binomial mixed effect model was the best fitting model, with higher AADT, a greater number of lanes, presence of sidewalk, presence of left-side gravel shoulder, and higher speed limits found to significantly increase WWC frequency. Conversely, the presence of escape lanes, acceleration or deceleration lanes, and divided roadways all were found to significantly reduce WWC frequency (Osman et al. 2022). However, it is not recommended to model limited access and non-limited access roadways together since they have very different characteristics which could impact WWD behavior.

Mia et al. (2022) conducted a study to identify the WWD entries at regional highway ramps in Bexar County, Texas. Spatial clustering was used to identify hot spots based on three types of WWD events: WWCs without 911 calls, WWCs with associated 911 calls, and 911 calls without WWCs. The findings showed that 213 of the 571 studied exit ramps were responsible for around 98% of WWD entries. Four hotspot locations were identified, with Friday, the weekend, and the closing hours of alcohol-serving establishments all identified as being associated with high possibilities of WWD events (Mia et al. 2022).

A few studies used machine learning models to identify the locations with high WWD risk. While machine learning models can be more accurate than traditional statistical models (such as Poisson or negative binomial regression models), they can be difficult to interpret or apply to new data. Chang (2022) investigated the impacts of geometric design features and traditional traffic devices on the number of WWD events at PC interchanges in 13 different states. Three different machine learning models were used: multiple correspondence analysis, XGBoost and lasso-logistic regression. The results showed that multiple correspondence analysis was able to identify the design features which impacted WWD event frequency, while XGBoost and lasso-logistic regression were able to quantify the effects of these features. The eight design features found to reduce WWD were extending the median on the crossroad, having street lighting at ramps, more traffic on exit ramps than entrance ramps, having two driveways on the ramp side at two-way crossroads, using signals or all way stops at ramp terminals, having corner radii from 50 to 100 feet between the crossroad and the exit ramp, having the nearest access point to the exit ramp not being located within 51 to 500 feet, and having any channelizing islands be longer than 100 feet (Chang 2022, 83-85). Another study conducted by Ashraf, Dey, and Mishra (2023) in Florida showed that the XGBoost model outperformed the autoencoder rare event modelling approach. Shapley additive explanation values were calculated to interpret each parameter's importance and impact on the model's ability in predicting roadway segments with WWCs. Based on these values, the most important feature was the length of the segment, with longer roadway segments more likely to have WWCs. Higher AADT volumes and more highly developed land use also resulted in

segments having a higher chance of WWCs, while increased left and right shoulder widths, lane widths, and median widths caused segments to have lower chances of WWCs (Ashraf, Dey, and Mishra 2023).

Modeling and optimization approaches in non-WWD studies

There have also been studies not focused on WWD which contain methods which could potentially be adapted to identify WWD hotspots and optimal countermeasure deployment locations. Studies related to hotspot modeling and identification were examined to identify any potential alternatives to the UCF WWCR modeling and optimization approach. A study in Hungary compared different black spot identification methods and highway segmentation methods using highway crash data from 2013 to 2015. Four black spot identification methods (empirical Bayesian, excess empirical Bayesian, accident frequency, and accident ratio) and four segmentation methods (spatial clustering, constant length segments, constant AADT segments, and the segmentation method used in the Highway Safety Manual) were considered. The empirical Bayesian method performed better than the other methods in most of the tests, with the empirical Bayesian method using spatial clustering generally providing the best results (Ghadi and Török 2019, 7). Another study conducted in Australia developed a crash count model and a crash severity model to identify crash risk using data from 2010 to 2013. A joint model was then developed by combining both the previous models using a correlation term. To identify the high-risk locations, potential for improvement values and excess weighted risk score values were calculated. The results showed that the joint model had different variables compared to the crash count and crash severity models and was more accurate than the other models. This joint model not only predicted overall crash counts, but also predicted crash counts for different severity levels and provided additional information that the individual models did not provide (Afghari, Haque, and Washington 2020). A study in Ann Arbor, Michigan, used connected vehicle pilot test data to identify high-risk rear-end crash locations by implementing the disturbance hypothesis along with time to collision with disturbance. The results showed that a higher Pearson's correlation coefficient between risk and rear-end crash rate was achieved through time to collision with disturbance than traditional methods. Additionally, the connected vehicle data and historical rear-end crash data had the same hotspot locations. This approach was efficient since it reduced the crash data collection time needed for the traditional methods to be used (Xie et al. 2019, 317-318).

In China, a study was conducted to identify crash hotspot locations in an urban road network and analyze their spatiotemporal evolution patterns by applying data mining and space-time cube methods. The space-time cube method was useful as a spatiotemporal data mining technique to identify hotspots. The results showed that exit ramp gores were high-risk crash locations at the spatiotemporal scale (Wu, Meng, and Song 2022, 1527-1528). A study in Iran focused on identifying crash hotspots for Karaj-Chalus Mountain Road, which is a dangerous road with a cold climate. This study identified 20 hotspot locations on the studied road using spatial multi-level modeling, with 92% of the accidents in these hotspots taking place during cold months. It was found that geometric parameters related to sight distance were important in identifying high risk locations (Azari et al. 2023, 137). Since Idaho has cold weather and some mountainous roads, the results of this study could be of benefit to ITD. In general, the hotspot

identification methods used in these studies would be inappropriate or difficult to apply to WWCs compared to the UCF WWCR modeling and optimization approach.

Optimization approaches used for sensor deployments and highway safety improvements were also studied to help develop optimization techniques for identifying exits with high WWCR. A study in New York aimed to determine the best deployment locations for additional environmental sensor stations to the existing road weather information system network under certain budget, existing traffic, and crash conditions. The methodology used a true multi-objective optimization with Java 8 which incorporated vehicular accident data, traffic volume, area coverage, availability of maintenance and power nearby, and the previously installed environmental sensor stations as inputs. The optimization output was a Pareto set of solutions as a first stage, with a single preferred solution selected by decision makers as a second stage (Fetzer et al. 2018, 515-516). In another study, an interactive multi-objective resource allocation methodology was generated to enhance highway safety. A systematic approach was used to specify resources between highway segments by taking into consideration the decision maker's input of expected severity of a crash. The input data for this methodology were crash distributions by type and severity levels on each roadway segment, crash reduction factors for the crash countermeasures of interest, length of the defective road, and unit cost per mile for countermeasures for each crash (Chowdhury, Garber, and Li 2000, 138). A study in Michigan discussed strategies to identify the optimal funding allocation for safety in urban intersections. Multiple optimal resource allocation methods were applied which increased the safety benefits under specific budget and policy requirements, with different methods having various advantages and disadvantages regarding total benefits and distribution of safety benefits to different counties (Mishra et al. 2015, 130-131). These studies provided a foundation for the lone wolf optimization algorithm developed during this project for Idaho limited access roadways.

Countermeasures Used to Address the WWD Problem

The studies discussed in the previous sections provide insight on factors that influence WWD behavior and approaches to identify WWD hotspot locations. Once these factors and high-risk locations are identified, proper countermeasures can be deployed to effectively combat the WWD problem. This section discusses general guidelines for deploying various types of WWD countermeasures and studies which examined the effectiveness of these countermeasures.

Guidelines for deploying WWD countermeasures

When deploying WWD countermeasures on roadways, the Manual on Uniform Traffic Control Devices (MUTCD) is typically the first place to look for guidelines. Baratian-Ghorghi and Zhou (2017) conducted a literature review of WWCs and the evolution of the MUTCD in the context of WWD mitigation. The first edition of the MUTCD in 1935 did not initially outline any guidelines on mitigation of WWD at exit ramps, but it did include the use of "One Way" signs at locations where vehicles could potentially enter the wrong direction. Since then, the MUTCD has incorporated some guidelines for WWD mitigation

which include larger Do Not Enter (DNE) signs, retro-reflective raised pavement markings, and revised signal design (Baratian-Ghorghi and Zhou 2017, 281). Due to the limited WWD guidelines present in the MUTCD, the researchers concluded their findings by making the case for an updated MUTCD reflecting these new practices (Baratian-Ghorghi and Zhou 2017, 288). Rapid updates in the field of WWD prevention mean that the best way to reduce WWD and save lives is for state and local agencies to investigate and deploy innovative WWD countermeasures on their own until national guidance is able to catch up with the state of the practice.

Intelligent transportation system applications for mitigating WWD

Many state DOTs and organizations have investigated the benefits of intelligent transportation system (ITS) technologies as countermeasures to prevent WWD. Hosseini et al. (2022) investigated six different ITS countermeasures to mitigate WWD and concluded that all of them were successful in detecting WW drivers and reducing WWD incident rates (Hosseini et al. 2022, 255-256). However, a shortcoming of many WW detection and warning systems was the lack of real-time warning to drivers about the locations of WW drivers. To address this issue, Texas A&M University conducted research on connected vehicles and developed a prototype connected vehicle WWD detection and management system (Hosseini et al. 2022, 255). Testing of this prototype in a closed-course environment found that real-time alerting of drivers was achievable and that law enforcement and TMC operators were also able to receive real-time alerts of WWD events (Texas DOT 2018, 22). This testing shows the potential for a future where WWD events can be reduced using these connected vehicle technologies, even though these technologies are not currently ready for deployment. Illinois DOT also explored different WWD detection technologies such as inductive loop detectors and video image processors. In addition, warning detection technologies such as LED WW signs and changeable message signs were written in their guidelines (Illinois DOT 2014, 50-57).

WWD signing and pavement marking countermeasures

Agencies and researchers have developed guidelines regarding WWD signage and pavement markings which go beyond the guidelines found in the MUTCD. Illinois DOT (2014) developed guidelines for various countermeasures to combat WWD, including when it is best to implement these countermeasures. At exit ramps, the most effective placement and choice of signing and pavement markings depends on the interchange type. For example, a “Keep Right” sign should be installed at PC interchanges if the median width is greater than 8 feet (Illinois DOT 2014, 21). North Carolina DOT developed a toolbox of signage and pavement marking countermeasures to deal with WWD. Signage countermeasures included dynamic warning beacons for WW or DNE signs, turn prohibition signs, and “Freeway Entrance” signs at on-ramps, while pavement marking countermeasures included WW pavement marking arrows and stop lines at exit ramps (North Carolina DOT 2017, 4-16). Another WWD mitigation strategy recommended by the NTSB (2012, 47) is to make exit ramps distinguishable from entrance ramps; this can be achieved by installing signing and pavement markings and adjusting the lighting.

Geometric design guidelines to reduce WWD

Another important consideration is the impact that the geometric design of ramps can have on WWD frequency. As such, agencies and organizations have created guidelines to address ramp configuration and help reduce WWD. The Illinois DOT guidelines contain a section dedicated to geometric design. One example of a geometric design guideline used to curb WWD is using acute angles to connect exit ramps to one-way streets, which is expected to result in less WWD (Illinois DOT 2014, 32). These guidelines also discussed geometric design choices for different interchange types. The NTSB (2012, 48-49) also mentioned to consider interchange design, such as the angle the exit ramp is at relative to the crossing road. The toolbox developed by North Carolina DOT (2017, 17-22) also covered geometric design considerations to reduce WWD, such as installing channelizing islands on exit ramps and installing roundabouts at ramp terminals.

Crash-based countermeasure approach for different WWC types

One final way that agencies and organizations have created guidelines to mitigate WWD is by evaluating WWC history at high-risk corridors. An NCHRP report emphasized the importance of WWC identification and pairing the correct countermeasure for certain WWCs (such as head-on or opposite direction sideswipe). The type of countermeasure to consider also depends on facility type, such as whether the crash occurred at an intersection or on a two-lane undivided highway. Countermeasures such as improving pavement friction and installing centerline rumble strips should be considered to keep vehicles in their respective lanes. To reduce the possibility of head-on WWCs from occurring, countermeasures such as widening the shoulders or widening the median should be considered. Installing a cable median barrier should also be considered to reduce the severity of WWCs (NCHRP 2022, 7-32).

Effectiveness of WWD countermeasures

The guidelines discussed in the previous section mention many potential countermeasures to curb WWD activity; however, some countermeasures can be more effective than others, especially for certain locations or types of WWD activity. When deciding what countermeasure to implement, special attention must be paid to the intended purpose of the countermeasure, characteristics of the locations where it will be deployed, and the costs associated with a particular countermeasure. It is also important to keep in mind that the effectiveness of WWD countermeasures is relative to the previous site conditions. For instance, deploying ITS countermeasures at exits with limited signage or pavement markings could provide different benefits than deploying them at sites which already have extensive signage and pavement markings. However, if signage and pavement markings are insufficient to curb WWCs then ITS countermeasures should be considered to improve the status quo and reduce WWCs further. Additionally, the deployment of WWD detection systems in areas where they were not previously present could result in WWD frequencies being much higher than previously expected based on historical data. This is partially due to the technology detecting WWD activities that do not result in crashes, whereas historical data largely rely on crashes to represent the WWD problem. Understanding

the factors that impact WWD in a certain area is critical to implementing the most effective countermeasures. Studies which evaluated the effectiveness of various WWD countermeasures (both non-ITS solutions and ITS technologies) are discussed in this section.

Non-ITS solutions

Countermeasures such as improved signage and pavement markings are common solutions to countering WWD. These solutions are typically considered low-cost options when compared against ITS solutions. One of the simplest options for agencies to exercise in the fight against WWD is to adopt new and/or improved signage. For example, California implemented a series of sign-based countermeasure improvements in the early 1970s which included increasing the visibility of signs, mounting signs lower, and putting WW and DNE signs on the same post. These improvements resulted in reducing WWD frequency from 50-60 per month to 2-6 per month at most problematic locations (ENTERPRISE Transportation Pooled Fund Program 2016, 31-32). In another study, Finley, Venglar, and Ouyang (2016) studied the effectiveness of lowered DNE and WW signs in Texas. Before-after analyses determined that there was a 56% reduction in WW events after installation of these lowered signs (Finley, Venglar, and Ouyang 2016, 10). Based on these results, it was recommended that these countermeasures be adopted by other agencies. One limitation to note is that the mounting height of these signs was 2 feet, which most agencies cannot do without a request to experiment since the MUTCD recognizes a minimum mounting height of 3 feet (Finley, Venglar, and Ouyang 2016, 10). A study in Alabama investigated the use of direction rumble strips to reduce WWD. Two high-risk off-ramps along I-65 in Alabama were selected for implementation of these rumble strips. Field driving tests were performed, which yielded sound and vibration data for different speed categories. These data quantified the distinction between right-way drivers' and WW drivers' perceptions. Before-after analyses found that the number of WWD incidents decreased by 90% and average WWD distances decreased by 85% due to these countermeasures. This research study concluded that WW drivers can perceive certain sounds and vibrations when passing over the direction rumble strips, which makes them an effective type of low-cost countermeasure (Xue, Zhou, and Xu 2020).

WWD event data and costs are not the only thing to consider when evaluating WWD countermeasure effectiveness. It is also important to consider how these countermeasures are perceived by roadway users. Researchers working closely with Texas DOT conducted two closed-course studies to examine the effectiveness of WWD countermeasures on impaired drivers. The closed-course studies indicated that alcohol-impaired drivers tended to look at the pavement in front of their vehicle rather than above or to the sides of the road. Although these studies indicated that countermeasures such as oversized WW signs, red retroreflective sheeting on the support of signs, and red flashing LEDs did not reduce WWD among impaired drivers, participants reported that finding the WW sign became easier with these countermeasures present (Texas DOT 2014, 114-115).

ITS solutions

While many non-ITS solutions to curb WWD have been present for decades, ITS solutions are more recent tools which are becoming more prominent. Extensive research has been conducted on the effectiveness of ITS countermeasures in reducing WWD rates. Existing WWD countermeasures (both ITS and non-ITS) in Florida were evaluated using four methodologies: analyzing existing studies and data, using focus groups in field testing, gathering public opinion in the form of a survey, and using a driving simulation to isolate variables and evaluate the impact of individual countermeasures. Seven types of countermeasures were studied: WW signs with LEDs, new signage and pavement marking standards, red flush-mounted internally illuminated raised pavement markers, red rectangular rapid flashing beacons, wigwag flashing beacons, delineators, and blank-out WW signs that flash upon WWD detection. The research study indicated that the red rectangular rapid flashing beacons ranked as the best countermeasure to mitigate WWD, with wigwag flashing beacons ranked second. Internally illuminated raised pavement markers were recommended as a supplemental countermeasure to curb WWD (Florida DOT [FDOT] 2017, 82).

Substantial research has been conducted by Professor Al-Deek's UCF research team regarding the effectiveness of ITS WWD countermeasure systems. These systems include WWD detection capabilities and flashing countermeasures to alert detected WW drivers and notify TMCs of these detections. With these detection and notification capabilities, TMCs can monitor if the WW driver turns around and quickly alert law enforcement if needed. The first study compared the effectiveness of LED South Florida WW signs and Central Florida RFB WW signs in mitigating WWD using three different evaluation methods. The first method was a before-after analysis of WWD 911 calls and citations that occurred at 17 exit ramps where LED WW signs were deployed. The second method was analyzing images collected at 17 LED and 35 RFB sites to determine occurrences of WW vehicles that turned around. The final method was a survey for travelers and agency officials to obtain their opinions regarding LED and RFB WWD countermeasure technologies. Based on 2.5 years of data, the study concluded that both the LEDs and RFBs helped reduce WWD, with 77.1% of WW drivers turning around at the RFB sites and 13.8% at the LED sites. One potential reason for this large difference in turnaround percentage was the additional field of view supplied by an extra camera at the RFB sites. The RFB sites also performed better than the LEDs during the nighttime. Surveys in Florida found that the RFBs were preferred over the LEDs by 70% of law enforcement officers, 80% of transportation officials, and 74% of drivers. These preferences were mainly due to the extra set of RFB signs (four RFB signs per site compared to two LED signs per site) and better flashing mechanism compared to the LED signs. Improvements recommended for future deployments included the use of an additional set of signs and cameras for LED sites and modifying flash patterns and external lighting for RFB sites (Kayes et al. 2018, 104). It should be noted that the turnaround percentage for the RFBs on the CFX system has increased to over 87% as of late 2022, with 1070 of the 1225 detected WW drivers verified to have turned around or self-corrected before reaching the mainline (Ancken 2022).

To build on the study by Kayes et al. (2018), continued research was performed using additional data and two methods to compare LEDs and RFBs: before-after analyses using Chi-squared tests and

comparison group methods and determination of self-correction percentages. The results indicated that both ITS technologies (RFBs and LEDs) were effective at reducing the occurrence of WWD (Kayes, Al-Deek, and Sandt 2020, 326). However, RFBs were shown to be much better than LEDs since RFBs resulted in fewer WWD 911 calls and citations (69.4% reduction in these events compared to 48.1% reduction for LEDs) and more self-corrections (81.0% compared to 16.7% for LEDs) (Kayes, Al-Deek, and Sandt 2020, 325-326). LEDs were cheaper and almost as effective as RFBs, but there were limitations with LEDs since they typically utilized one camera rather than the multiple cameras utilized by the RFBs (although some of the studied RFBs only had one camera and still had better performance than the LEDs) (Kayes, Al-Deek, and Sandt 2020, 326-327).

The financial benefits of the RFB and LED WWD countermeasures deployed in Florida (as well as the benefits for potential future deployments) were also estimated in two different papers. In the first paper, three methods were used to conduct benefit-cost analyses for the RFB WWD countermeasures deployed on Central Florida exit ramps. The first method involved assessing WWCR reduction by looking at WWD turnaround percentages; this method was recommended when there is a lack of sufficient WWD event data (Sandt et al. 2020, 13). The second method involved using the WWCR reduction approach with the reduction in WWD events (911 calls and citations) as the measure of effectiveness. This method, which was recommended when there is sufficient WWD event data available, used a comparison group of ramps that were similar in geometry and traffic volumes to the RFB ramps, but which did not have RFBs installed (Sandt et al. 2020, 13-14). The third method did not involve a WWCR reduction approach but used a similar before-after analysis as the second method. While this method required a sufficient sample size and was not as accurate as the first two methods, it could be employed quickly compared to the other methods (Sandt et al. 2020, 14). It was recommended for agencies to adopt these methods as appropriate to determine if RFBs are a worthwhile investment. The results of these evaluations in Central Florida showed that RFBs were a very effective and worthwhile investment, with a maximum estimated life-cycle injury savings of approximately $40 million and life-cycle benefit-cost ratios for injury savings ranging from 4.77 to 7.20 for the different methods (Sandt et al. 2020, 19).

The second paper on financial benefits of ITS WWD countermeasures focused on the FTE toll road network. A six-step methodology was developed to estimate fatality and injury savings resulting from deploying WWD countermeasures and provide guidance for agencies to select cost-effective countermeasures. The first step in the methodology was analyzing WWD crash data to determine the severity of WWCs and their financial impacts. In the second step, data on advanced WWD countermeasures of interest were collected (such as expected lifespans and capital costs). The third step was calculating WWCR reduction for each exit based on the countermeasure type being deployed. Step four involved calculating life-cycle injury savings benefits and costs for each exit that did not have advanced WWD countermeasures. The fifth step entailed comparisons of various countermeasure types, effectiveness, and costs and the final step involved calculating benefits and costs for sites with already deployed advanced WWD countermeasures (Sandt and Al-Deek 2021, 92-94). Following this methodology, it was shown that RFBs were expected to provide more savings than LEDs for the FTE network, with a life-cycle benefit-cost ratio of 40.12 (estimated fatality and injury savings of almost $300

million) for the ideal RFB exits compared to a life-cycle benefit-cost ratio of 22.70 (estimated fatality and injury savings of approximately $100 million) for the ideal LED exits (Sandt and Al-Deek 2021, 100).

Another paper discussed the impacts of various factors on law enforcement response time to WWD events and the benefits of WWD ITS countermeasures for law enforcement. Analysis of WWD data from 2003 to 2018 determined that the average response time was 18.8 minutes (Kayes, Al-Deek, et al. 2019, 517). Two ordinal logit models were developed, with the first model considering all Florida roadways and the second model considering only Florida limited access roadways. These models showed that locations in close proximity to regional TMCs, rest areas, urban areas, local roads, and state roads had lower response times while limited access facilities yielded higher response times (with toll roads having lower response times than other limited access facilities). Examining the WWD data revealed an average response time of 10.9 minutes for the 21 cases where law enforcement was dispatched to catch WW drivers who continued going WW. An analysis of the ITS countermeasures deployed on Florida toll roads suggested that these devices have saved law enforcement officials over 116 hours by not having to be dispatched for the 307 WW drivers who turned around, allowing these officers to attend to other incidents (Kayes, Al-Deek, et al. 2019, 523). These results show that ITS countermeasures like RFBs and LEDs have multiple safety and financial benefits for drivers and law enforcement officers.

Separate research in Florida investigated the effectiveness of rectangular rapid flashing beacons by examining three aspects: a public opinion survey to gauge how people perceive the effectiveness of these devices, a before-after study on driver behavior, and a review of six months of collected video data at rectangular rapid flashing beacon sites. The public opinion survey revealed that 69.5% of participants preferred the combination of WW signs on both the left and right sides of an off-ramp with red rectangular rapid flashing beacons on the top and bottom (as the majority believed this configuration attracts the most attention) (Ozkul and Lin 2017, 578). Field observations and statistical analysis of driver behavior determined that driving behaviors were not adversely affected by the devices. Review of the collected video data at each of the two sites showed that 85% and 60% of WW vehicles that activated the beacons turned around, respectively (Ozkul and Lin 2017, 579).

Outside of Florida, the implementation of enhanced signing has also proven to be effective in Texas. A report from the ENTERPRISE Transportation Pooled Fund Program (2016, 31) mentioned that enhanced signing in San Antonio resulted in a 34.6% reduction in the monthly TMC WWD event logs. Another report found that LED WW signs in Texas led to a 38% reduction in WW movements on a test corridor in San Antonio (Finley, Venglar, and Ouyang 2016, 10).

In 2018, the North Carolina Turnpike Authority installed a WW detection system along the Monroe Expressway. This system detected WW motorists on the mainline and alerted TMC personnel. Researchers analyzed the effectiveness of this WW detection system, as well as the design of interchanges and associated traffic flow data. A PC interchange inventory was developed to be used by North Carolina DOT to identify and address design flaws that could contribute to higher rates of WWD. The results concluded that the WW detection system needed more video footage to avoid misidentifying the entry point for WW drivers (North Carolina DOT 2021, 33). Also, since the Monroe

Expressway was new, the researchers recommended drawing conclusions about the effectiveness of the WW detection system once enough WWD event history was collected (anywhere from 3 to 5 years of data would be a sufficiently large sample size) (North Carolina DOT 2021, 33).

Another study proposed a different countermeasure to combat WWD: the use of transversal stripes to detect WW movement. At a low cost, signal emitters could be placed along the entire road to detect the direction of the vehicle via an input and output signal. An electronic control unit would be installed in a vehicle to receive these signals. There were three possible alarms which could be triggered depending on how far the vehicle has traveled: Alarm 0 where the vehicle has not done anything wrong, Alarm 1 where the vehicle has driven WW unintentionally, and Alarm 2 where the vehicle has intentionally driven WW (Conesa, Cavas-Martinez, and Fernandez-Pacheco 2013, 5115). To evaluate this agent-based architecture, 70 tests were done by 7 users, which resulted in a 100% success ratio (Conesa, Cavas-Martinez, and Fernandez-Pacheco 2013, 5123).

Overall, the studies of WWD countermeasure effectiveness discussed in this chapter show that there are many effective options for WWD mitigation. Table 2.1 summarizes the findings from the studies that involved real-world WWD countermeasure deployments. RFB and LED signs in particular have been successful in reducing WWD events, so these countermeasures were evaluated for Idaho limited access exit ramps, as discussed in Chapter 5. One important observation from these studies is that the effectiveness of any WWD countermeasure can vary from one location to another depending on site and driver characteristics. Therefore, actual deployments are needed to accurately estimate the potential benefits of ITS WWD countermeasures in Idaho.

Table 2.1 Summary of WWD Countermeasure Deployment Effectiveness Studies

WWD Countermeasure	Scope	Findings	Reference
Increased sign visibility, lowered signs, WW and DNE signs on the same post.	California in the 1970s.	WWD reduced at problem sites from 50-60 per month to 2-6 per month.	ENTERPRISE Transportation Pooled Fund Program (2016)
Lowered WW and DNE signs.	Texas from 2011-2014.	56% reduction in WW events.	Finley, Venglar, and Ouyang (2016)
Direction rumble strips.	Alabama from 2018-2019.	WWD incidents decreased by 90% and average WWD distances decreased by 85%.	Xue, Zhou, and Xu (2020)
LED and RFB WWD detection and countermeasure systems.	Florida from 2012-2017.	77% of WW drivers turned around at the RFB sites (double set of signs) and 14% turned around at the LED sites (single set of signs).	Kayes et al. (2018)
LED and RFB WWD detection and countermeasure systems.	Florida from 2011-2018.	69% reduction in WWD events and 81% self-correction rate at RFB sites; 48% reduction in WWD events and 17% self-correction rate at LED sites.	Kayes, Al-Deek, and Sandt (2020)

WWD Countermeasure	Scope	Findings	Reference
LED and RFB WWD detection and countermeasure systems.	Florida from 2014-2020.	RFBs: Life-cycle benefit-cost ratio of 40.12 with estimated fatality and injury benefits of $300 million for the ideal exits. LEDs: Life-cycle benefit-cost ratio of 22.70 with estimated fatality and injury benefits of $100 million for the ideal exits.	Sandt and Al-Deek (2021)
LED and RFB WWD detection and countermeasure systems.	Florida from 2014-2018.	Estimated to have prevented nine WWCs and saved law enforcement over 116 hours by causing WW drivers to turn around.	Kayes, Al-Deek, et al. (2019)
RFB WWD detection and countermeasure systems.	Florida from 2012-2019.	Life-cycle injury benefits of approximately $40 million and life-cycle benefit-cost ratios ranging from 4.77 to 7.20.	Sandt et al. (2020)
RFB WWD detection and countermeasure systems.	Florida from 2015-2022.	1070 of the 1225 detected WW drivers (87%) self-corrected before reaching the mainline.	Ancken (2022)
WW signs with rectangular rapid flashing beacons.	Florida from 2015-2016.	85% and 60% of detected WW drivers self-corrected at the two deployment sites.	Ozkul and Lin (2017)
Enhanced WW signage, including LED signs.	Texas from 2012-2016.	35% reduction in monthly TMC WWD logs.	ENTERPRISE Transportation Pooled Fund Program (2016)
LED WW signs.	Texas from 2011-2014.	38% reduction in WWD events.	Finley, Venglar, and Ouyang (2016)

WWD Research Projects and Countermeasure Deployments in the US

In addition to understanding the research on the guidelines and effectiveness of WWD countermeasures, it was also important to examine what transportation agencies across the US are doing with regards to WWD research and countermeasure deployment. Many US agencies have deployed enhanced or advanced WWD countermeasure systems, but other agencies are still in the research phase. To obtain the latest available information on the state of the practice in the US, the DOT websites for all 49 states excluding Idaho, plus the District of Columbia, were explored. Out of these 50 agencies, the following 18 agencies had no information on their websites about WWD countermeasure deployment: Alaska, Georgia, Hawaii, Louisiana, Maine, Minnesota, Mississippi, Montana, Nebraska, New Hampshire, New Jersey, North Dakota, South Carolina, Vermont, Washington, Washington D.C., West Virginia, and Wyoming. Summaries of the reported WWD research projects and/or countermeasure deployments for the remaining 32 agencies are discussed in this section, subdivided by the following US regions: Northeast, Southeast, Midwest, Southwest, and West.

Northeast region

Connecticut DOT is currently taking steps to mitigate WWD by conducting a WWD mitigation pilot program. In this pilot program, 360-degree cameras are being installed at 16 exit ramps. When the camera captures a WW driver, flashing red WW signs will be activated to warn the WW driver (Connecticut DOT n.d.).

In 2022, Delaware experienced an increase in fatal WWCs. To address this, Delaware DOT unveiled a pilot program where two locations were chosen for installation of a WW detection and alert system. This system was coupled with flashing red DNE and WW signs and allowed Delaware DOT to dispatch state police and post messages on variable message signs to make motorists aware of WW drivers in the area. DelDOT has also been working on enhanced signing and pavement markings at freeway ramps (Delaware's Government 2023).

Maryland DOT is actively deploying WWD countermeasures. From 2012-2018, there were six fatalities attributed to WWD. To mitigate WWD, safety improvements (such as installing additional WW signs, DNE signs, and pavement arrows) were implemented at the US 50 and Jennifer Road interchange's exit ramps. Pavement arrows and LED WW signs were also added at the US 50 and Buschs Frontage Road exit ramp. Additionally, yellow extension lines were painted on the pavement at the US 50 and Whitehall Road exit ramp to make the distinction between the entrance and exit ramp clearer. Plans to make improvements at 22 interchanges along I-97 and US 50 were also mentioned (Maryland DOT 2018).

In 2013, Massachusetts DOT explored low-cost countermeasures to mitigate WWD, mainly larger DNE and WW signs and enhanced pavement markings. Due to the persistence of the WWD problem, Massachusetts DOT recently decided to explore a new pilot program where 16 ramp locations have been identified for installing WW detection systems. This pilot program also features flashing warning lights on signs (Jacobson 2023).

During 2021, New York DOT released policy guidance on WWD countermeasures. These countermeasures included double-posted DNE signs, retroreflective strips on all regulatory posts, freeway entrance signs for ramps that are adjacent to exit ramps, WW arrows for on-ramps and off-ramps, red delineators, ITS solutions (including detection systems), and improved street lighting (New York DOT 2021, 1-3).

In 2015, Rhode Island DOT completed a project in which more than 200 ramps received upgraded signing and striping to reduce WWD. WWD detection systems were also installed at 24 high-risk areas (mostly in the Providence area). After a year of deployment, Rhode Island experienced a 30% reduction in WWD incidents (Rhode Island DOT n.d.).

A news story discussed the role of Pennsylvania DOT in combatting WWD. The head of Pennsylvania DOT mentioned that they were studying what Rhode Island had been doing to combat WWD. Pennsylvania DOT is in the research phase of figuring out the best, most cost-effective countermeasures

to implement and might eventually look at implementing countermeasures such as lowering DNE and WW signs, using electronic highway message boards to warn motorists of WW drivers, and installing a WWD detection system (Burke 2016).

Southeast region

Alabama DOT released a report which discussed filtering crash data to determine high risk locations on freeways and multilane highways and determining problematic areas for WWD. Existing countermeasures to prevent WWD were compared against proposed countermeasures. Signage improvements were recommended, such as ensuring DNE signs face the target drivers (as more than half of DNE signs were discovered to not be facing the target drivers) (Alabama DOT 2018, 37-39). Based on the data, recommendations were made for both short-term, low-cost countermeasures (such as adjusting traffic signals and installing and improving signage and pavement markings) and long-term, high cost countermeasures (such as WWD detection systems and geometric improvements like raised medians and channelizing islands) (Alabama DOT 2018, 42-44).

Arkansas DOT releases annual reports of WWCs with the latest report dated 2020 when accessed for this literature review. These reports showed that Arkansas DOT completed a statewide safety improvement program in 2018 to curb WWD incidents. This program included improvements such as installing red delineators, thermoplastic WW pavement arrows, “cat track” pavement markings (which assist left-turning motorists in entering the correct ramp in the case of side-by-side ramps), and ensuring WW and DNE signs were lowered and had brighter sheeting with reflective post panels (Arkansas DOT n.d.).

FDOT outlined the initiatives being taken to combat WWD in Florida. They work to fulfill the minimum requirements set forth in the MUTCD, such as installing DNE and WW signs and pavement markings. FDOT has also conducted extensive research in developing effective countermeasures for WWD. They make use of WWD detection systems to detect WW drivers, dispatch law enforcement, and alert other motorists that there is a WW driver in the area. LEDs on WW signs are often used as a part of WWD alert systems. FDOT also works to increase public awareness of the WWD problem by explaining the countermeasures in place, as well as what to do during a WWD encounter (FDOT n.d.). A journal paper detailed how FDOT has implemented countermeasures to combat WWD. The State Traffic Engineering and Operations Office was prompted to evaluate the concern of WWD and performed a statewide study to assess WWC history for a five-year period, take inventory and conduct field reviews at certain locations, and recommend countermeasures. During this study, the State Traffic Engineering and Operations office sought FHWA’s consent to test red rectangular rapid flashing beacons and in-pavement reflective pavement markers (Ponnaluri 2016a, 93-94). A human factors study was also conducted to determine why drivers go WW. Results from this statewide study yielded new requirements for signing and pavement markings and new planning considerations for future interchange types (as some interchanges were riskier than others in the context of WWD) (Ponnaluri 2016a, 96-97). One example of WWD countermeasure implementation (as there were many throughout the state) was the installation of new DNE and WW signs, vehicle-alerting technology, and LED signs

with vehicle detection throughout an 18-mile stretch of the Homestead Extension of Florida's Turnpike (Ponnaluri 2016a, 94-95). Additionally, CFX has installed WW signs with flashing lights (RFBs or LEDs), detection, and cameras at 55 exits on their toll road system to detect and alert WW drivers, with the first system active in February 2015. CFX has also deployed WWD detection systems at 10 mainline locations (CFX, 2023). As detailed in the previous section, multiple analyses and evaluations have been conducted on these RFBs showing their effectiveness in reducing WWD and saving lives.

The Kentucky Transportation Cabinet has received funding from FHWA to find solutions for combatting WWD. They plan to install WWD detection and countermeasure systems consisting of four components: detection system, deterrent (warning) system, alert system, and mainline monitoring system. Existing roadway signage will be integrated into this system (Kentucky Transportation Cabinet 2022).

North Carolina DOT not only developed a toolbox to tackle WWD (as discussed previously in this document) but also sponsored another research project to examine problem sites and recommend site-specific improvements. To identify the problem interchanges, the researchers examined crash report data, videos, and law enforcement data, and conducted field investigations for the identified interchanges. Some improvements recommended to mitigate WWD included the addition of a median to prevent WW left turns from a crossing street and addition of pavement arrows to indicate correct entry direction (North Carolina DOT 2018, 19). Since the conclusion of this research project, North Carolina DOT deployed a WWD detection system along the Monroe Expressway (as detailed in the previous section).

Tennessee DOT sponsored a research project which focused on selecting the best WWD prevention technology for the state. This project involved an extensive literature review, gathering of WWC data to identify contributing factors, two-phase testing for three types of WW prevention systems (first phase of testing in a closed environment and the second phase in the field), and evaluating the general performance of these systems. Ultimately, the TraffiCalm WW prevention system was recommended due to its accuracy in detecting WW vehicles and minimizing false detections. The TraffiCalm system also had a longer useful life than the other studied systems, which meant that the life cycle cost was relatively low. TraffiCalm also provided a full package which included WWD detection, warning, and alerting (Tennessee DOT 2021, 49).

Virginia DOT is conducting research on the magnitude of the WWD problem and intends on adopting a toolbox to deploy WWD countermeasures recommended by the research. These countermeasures will also be integrated into Virginia's existing ITS infrastructure while also keeping in mind the geometric design of existing interchanges (Virginia DOT n.d.).

Midwest region

Illinois DOT has a webpage that serves as a hub for all traffic safety topics, including WWD. The WWD webpage contains two documents that illustrate Illinois's mission to mitigating the WWD problem: "Guidelines for Reducing Wrong Way Crashes on Freeways" (discussed earlier in this document) and

"Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways, Phase II" (results of which were discussed in journal papers previously discussed in this document) (Illinois DOT n.d.).

Indiana DOT issued a document that outlined all the research needs for Indiana DOT during the 2024 fiscal year. One item indicated that they are considering researching locations with high occurrences of WWD and interstate U-turns (Indiana DOT 2023, 4).

An article on the Iowa DOT website explained how Iowa DOT has been investigating WWD since at least 2010. High risk locations have been defined and sensors and cameras have been installed to mitigate the WWD issue. Other WWD countermeasures utilized by Iowa DOT included pavement markings like large white arrows in the through lanes and larger DNE signs. Iowa DOT will continue to install enhanced signage and pavement markings, as well as more cameras. They are also currently working on figuring out a method to quickly alert the TMC or law enforcement when sensors detect WW vehicles (Iowa DOT 2021).

Kansas DOT partnered with Kansas State University to conduct research on the WWD problem and ways to mitigate it. The research project is almost complete and has yielded the following results: identification of WWD hotspots using the Kansas DOT crash database, installation and evaluation of countermeasures along I-70, development of a method to collect and evaluate ramp data for effective countermeasure installation, and recommendations for implementation of countermeasures for PC interchanges (such as oversized and lowered WW signs, LED WW signs, and red retro-reflective delineators). As a result of these efforts, WW fatalities were reduced by more than 36% when comparing the study period of 2015-2018 to the before period of 2010-2014 (Salina Post 2021).

Michigan DOT has remained committed in their fight to reduce WWD through deployment of various countermeasures. Such countermeasures included installing additional WW signage, changing the height of WW signs, adding reflective delineators, and implementing WWD detection systems. All interchanges in Michigan contain red and white "WRONG WAY DO NOT ENTER" signs. Michigan DOT has also installed sensors at two ramps at US-131 in downtown Grand Rapids and will continue deploying countermeasures as more funding becomes available (Sergent 2023).

Missouri DOT implemented BlinkLink technology on several ramps along I-44 in St. Louis to curb WWD accidents. BlinkLink is a technology that utilizes radar, cameras, and sensors to detect WW drivers. The BlinkLink system then activates flashing lights on WW signs to alert the driver of their misdirection and alerts Missouri DOT, who then dispatches law enforcement (HEC Media n.d.).

Ohio DOT first installed WWD detection systems during 2019 on I-71 in Cincinnati. Ever since, Ohio has seen a reduction in WWD, with most WW drivers turning around before reaching the mainline. Currently, Ohio DOT is installing WWD detection systems on I-71 and I-90 in Cleveland. These systems include WW signs that flash when a WW driver is detected (Ohio DOT 2022).

A signage manual used by South Dakota DOT contains a small section dedicated to South Dakota's efforts in combating WWD. To address locations where WWD is a concern, the South Dakota DOT considers using red reflective strips on delineator posts on exit ramps (South Dakota DOT 2021, 12).

Wisconsin DOT is actively mitigating WWD events by doubling up on WW and DNE signage on ramps. They are also considering separating exit and entrance ramps for future construction as exit and entrance ramps that are side-by-side can be confusing to drivers. In addition, Traffic and Parking Control Co. created a WW alert system that is deployed at 20 locations in Milwaukee County (Silver 2019).

Southwest region

A report by Arizona DOT investigated WWD incidents in Arizona and discussed several risk factors. It also discussed WWD countermeasures used across other states and in other countries. By the time this report was published, Arizona DOT had deployed a new style of WW signs (over-sized and low-mounted) at 50 locations in rural and urban areas; this style would be adopted for future design projects as well (Arizona DOT 2015, 10). Arizona DOT has also deployed WWD detection systems with radar detection at two sites and three WW LED warning systems (Arizona DOT 2015, 11). The report also outlined plans for countermeasures, including information on individual detection and notification elements, a comprehensive pilot deployment plan, and monitoring plan for when WWD events occur (Arizona DOT 2015, 35-66). Additionally, the official Arizona DOT website discusses the "Drive Aware, Get There" campaign which is intended to familiarize motorists with the proper steps to take when there is a WW driver on the road. This website also mentions the steps taken to reduce WWD, such as the thermal camera detection system pilot project implemented on I-17. Arizona DOT has also installed larger and lowered WW and DNE signs on hundreds of freeway ramps in Phoenix and rural highways (Arizona DOT n.d.).

New Mexico DOT is testing warning signs at two locations along I-25 to mitigate WWD. They hope to acquire funding to install more signage, sensors, and alarms and look to mimic Arizona since Arizona DOT has been successful in curbing WWD through their own WWD detection and alert system (Laflin 2022).

Oklahoma DOT tested a WWD detection system on I-40 on six ramps in eastern Oklahoma. The system used thermal cameras that detected vehicles entering in the wrong direction and activated flashing lights on WW signs. The system also included internally lit DNE signs to allow for better visibility of signage at night. This was the first phase of installing the system statewide (Oklahoma DOT 2022).

Multiple WWD countermeasure deployment efforts in Texas were discussed earlier in this chapter. A news article discussed the magnitude of the WWD problem in Texas as well as countermeasures currently in place to address the issue of WWD. Texas has signage and pavement markings on each exit ramp for highways throughout the state. In 2017, TxDOT deployed a pilot program which entailed installing WWD detection systems along I-30. TxDOT continues to remain dedicated to preventing WWD

and intends to use technology countermeasures in 2024 to prevent WWCs along Woodall Rogers Freeway and some parts of Central Expressway in Dallas (Fink 2022).

West region

Several resources on the Caltrans webpage point to a series of pilot projects California has completed over the years. Pilot projects to combat WWD included the use of red retroreflective raised pavement markers on exit ramps, implementation of advanced WWD detection and notification systems, and installation of LED-illuminated signs and in-pavement LED illuminated flashing lights (Caltrans n.d.).

A news release from Colorado DOT mentioned that WWD detection systems will be installed at 87 ramps along I-70. This project will also include the improvement of existing WWD detection systems and signage (Colorado DOT 2021).

Nevada DOT is currently deploying countermeasures to curb WWD through a pilot program. This pilot program involves installing flashing warning signals on WW signs, as well as installing additional WW signs. The mounting height for the first set of WW signs is set to 4 feet as opposed to the traditional 7 foot mounting height. WW alert systems are also being installed. These systems make use of closed-circuit cameras and radar to alert WW drivers that they are traveling in the wrong direction (Nevada DOT n.d.).

Oregon DOT is currently undergoing a design phase for WWD mitigation along I-5. They seek to evaluate each interchange and adopt low-cost treatments such as signing and striping. For interchanges deemed to have a high risk for WWD incidents, more expensive measures will be adopted such as automated warning systems and increased lighting (Oregon DOT n.d.).

The Utah Transportation Commission recently approved a funding request to install a WWD detection and alert system at 20 locations, mostly along I-15 in Salt Lake City. Utah DOT has been testing a WWD detection and alert system at one off-ramp on I-15. They have also installed additional signs and modified traffic signals to better indicate the correct driving direction (Utah DOT 2023).

Literature Review Summary and Conclusions

This literature review shows that there has been substantial research on factors which affect WWC frequency and severity, but there has been limited research on non-crash WWD events and modeling to identify WWD hotspots. Typical factors that increased WWC frequency were nighttime hours, weekend days, driver intoxication, and elderly drivers. Some studies also found that fatal WWCs were more common in rural areas than in urban areas, which shows the importance of ITD's efforts to combat WWD in the primarily rural state of Idaho. Many studies had limited sample sizes (since they only considered WWCs) and only considered one category of potential factors (driver factors, design, etc.) for specific locations, which limited the accuracy and transferability of these results. Research by UCF on WWCs and non-crash WWD events found that non-crash data helped to substantially increase sample

sizes and provide a better understanding of the WWD problem than only focusing on crashes. Analyzing and modeling WWD citations, 911 calls, and detection data provided more accurate insights into the impacts of driver demographics and ramp design on WWD behavior.

These non-crash WWD data are also important to identify WWD hotspots and exits with high WWCR. Professor Al-Deek and his UCF research team have been leaders in this area through the development of their WWCR modeling and optimization methodology. The WWD hotspots model identifies WWD hotspot segments with high WWCR based on actual WWCs and potential WWCs which could occur in the future due to non-crash events, interchange design, traffic volumes, and other roadway or area characteristics. This model has been improved many times over the years, with the latest model able to model each direction of a limited access roadway separately and account for correlation between overlapping segments. Roadway segments were modeled instead of individual exits since it is often unknown where a WW driver entered from. To determine high-risk exits, the WWCR reduction lone wolf optimization algorithm used the results from the WWCR segment model. WWD events with unknown origins were distributed to the nearest possible exits, which was much more accurate than assuming all these events came from the nearest exit. By considering different constraints, such as budget limitations and installation feasibility, this algorithm was able to provide tailored and cost-effective deployment strategies for multiple agencies. Applications of this approach to South Florida limited access roadways, the CFX toll road system in Central Florida, the FTE statewide toll road system, and all Florida limited access facilities showed major benefits in WWCR reduction and cost savings compared to blanket implementation of countermeasures on entire roadways or hotspot segments. The ability of this approach to identify lone wolf exits with high WWCR was important to ensure that agencies identified the riskiest locations for priority deployment of countermeasures. Based on the success of this approach in Florida, it was utilized for this Idaho project, with adjustments and improvements as needed to best match Idaho's roadway network and available data. This approach will help ITD best understand WWD behavior on their limited access roadways using any and all available data and identify the most cost-effective locations for WWD countermeasure deployment.

Understanding the available WWD countermeasures and their effectiveness is also important to help ITD most effectively combat WWD. The MUTCD provides basic solutions to addressing the WWD problem, with agencies across the nation adopting their own guidelines beyond the MUTCD tailored to their particular needs. It is standard to incorporate WW signage and pavement markings, which have been proven to be effective low-cost choices. However, these low-cost countermeasures often have limited success in reducing the WWD problem, especially at high-risk locations. Modifications to ramp geometry are another choice for agencies to reduce WWD activity, but these modifications can be costly and their impacts can differ based on interchange design and location. In recent years, ITS solutions have become popular choices for mitigating WWD. These technologies have achieved higher success than traditional methods in combating WWD, with RFBs ranking as the most effective ITS choice, especially when paired with a WWD detection system to help TMCs monitor and alert law enforcement about WW vehicles that do not self-correct. Although ITS solutions tend to carry higher costs, their fatality and injury reduction benefits far outweigh their costs, making investments in these technologies

worthwhile. In addition, ITS solutions can also help reduce law enforcement response times, providing another justification for agencies to consider utilizing the technologies. However, the best solution for one location might not work well in another location, so it is important to understand what different states (especially states close to Idaho) have been doing to combat WWD.

Investigation of WWD countermeasure deployments across the US shows that there more states are actively seeking solutions to curb the WWD problem than states without such efforts. This momentum is a step in the right direction, as WWD is a national problem. Many agencies are embracing ITS technologies through the implementation of enhanced signage and WWD detection systems. Other agencies are utilizing low-cost solutions such as deploying oversized and low-mounted WW signs, while some agencies are making use of both low-cost solutions and ITS solutions to compound the effect of reducing WWD. Several states around Idaho (Oregon, Nevada, Utah, and Arizona) have implemented WWD detection and alerting systems along various roadway corridors. It is recommended for ITD to use the findings from these deployments to effectively deploy the most appropriate WWD countermeasures in the future.

Overall, this literature review shows that WWD treatment is an important issue for many agencies across the US. Florida and Texas are two of the leading states in WWD research, with the WWCR modeling and optimization approach developed by Professor Al-Deek and his UCF research team being successful at identifying optimal WWD countermeasure deployment locations. Applying this approach to Idaho (with appropriate modifications) and evaluating the potential benefits of RFB and LED countermeasures (like those successfully deployed in Florida) will help ITD best combat WWD on their high-speed roadways, reducing crashes and saving lives.

3. Idaho Limited Access Roadway Data Collection and Analysis

Quality data are crucial to help ITD identify the extent of the WWD problem on Idaho limited access roadways. Without a sufficient quantity of high-quality data, it will not be possible to develop accurate models for identifying significant factors and WWD hotspots. Roadway data and WWD event data are the two main types of data needed for this project. This chapter discusses the collection and analysis of roadway data, with Chapter 4 discussing the WWD event data. Roadway data are important since exit design and traffic volume characteristics influence WWD frequency. These data are also needed to ensure that only limited access roadways are considered and to segment the roadways before modeling. The UCF research team collected three different categories of roadway data. The first category was macroscopic data; this included high-level data on exits (such as locations, crossing streets, interchange design, and area type), mainline segment locations, and various traffic volumes which could influence WWC frequency. The second category was microscopic data for individual exit ramps and entrance ramps. These microscopic data included information on exit ramp terminals (such as lighting, intersection type and control, and number of exit ramp lanes), crossing streets (median type and allowable turning movements), and entrance ramp openings (lighting presence, number of lanes, width, and location relative to the exit ramp). The final category was existing signage and pavement markings which could deter WW drivers (such as WW signs, DNE signs, and pavement arrows).

This chapter discusses the procedures used to collect these various roadway data. It also summarizes the collected data and provides insights and recommendations to help ITD reduce WWD. The collected roadway data were submitted to ITD in two spreadsheet files (one containing the macroscopic and microscopic data and one containing the existing signage and pavement markings data) as a supplement to this final report.

Macroscopic ITD Limited Access Roadway Data

A proper understanding of the Idaho limited access roadway network is important before collecting and analyzing WWD event data. Identifying the names and locations of the ITD limited access roadways will ensure that the collected WWD event data are for these facilities and not for arterials or other non-limited access roadways. Mileage information and latitude and longitude coordinates for interchanges will help identify the nearest exits where WW vehicles could have entered from. Interchange designs, traffic volumes, and area types will be considered in the modeling process as potential independent variables to determine how these factors impact WWC frequency. This section discusses the collection of these macroscopic roadway data for the ITD limited access roadway network.

Identification of ITD limited access network and interchanges

The UCF research team identified six ITD limited access roadways via review of maps and discussions with the ITD project management team. These roadways are I-90, I-84, I-184, I-86, I-15, and US 20 from I-15 in Idaho Falls to Cottonwood Drive in St. Anthony. Each direction of these roadways was considered

separately since WWD can vary by direction (i.e., one direction of a roadway could have more WWD than the other direction), resulting in 12 directional limited access roadways. A unique roadway ID from A through L was assigned to each of these roadways, as shown in Table 3.1. Interchange and exit ramp locations were then identified for each roadway, with Table 3.1 showing the number of exits on each roadway. In total, there were 185 unique interchanges containing 341 exits with 352 exit ramps on these 12 roadways. For each roadway, the interchanges were numbered either starting at 1 for the westernmost interchange on roads that go EB and WB or starting at 1 for the southernmost interchange on roads that go northbound (NB) and southbound (SB). These interchange numbers were combined with the roadway IDs to obtain unique exit IDs for each exit. Note that the exit counts for I-90 EB, I-90 WB, I-84 EB, I-84 WB, I-15 NB, and I-15 SB each include one exit outside of Idaho from which WW vehicles could potentially enter Idaho. For example, the exit at Spokane Bridge Road in Washington was counted for I-90 WB since WW vehicles going EB in WB from this exit could enter Idaho. If these non-Idaho interchanges were either the westernmost interchange (for EB-WB roads) or southernmost interchange (for NB-SB roads), they were given an interchange number of 0 (as was the case for the aforementioned Spokane Bridge Road exit, which has an exit ID of B0). Another important note is that US 20 EB and WB contain some unsignalized intersections between interchanges; these unsignalized intersections were counted as exits in Table 3.1.

Table 3.1 Number of Exits for ITD Limited Access Roadways

Roadway	Roadway ID	Number of Exits
I-90 EB	A	33
I-90 WB	B	32
I-84 EB	C	62
I-84 WB	D	61
I-184 EB	E	4
I-184 WB	F	5
I-86 EB	G	14
I-86 WB	H	14
I-15 NB	I	37
I-15 SB	J	37
US 20 EB	K	22
US 20 WB	L	20

In addition to exit ramps, limited access WWD can also originate from mainline crossovers. These WWD crossovers can be caused by a variety of factors, such as icy roads, construction, or mechanical failures. The UCF research team conducted some analyses on these crossovers, even though they would not be prevented by exit ramp countermeasures, to help ITD understand where and why they tend to occur.

These analyses are discussed in Chapter 4. To locate areas with high crossover frequency, the six Idaho limited access roadways were split into 325 mainline segments. Each roadway direction was not considered separately for these mainline segments since crossover WWD events involve both sides of the roadway, not just one side like WWD events which originate from exit ramps. Table 3.2 shows the roadway ID and number of mainline segments for each roadway. The first segment on each roadway starts at the westernmost (for EB-WB roadways) or southernmost (for NB-SB roadways) entrance ramp from which right-way vehicles could enter Idaho and ends at the next entrance ramp as you go along the road eastward or northward (no matter which side of the roadway the entrance ramp is on). The second segment starts at the ending point of the first segment and continues to the next entrance ramp, with this segmentation process repeating for the entire portion of the roadway in Idaho. For example, the first mainline segment on I-90 starts at the I-90 EB entrance ramp from Spokane Bridge Road in Washington and ends at the I-90 WB entrance ramp from W Pointe Parkway. The second mainline segment then starts at the I-90 WB entrance ramp from W Pointe Parkway and ends at the I-90 EB entrance ramp from W Pointe Parkway.

Table 3.2 Number of Mainline Segments for ITD Limited Access Roadways

Roadway	Roadway ID	Number of Mainline Segments
I-90	M	63
I-84	N	119
I-184	O	8
I-86	P	27
I-15	Q	73
US 20	R	35

Macroscopic roadway data collection sources and procedures

The following macroscopic data were collected for each of the exits shown in Table 3.1: exit number, crossing roads, distance from the previous exit, interchange type, number of exit ramps, latitude, longitude, Idaho county, area type (urban or rural), mainline AADT, exit ramp AADT, and crossing AADT. For each mainline segment shown in Table 3.2, the following macroscopic data were collected: length, latitude and longitude of starting and ending points, primary Idaho county, and area type. The two sources used to collect these data were Google Maps (Google 2024) and Geographic Information System (GIS) data from the IPLAN website (ITD 2021).

Roadway data collection using Google Maps

Google Maps was used to identify the exit number, crossing roads, interchange type, number of exit ramps, latitude, and longitude for each exit, as well as the starting and ending latitude and longitude for the mainline segments. The UCF research team identified eleven possible interchange categories for

Idaho interchanges: full diamond (FD), partial diamond (PD), split diamond (SD), other diamond (OD), partial cloverleaf (PC), rest area (RA), two-leg directional (2L), three-leg directional (3L), slip ramp (SR), unsignalized intersection (UI), and Other. Examples for each of these categories are shown in Figures 3.1 through 3.11. All of these figures (and all other figures with examples from Google Maps or IPLAN throughout the rest of this report) are oriented so north is pointing upwards. The "Other" category includes unique interchange designs along with interchange designs which do not fit in any of the other ten categories (such as trumpet interchanges), but which do not make up at least 2% of ITD interchanges.

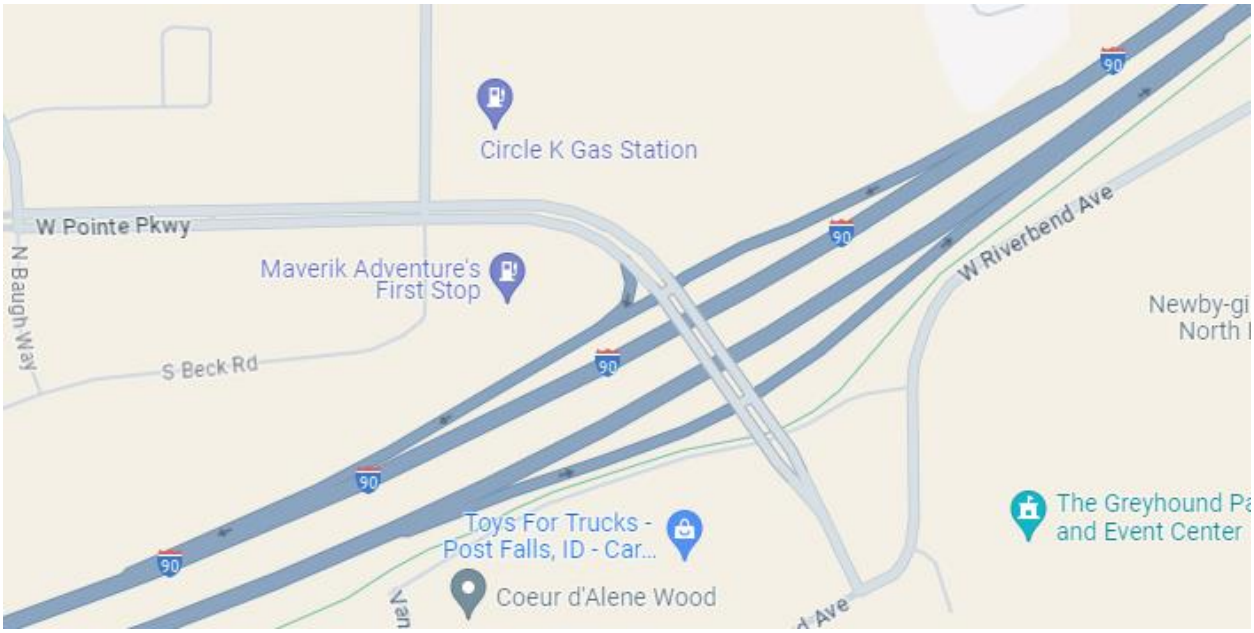

Figure 3.1 Full diamond (FD) interchange at I-90 and W Pointe Parkway

Figure 3.2 Partial diamond (PD) interchange at I-90 and E Seltice Way

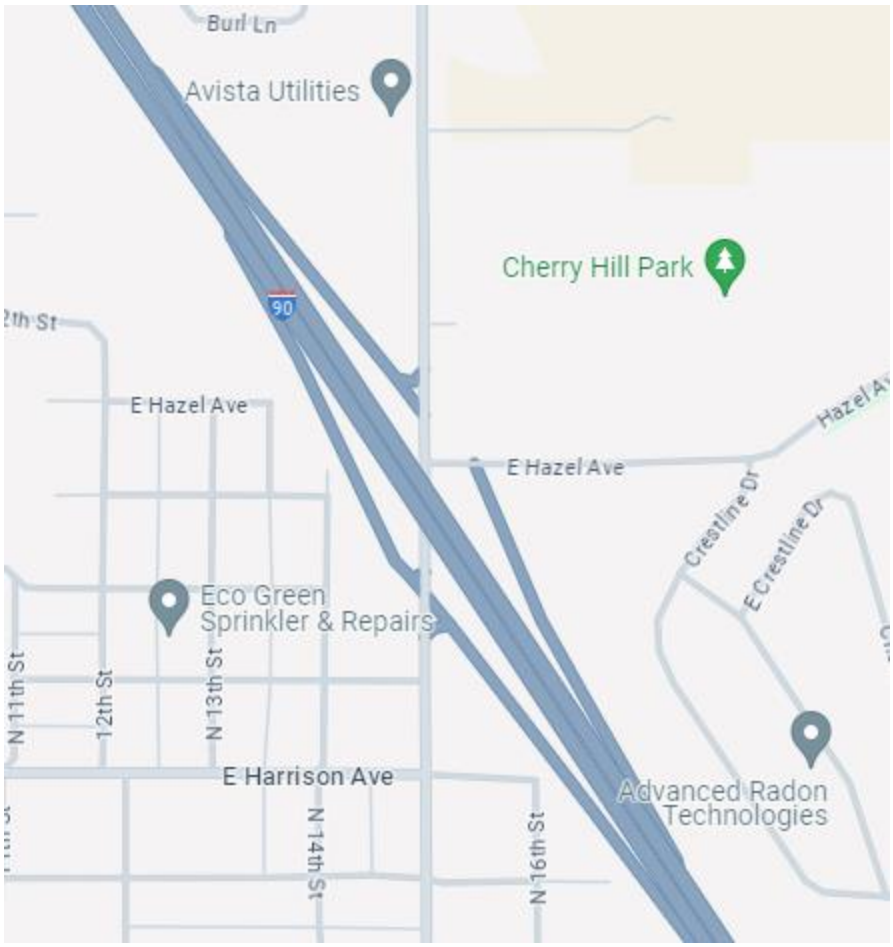

Figure 3.3 Split diamond (SD) interchange at I-90 and N 15th Street/E Hazel Avenue

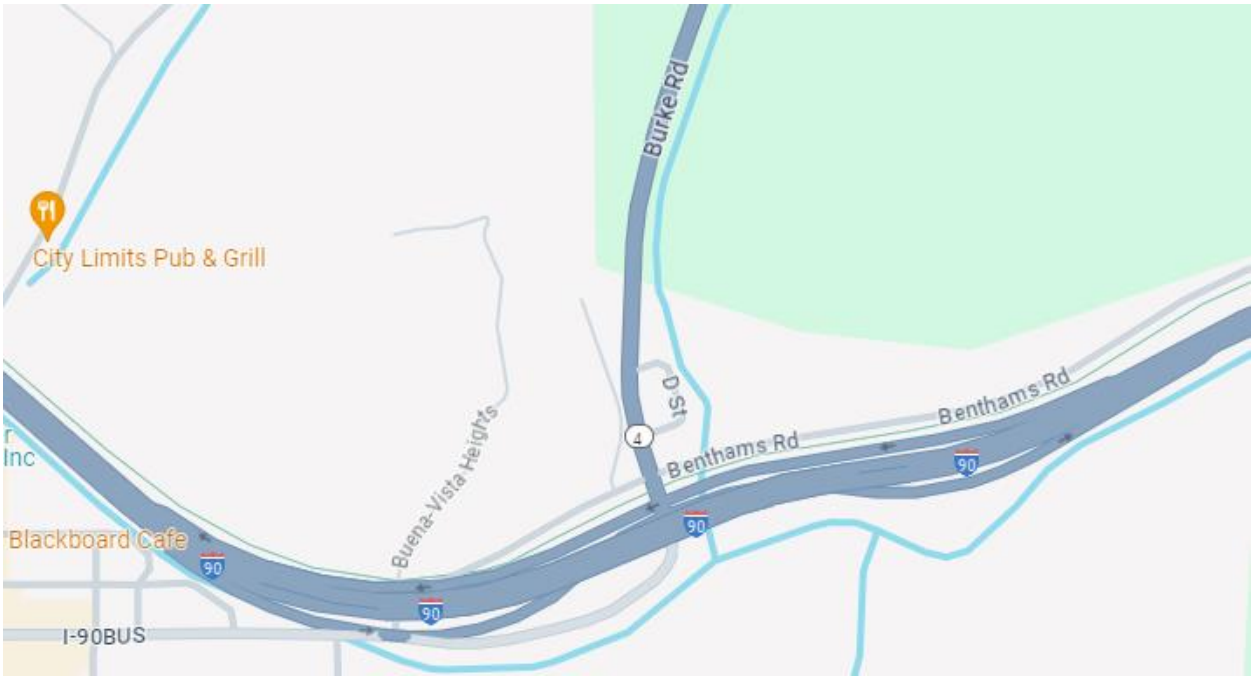

Figure 3.4 Other diamond (OD) interchange at I-90 and Burke Road

Figure 3.5 Partial cloverleaf (PC) interchange at I-90 and State Road 41/E Seltice Way

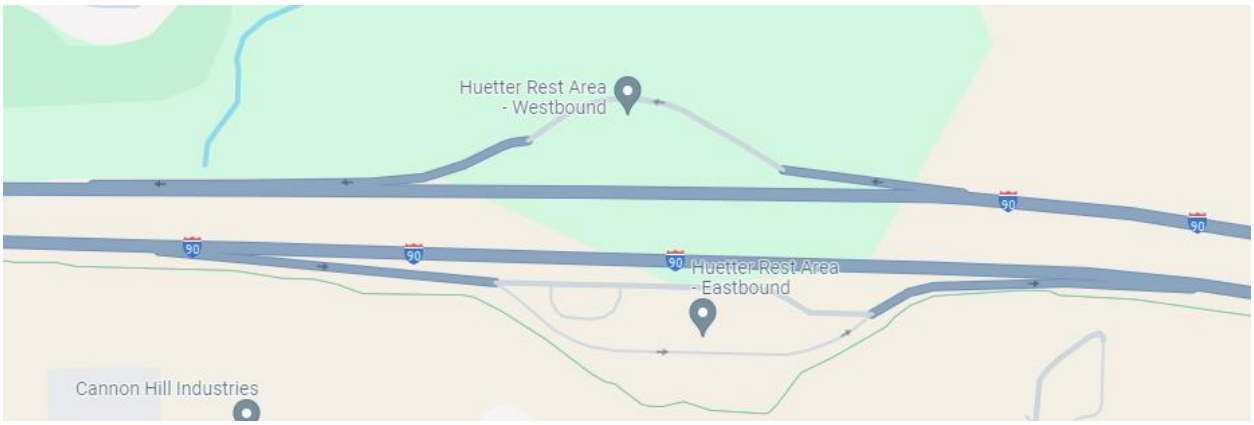

Figure 3.6 Huetter rest area (RA) interchange on I-90

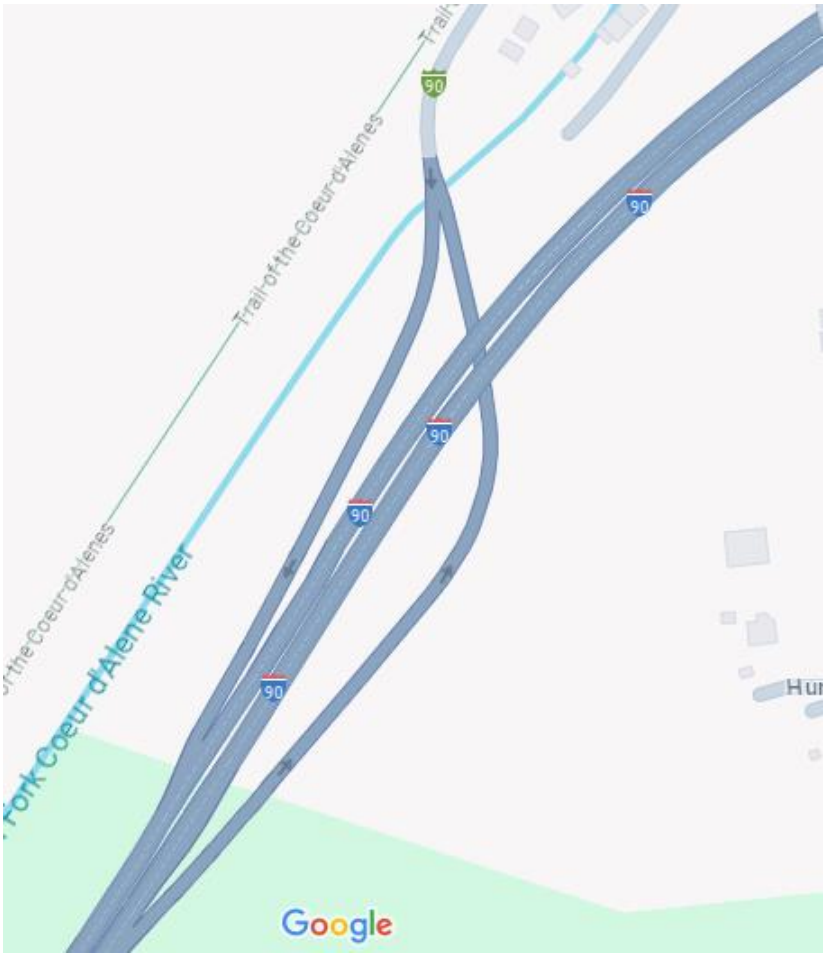

Figure 3.7 Two-leg directional (2L) interchange at I-90 and I-90 Business Loop

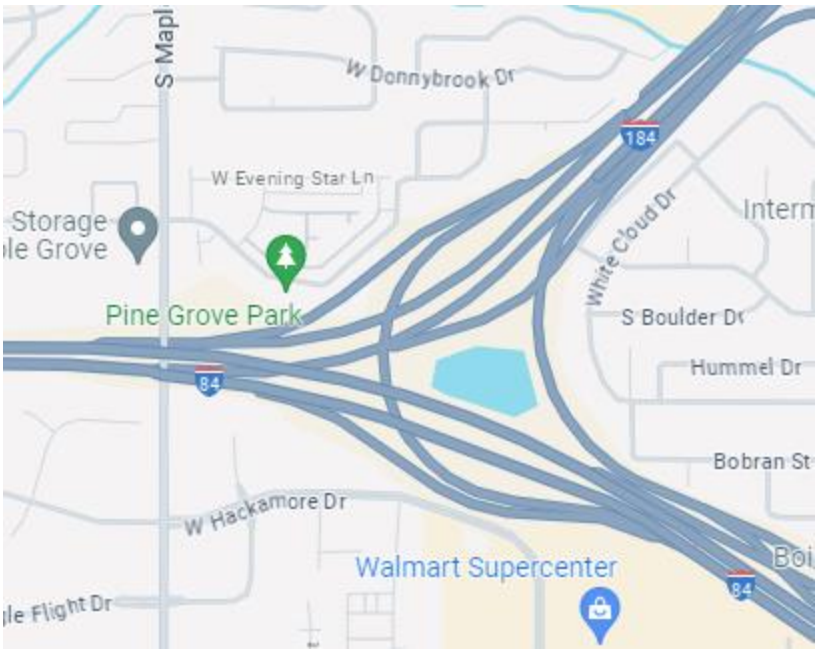

Figure 3.8 Three-leg directional (3L) interchange at I-84 and I-184

Figure 3.9 Slip ramp (SR) interchange at I-90 and Ruddy Gulch Road

Figure 3.10 Unsignalized intersection (UI) at US 20 and N 7th E

Figure 3.11 Other interchange at I-84 and Old U.S. 30

Figure 3.12 shows the interchange at I-90 and W Pointe Pkwy as an example of how these data were collected using Google Maps. The figure shows that this interchange has an exit number of 1, a crossing road of W Pointe Pkwy, is an FD interchange, contains 1 EB exit ramp and 1 WB exit ramp, and has a latitude of 47.701475 and a longitude of -117.019721.

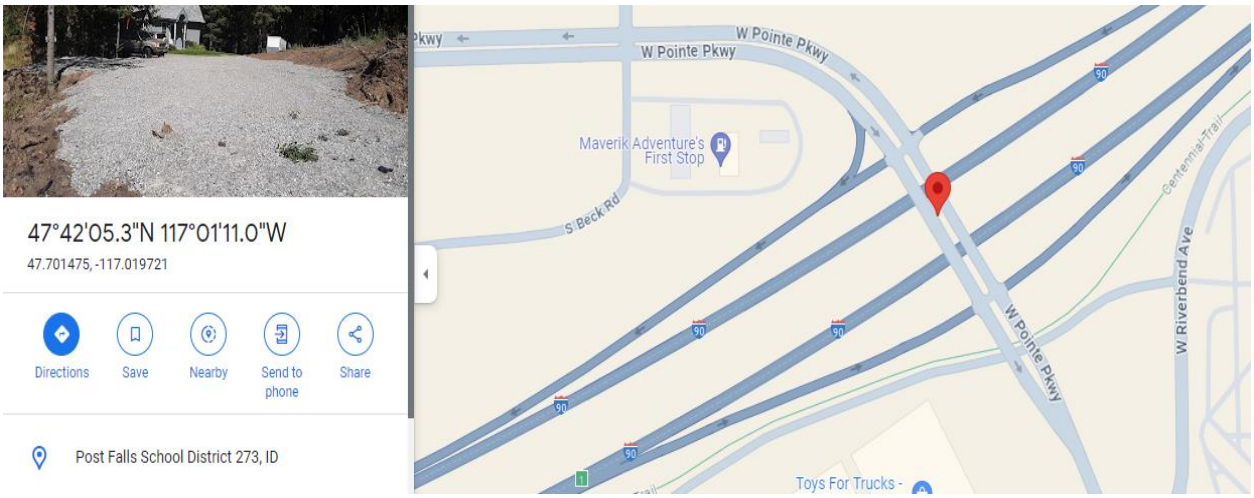

Figure 3.12 Example of roadway data collection using Google Maps

Roadway data collection using IPLAN

The remaining roadway data for exits (distance from the previous exit, county, area type, mainline AADT, exit ramp AADT, and crossing AADT) and mainline segments (length, county, and area type) were collected using the GIS files on the IPLAN website. Both the General Information App and the AADT – Cumulative App were utilized. First, the General Information App was used to obtain the distances between exits, county information, and area type (rural or urban). For the distances between exits and lengths of the mainline segments, the mileposts provided in the General Information App were used, with these distances estimated to the nearest tenth of a mile. To obtain the county and area type data, two layers were added to the General Information layers: a layer containing the Idaho counties and a layer containing the 2020 Census urbanized areas for the US. Using these layers, the county and area type for each exit could be easily determined. If an interchange was located in two counties, each direction's exit was considered to be in the county which contained that direction's exit ramps. Similarly, if an interchange was in both urban and rural areas, the appropriate area type for each exit was determined based on the area type of that direction's exit ramps. For exits outside of Idaho, Google Maps was used to identify the county, with the area type identified in the same manner as Idaho exits.

To collect the AADT values, the AADT – Cumulative App was used. For each exit, five years (2018-2022) of mainline, exit ramp, and crossing AADT values were collected. Previous WWD research in Florida by the UCF research team found that five years of data is typically sufficient for modeling, so the most recent five years of available AADT data when collecting these data were obtained. The procedures used to collect each type of AADT (mainline, exit ramp, and crossing) for each exit are discussed in the

following paragraphs, with exits from I-184 used as examples. If a specific AADT value was not available for a specific exit or year, that value was left blank. This is important to ensure that these missing values do not affect the multi-year averages which will be used in modeling. Note that AADT volumes were used since more detailed traffic volume information were not available for Idaho limited access roadways. This means that information on directional anomalies or volume differences between daytime and nighttime could not be collected.

The mainline AADT values are the traffic volumes that a WW vehicle would encounter if they entered the limited access roadway from the exit ramp(s) at the studied exit. For example, Figure 3.13 shows the mainline AADT segment for I-184 EB at N Curtis Rd (exit ID of E4) highlighted in blue. The total mainline AADT for this segment in 2021 was 76,500 vehicles. However, this is the combined volume for the EB and WB directions. Since a WW vehicle going WB in the EB direction would only encounter vehicles going EB, this total volume was divided by 2 to estimate the number of vehicles in the EB direction. Dividing by 2 was considered to be the best approach since detailed information on the split of AADT by direction was not available. If different AADT values were provided for each direction of the mainline at a specific exit, the value for the appropriate direction was used instead of dividing the total AADT by 2. For the example shown in Figure 3.13, the mainline AADT in 2021 for exit E4 is 76,500/2 = 38,250 vehicles. To make the collected AADT values better suited for modeling, they were divided by 1000 (as this will make the coefficients for the AADT values in the models have similar magnitudes to the coefficients for other variables). Therefore, the reported mainline AADT in 2021 for exit E4 was 38.25.

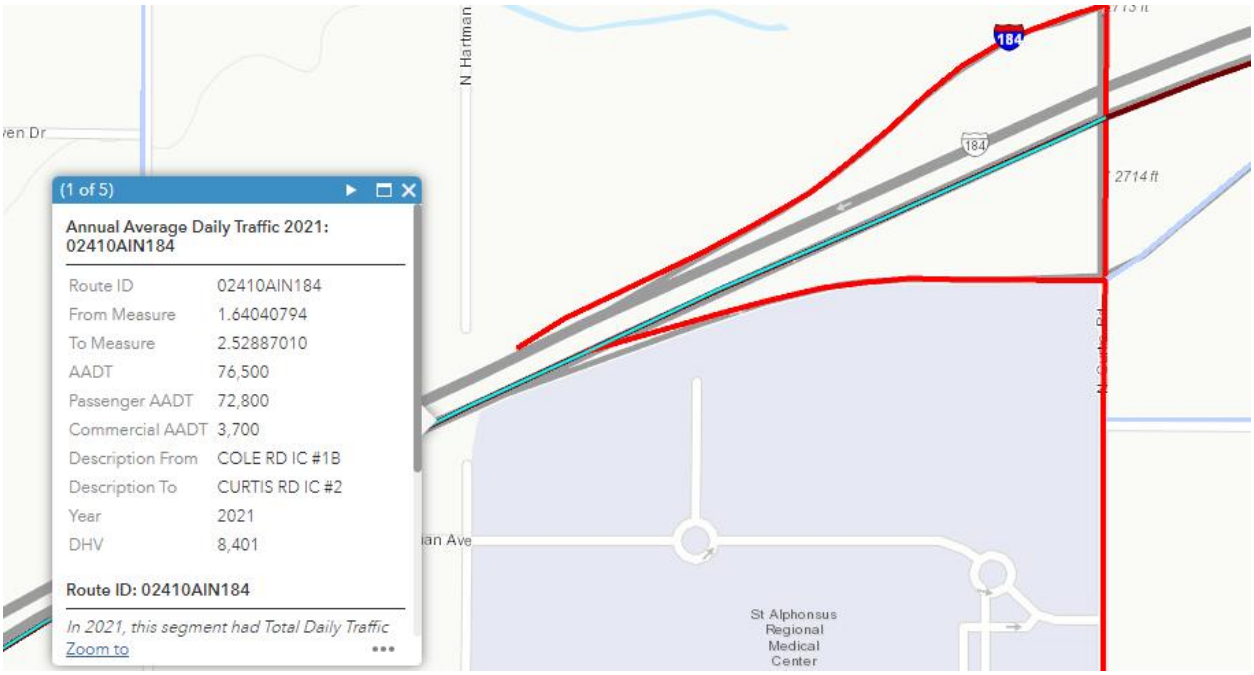

Figure 3.13 Example of mainline AADT in 2021 for exit E4 (I-184 EB at N Curtis Road)

The exit ramp AADT values are the traffic volumes that a WW vehicle would encounter on the exit ramp(s) at the studied exit before the vehicle reaches the limited access mainline. Figure 3.14 shows the

exit ramp AADT segment for I-184 EB at N Curtis Rd (exit ID of E4) highlighted in blue. The total exit ramp AADT for this segment in 2019 was 18,500 vehicles. Since the exit ramp only has traffic in one direction, the entire value can be used since the WW vehicle would face all these vehicles. This means that the AADT does not have to be divided by 2 (like for the mainline), so the reported exit ramp AADT in 2019 for exit E4 is 18.5 (after dividing by 1000 like the mainline AADT).

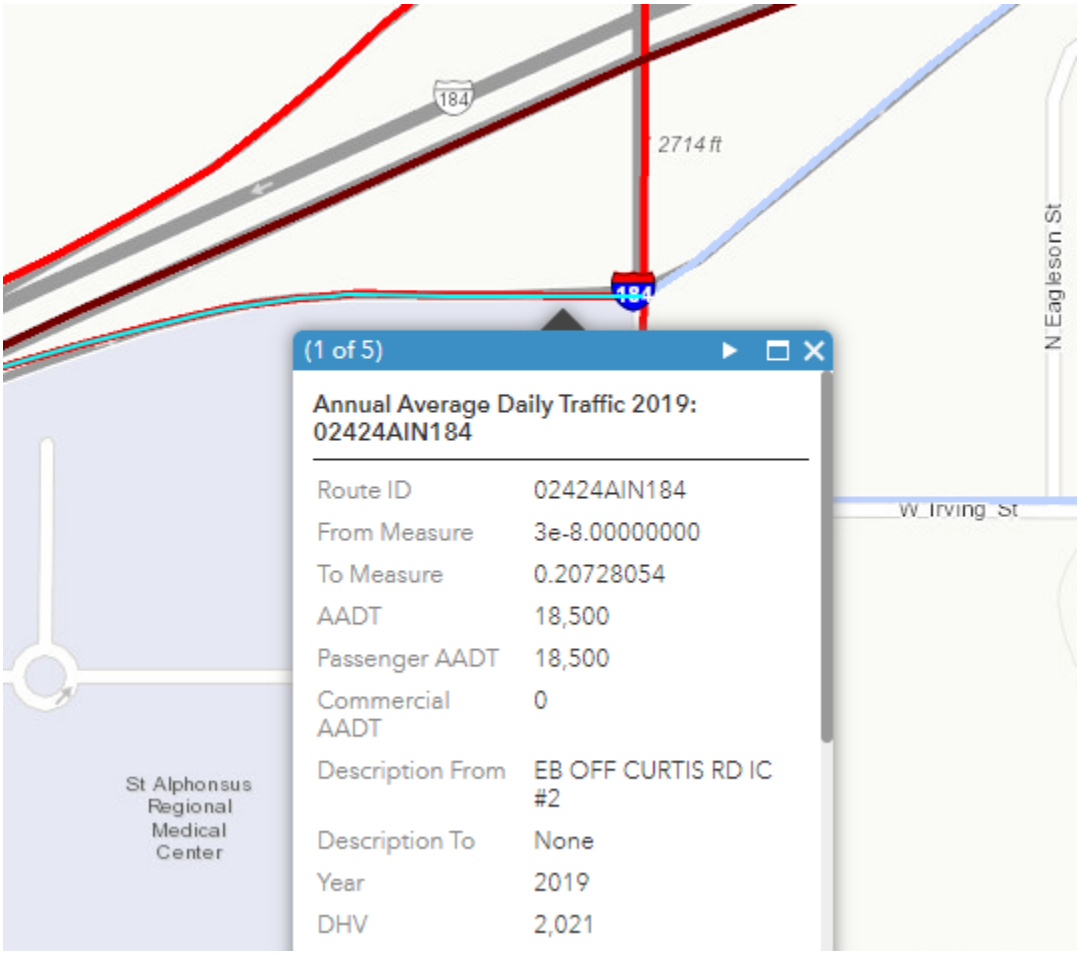

Figure 3.14 Example of exit ramp AADT in 2019 for exit E4 (I-184 EB at N Curtis Road)

The example shown in Figure 3.14 is the simplest case when an exit has only one exit ramp and the AADT segment is the same for the entire ramp. Slightly different procedures were used for cases with multiple exit ramps or where one exit ramp contained multiple AADT segments. For exits with multiple exit ramps, the AADT values for all exit ramps were added together and then averaged to obtain mean exit ramp AADT values for each year. This was done since it is often unknown from which exact ramp a WW vehicle entered from, so taking the average represents the expected AADT that a WW driver would face at that exit. For exit ramps with multiple AADT segments, only the segment where the ramp met the crossing road (either at an intersection or by merging directly onto the crossing road) was considered. This is because that segment represents the AADT that a vehicle would encounter if it were trying to enter the ramp going WW.

The crossing AADT values are the traffic volumes on the crossing road(s) from which a vehicle could potentially go WW on the exit ramp(s) at the studied exit. Figures 3.15 and 3.16 show the crossing AADT segments for I-184 EB at N Curtis Rd (exit ID of E4) highlighted in blue. The segment in Figure 3.15 (AADT of 20,000 in 2019) is located north of the exit ramp (shown in the black rectangle) and is the segment from which crossing vehicles could turn right to go WW on the exit ramp. The segment in Figure 3.16 (AADT of 28,000 in 2019) is located south of the exit ramp (shown in the black rectangle) and is the segment from which crossing vehicles could turn left to go WW on the exit ramp. For each of these segments, only vehicles from one direction could enter the exit ramp going WW, so the crossing AADT values from which drivers could turn WW onto the exit ramp are 10,000 for the segment in Figure 3.15 and 14,000 for the segment in Figure 3.16. Therefore, the total crossing AADT in 2019 for exit E4 is 10,000 + 14,000 = 24,000, or 24 after dividing by 1000. For cases where the crossing AADT segment is the same on both sides of the exit ramp terminal, the total AADT for that segment is used, since vehicles from both directions could enter the exit ramp going WW. This is the same as using the procedures shown in Figures 3.15 and 3.16, but with both of these crossing road segments having the same AADT.

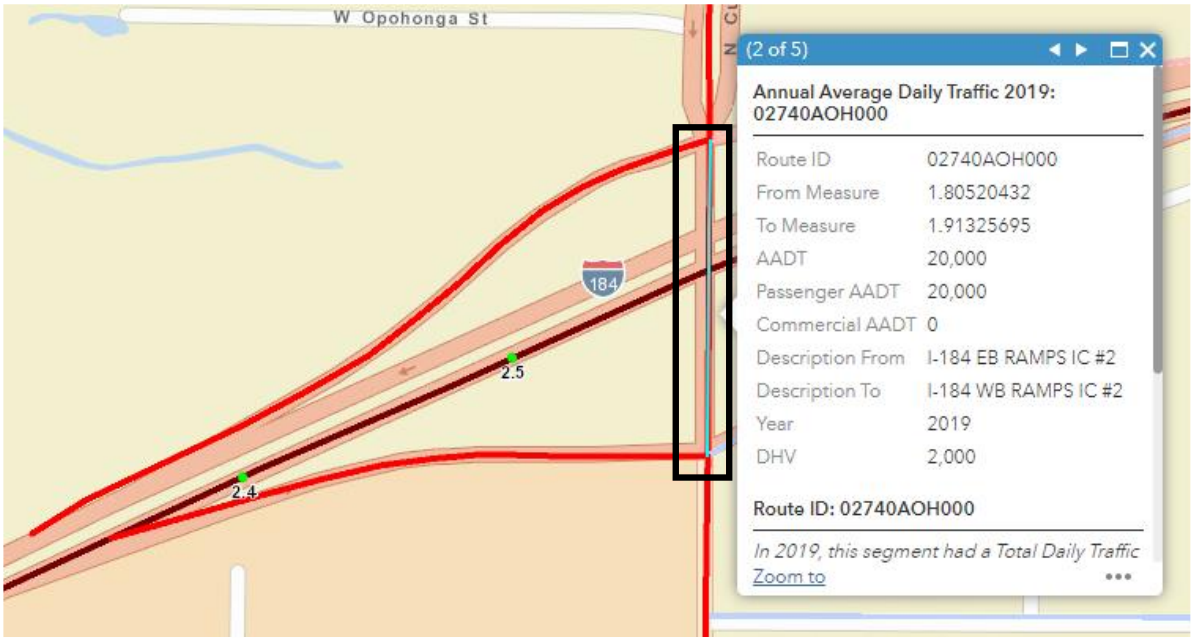

Figure 3.15 Example of crossing AADT in 2019 for right-turning vehicles at exit E4 (I-184 EB at N Curtis Road)

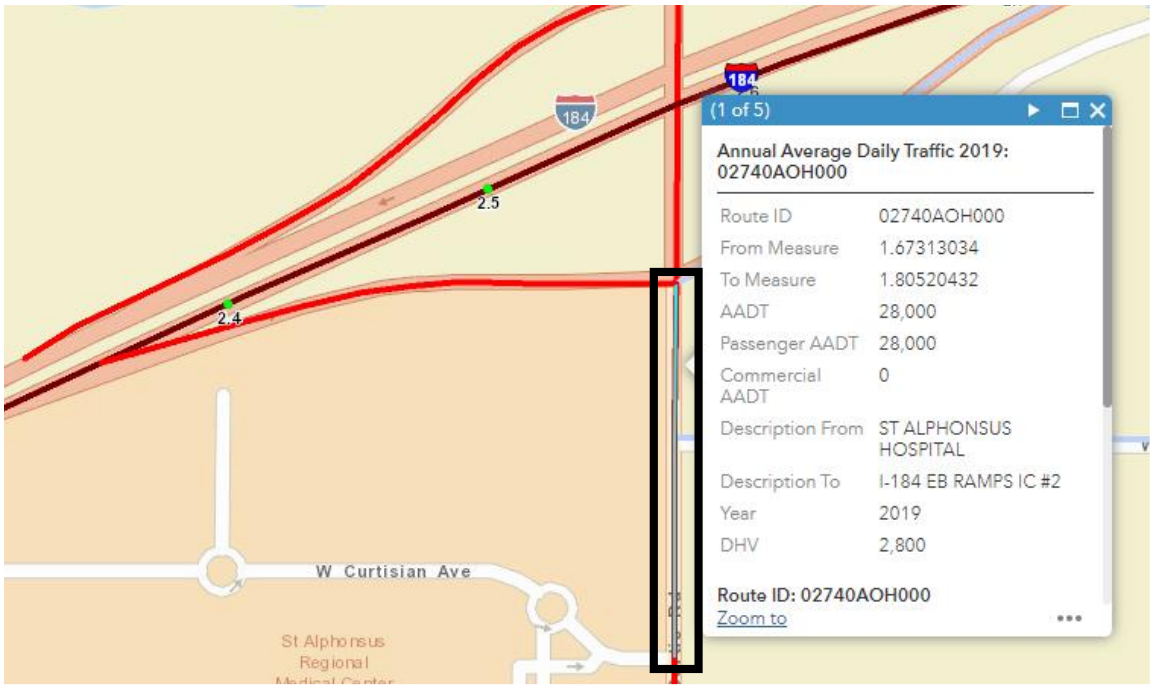

Figure 3.16 Example of crossing AADT in 2019 for left-turning vehicles at exit E4 (I-184 EB at N Curtis Road)

Like the exit ramp AADT values, there were some cases where the crossing AADT values had to be calculated differently. One example is where the exit ramp merges directly onto the crossing road rather than meeting the crossing road at an intersection, such as the 2L interchange shown in Figure 3.7. In these cases, the AADT on the crossing road does not represent vehicles that could potentially turn WW onto the exit ramp, since a vehicle could only enter the exit ramp going WW if it were already going WW on the crossing road. Therefore, crossing AADT values were not collected for these exits and these values were left blank in the spreadsheet. Another case that required different calculations was when the exit ramp terminal includes a road across from the exit ramp from which vehicles could enter the exit ramp in addition to the perpendicular crossing road. For these cases, the AADT for the opposing approach was added to the AADT for the perpendicular crossing road since this opposing approach represents additional vehicles which could enter the ramp going WW.

Summary of collected macroscopic data

Table 3.3 shows the number of interchanges in each of the interchange design categories discussed in the previous section and shown in Figures 3.1 through 3.11, along with each category's percentage of the total 185 interchanges. Note that the percentages in this table do not add up to exactly 100% due to rounding. Approximately 70% of the interchanges were some type of diamond interchange. These interchange designs will be considered during the modeling process to see if some designs tend to result in more WWCs than other designs.

Table 3.3 Number of Interchanges by Design Category for ITD Limited Access Roadways

Interchange Design Category	Count	Percentage of Total
Full Diamond (FD)	108	58.4%
Partial Cloverleaf (PC)	20	10.8%
Rest Area (RA)	12	6.5%
Other Diamond (OD)	9	4.9%
Partial Diamond (PD)	8	4.3%
Other	8	4.3%
Two-Leg Directional (2L)	4	2.2%
Three-Leg Directional (3L)	4	2.2%
Split Diamond (SD)	4	2.2%
Slip Ramps (SR)	4	2.2%
Unsignalized Intersection (UI)	4	2.2%
Total	**185**	**100%**

Tables 3.4, 3.5, and 3.6 summarize the collected mainline, exit ramp, and crossing AADT data, respectively, for each roadway and year from 2018 through 2022. The minimum, maximum, and mean AADT values are reported in these tables, with all values in thousands of vehicles. Blank values were not counted so they did not impact the reported mean values. In general, AADT values were lowest in 2020 (likely due to the COVID-19 pandemic) and highest in 2022. I-184 EB and WB had the highest mean AADT values for all three types of AADT, due to being a short roadway in an urban area. These AADT values will be considered during the modeling process to see how these volumes impact WWC frequency.

Table 3.4 Summary of Mainline AADT Data by Roadway and Year (2018-2022)

Roadway	2018 AADT*	2019 AADT*	2020 AADT*	2021 AADT*	2022 AADT*
I-90 EB	Minimum: 4.25 Mean: 12.28 Maximum: 30.25	Minimum: 4.30 Mean: 12.34 Maximum: 31.25	Minimum: 4.00 Mean: 11.81 Maximum: 28.75	Minimum: 4.55 Mean: 12.87 Maximum: 32.75	Minimum: 4.80 Mean: 12.84 Maximum: 32.25
I-90 WB	Minimum: 3.70 Mean: 12.30 Maximum: 30.25	Minimum: 3.45 Mean: 12.29 Maximum: 31.25	Minimum: 2.90 Mean: 11.84 Maximum: 28.75	Minimum: 3.40 Mean: 12.80 Maximum: 32.75	Minimum: 4.15 Mean: 12.81 Maximum: 32.25
I-84 EB	Minimum: 4.80 Mean: 18.71 Maximum: 69.50	Minimum: 4.80 Mean: 19.21 Maximum: 71.00	Minimum: 4.65 Mean: 17.54 Maximum: 64.00	Minimum: 5.25 Mean: 20.31 Maximum: 70.00	Minimum: 5.50 Mean: 20.34 Maximum: 70.00

Roadway	2018 AADT*	2019 AADT*	2020 AADT*	2021 AADT*	2022 AADT*
I-84 WB	Minimum: 4.80 Mean: 18.48 Maximum: 69.50	Minimum: 4.80 Mean: 18.97 Maximum: 71.00	Minimum: 4.65 Mean: 17.58 Maximum: 62.25	Minimum: 5.25 Mean: 20.09 Maximum: 70.00	Minimum: 5.50 Mean: 20.11 Maximum: 70.00
I-184 EB	Minimum: 30.25 Mean: 36.19 Maximum: 41.50	Minimum: 30.00 Mean: 36.69 Maximum: 42.25	Minimum: 27.25 Mean: 30.06 Maximum: 33.75	Minimum: 33.25 Mean: 34.63 Maximum: 38.25	Minimum: 33.50 Mean: 36.13 Maximum: 39.00
I-184 WB	Minimum: 28.50 Mean: 35.15 Maximum: 41.50	Minimum: 28.50 Mean: 35.55 Maximum: 42.25	Minimum: 22.75 Mean: 28.85 Maximum: 35.50	Minimum: 27.25 Mean: 32.00 Maximum: 38.25	Minimum: 29.25 Mean: 33.35 Maximum: 39.00
I-86 EB	Minimum: 3.80 Mean: 5.83 Maximum: 14.25	Minimum: 3.85 Mean: 5.85 Maximum: 14.25	Minimum: 3.50 Mean: 5.18 Maximum: 11.75	Minimum: 3.95 Mean: 5.83 Maximum: 13.25	Minimum: 3.70 Mean: 5.58 Maximum: 12.75
I-86 WB	Minimum: 3.80 Mean: 5.83 Maximum: 14.25	Minimum: 3.85 Mean: 5.85 Maximum: 14.25	Minimum: 3.50 Mean: 5.18 Maximum: 11.75	Minimum: 3.95 Mean: 5.84 Maximum: 13.25	Minimum: 3.70 Mean: 5.59 Maximum: 12.75
I-15 NB	Minimum: 1.70 Mean: 8.13 Maximum: 19.00	Minimum: 1.70 Mean: 8.09 Maximum: 19.00	Minimum: 1.60 Mean: 7.47 Maximum: 17.00	Minimum: 1.70 Mean: 8.38 Maximum: 19.00	Minimum: 1.70 Mean: 8.34 Maximum: 18.75
I-15 SB	Minimum: 1.70 Mean: 7.93 Maximum: 19.00	Minimum: 1.25 Mean: 7.92 Maximum: 19.00	Minimum: 1.45 Mean: 7.24 Maximum: 17.00	Minimum: 1.70 Mean: 8.20 Maximum: 19.00	Minimum: 1.70 Mean: 8.16 Maximum: 18.75
US 20 EB	Minimum: 5.75 Mean: 10.32 Maximum: 17.00	Minimum: 5.75 Mean: 10.48 Maximum: 17.50	Minimum: 5.25 Mean: 10.05 Maximum: 16.25	Minimum: 6.25 Mean: 11.31 Maximum: 18.25	Minimum: 6.25 Mean: 11.64 Maximum: 18.00
US 20 WB	Minimum: 4.35 Mean: 10.09 Maximum: 17.00	Minimum: 4.45 Mean: 10.24 Maximum: 17.50	Minimum: 3.80 Mean: 9.95 Maximum: 16.25	Minimum: 4.65 Mean: 11.28 Maximum: 18.25	Minimum: 4.50 Mean: 11.46 Maximum: 18.00

* All volumes shown in this table are in thousands of vehicles per day.

Table 3.5 Summary of Exit Ramp AADT Data by Roadway and Year (2018-2022)

Roadway	2018 AADT*	2019 AADT*	2020 AADT*	2021 AADT*	2022 AADT*
I-90 EB	Minimum: 0.02 Mean: 2.32 Maximum: 11.00	Minimum: 0.02 Mean: 2.42 Maximum: 11.00	Minimum: 0.02 Mean: 2.37 Maximum: 11.00	Minimum: 0.02 Mean: 2.57 Maximum: 11.50	Minimum: 0.02 Mean: 2.35 Maximum: 11.50
I-90 WB	Minimum: 0.02 Mean: 1.49 Maximum: 7.40	Minimum: 0.02 Mean: 1.60 Maximum: 7.00	Minimum: 0.02 Mean: 1.71 Maximum: 7.50	Minimum: 0.02 Mean: 1.55 Maximum: 7.00	Minimum: 0.02 Mean: 1.47 Maximum: 6.70
I-84 EB	Minimum: 0.07 Mean: 3.54 Maximum: 41.75	Minimum: 0.07 Mean: 3.59 Maximum: 41.50	Minimum: 0.07 Mean: 3.38 Maximum: 38.75	Minimum: 0.07 Mean: 3.71 Maximum: 46.25	Minimum: 0.07 Mean: 3.77 Maximum: 47.50
I-84 WB	Minimum: 0.07 Mean: 3.18 Maximum: 16.00	Minimum: 0.05 Mean: 3.28 Maximum: 18.00	Minimum: 0.05 Mean: 3.02 Maximum: 17.00	Minimum: 0.07 Mean: 3.31 Maximum: 18.00	Minimum: 0.07 Mean: 3.31 Maximum: 18.00
I-184 EB	Minimum: 10.50 Mean: 17.17 Maximum: 23.00	Minimum: 10.50 Mean: 17.33 Maximum: 23.00	Minimum: 8.70 Mean: 14.23 Maximum: 19.00	Minimum: 9.50 Mean: 16.67 Maximum: 25.50	Minimum: 11.00 Mean: 17.33 Maximum: 28.00
I-184 WB	Minimum: 5.00 Mean: 8.19 Maximum: 16.25	Minimum: 4.60 Mean: 8.66 Maximum: 18.00	Minimum: 3.50 Mean: 7.47 Maximum: 16.25	Minimum: 4.50 Mean: 9.41 Maximum: 23.75	Minimum: 4.30 Mean: 9.24 Maximum: 23.50
I-86 EB	Minimum: 0.03 Mean: 1.59 Maximum: 11.60	Minimum: 0.03 Mean: 1.63 Maximum: 11.75	Minimum: 0.05 Mean: 1.22 Maximum: 9.75	Minimum: 0.05 Mean: 1.35 Maximum: 10.85	Minimum: 0.05 Mean: 1.27 Maximum: 10.60
I-86 WB	Minimum: 0.03 Mean: 1.50 Maximum: 9.60	Minimum: 0.03 Mean: 1.53 Maximum: 9.90	Minimum: 0.05 Mean: 1.10 Maximum: 7.50	Minimum: 0.10 Mean: 1.23 Maximum: 8.40	Minimum: 0.10 Mean: 1.22 Maximum: 8.20
I-15 NB	Minimum: 0.02 Mean: 1.45 Maximum: 8.10	Minimum: 0.04 Mean: 1.50 Maximum: 8.10	Minimum: 0.03 Mean: 1.57 Maximum: 8.10	Minimum: 0.03 Mean: 1.57 Maximum: 8.10	Minimum: 0.03 Mean: 1.56 Maximum: 8.20
I-15 SB	Minimum: 0.02 Mean: 1.46 Maximum: 9.70	Minimum: 0.02 Mean: 1.49 Maximum: 8.60	Minimum: 0.03 Mean: 1.54 Maximum: 8.50	Minimum: 0.03 Mean: 1.73 Maximum: 8.50	Minimum: 0.03 Mean: 1.56 Maximum: 8.50
US 20 EB	Minimum: 0.50 Mean: 1.94 Maximum: 4.60	Minimum: 0.50 Mean: 2.03 Maximum: 4.60	Minimum: 0.50 Mean: 2.23 Maximum: 5.70	Minimum: 0.50 Mean: 2.49 Maximum: 6.20	Minimum: 0.43 Mean: 2.42 Maximum: 5.60

Roadway	2018 AADT*	2019 AADT*	2020 AADT*	2021 AADT*	2022 AADT*
US 20 WB	Minimum: 0.50 Mean: 2.20 Maximum: 4.05	Minimum: 0.50 Mean: 2.19 Maximum: 4.25	Minimum: 0.50 Mean: 2.25 Maximum: 4.70	Minimum: 0.90 Mean: 2.48 Maximum: 5.50	Minimum: 0.70 Mean: 2.28 Maximum: 5.20

* All volumes shown in this table are in thousands of vehicles per day.

Table 3.6 Summary of Crossing AADT Data by Roadway and Year (2018-2022)

Roadway	2018 AADT*	2019 AADT*	2020 AADT*	2021 AADT*	2022 AADT*
I-90 EB	Minimum: 0.01 Mean: 5.85 Maximum: 30.50	Minimum: 0.01 Mean: 5.94 Maximum: 30.50	Minimum: 0.01 Mean: 5.59 Maximum: 30.00	Minimum: 0.01 Mean: 6.17 Maximum: 33.50	Minimum: 0.01 Mean: 6.00 Maximum: 34.75
I-90 WB	Minimum: 0.02 Mean: 6.79 Maximum: 34.00	Minimum: 0.02 Mean: 6.83 Maximum: 33.75	Minimum: 0.02 Mean: 6.56 Maximum: 33.00	Minimum: 0.02 Mean: 7.13 Maximum: 35.00	Minimum: 0.02 Mean: 7.07 Maximum: 35.75
I-84 EB	Minimum: 0.03 Mean: 9.91 Maximum: 47.25	Minimum: 0.03 Mean: 10.03 Maximum: 47.25	Minimum: 0.03 Mean: 10.13 Maximum: 48.75	Minimum: 0.03 Mean: 11.04 Maximum: 50.75	Minimum: 0.03 Mean: 11.19 Maximum: 52.25
I-84 WB	Minimum: 0.03 Mean: 9.74 Maximum: 58.25	Minimum: 0.03 Mean: 9.89 Maximum: 58.25	Minimum: 0.03 Mean: 9.29 Maximum: 56.00	Minimum: 0.03 Mean: 10.42 Maximum: 60.75	Minimum: 0.03 Mean: 10.63 Maximum: 62.50
I-184 EB	Minimum: 14.00 Mean: 21.44 Maximum: 30.25	Minimum: 14.00 Mean: 20.89 Maximum: 29.25	Minimum: 10.35 Mean: 16.46 Maximum: 24.25	Minimum: 11.35 Mean: 17.90 Maximum: 26.75	Minimum: 10.95 Mean: 18.68 Maximum: 27.00
I-184 WB	Minimum: 23.00 Mean: 32.75 Maximum: 48.25	Minimum: 21.00 Mean: 30.92 Maximum: 45.50	Minimum: 13.50 Mean: 24.25 Maximum: 37.50	Minimum: 14.75 Mean: 26.75 Maximum: 41.50	Minimum: 15.25 Mean: 28.50 Maximum: 43.75
I-86 EB	Minimum: 0.07 Mean: 3.01 Maximum: 23.00	Minimum: 0.06 Mean: 2.98 Maximum: 23.00	Minimum: 0.08 Mean: 2.58 Maximum: 20.50	Minimum: 0.09 Mean: 2.58 Maximum: 19.50	Minimum: 0.09 Mean: 2.59 Maximum: 19.50
I-86 WB	Minimum: 0.04 Mean: 3.16 Maximum: 23.00	Minimum: 0.03 Mean: 3.30 Maximum: 23.00	Minimum: 0.04 Mean: 2.96 Maximum: 20.50	Minimum: 0.05 Mean: 2.95 Maximum: 19.50	Minimum: 0.05 Mean: 2.95 Maximum: 19.50
I-15 NB	Minimum: 0.06 Mean: 5.23 Maximum: 24.75	Minimum: 0.03 Mean: 5.35 Maximum: 24.50	Minimum: 0.01 Mean: 5.36 Maximum: 22.75	Minimum: 0.01 Mean: 5.87 Maximum: 25.25	Minimum: 0.01 Mean: 5.43 Maximum: 26.25

Roadway	2018 AADT*	2019 AADT*	2020 AADT*	2021 AADT*	2022 AADT*
I-15 SB	Minimum: 0.02 Mean: 4.68 Maximum: 22.00	Minimum: 0.03 Mean: 4.77 Maximum: 21.50	Minimum: 0.01 Mean: 4.77 Maximum: 21.50	Minimum: 0.01 Mean: 5.35 Maximum: 26.00	Minimum: 0.01 Mean: 4.96 Maximum: 25.50
US 20 EB	Minimum: 0.30 Mean: 6.30 Maximum: 16.50	Minimum: 0.30 Mean: 6.49 Maximum: 18.00	Minimum: 0.71 Mean: 6.44 Maximum: 20.00	Minimum: 0.81 Mean: 7.40 Maximum: 22.75	Minimum: 0.80 Mean: 7.18 Maximum: 21.75
US 20 WB	Minimum: 0.30 Mean: 4.88 Maximum: 13.25	Minimum: 0.30 Mean: 5.01 Maximum: 15.00	Minimum: 0.71 Mean: 5.08 Maximum: 16.50	Minimum: 0.81 Mean: 5.65 Maximum: 17.25	Minimum: 0.80 Mean: 5.83 Maximum: 15.00

* All volumes shown in this table are in thousands of vehicles per day.

Microscopic Exit Ramp and Entrance Ramp Characteristics

The design characteristics of exit and entrance ramps can have a major influence on WWD activity. Therefore, it is important to consider microscopic design characteristics when modeling WWD crashes. The UCF research team collected data for the 14 microscopic variables listed in Table 3.7 using Google Maps. Table 3.7 also contains a brief description of each variable, along with its variable type (categorical or integer), and all possible variable values identified for Idaho limited access exits. Detailed discussions of these variables, reasons why they were considered for the WWD hotspot modeling, and examples of values for certain variables are provided after the table. Some of these variables ended up not being considered in the modeling process due to not being applicable to all data or not being as informative for multi-exit roadway segments compared to single exits; see Chapter 5 for more details.

Table 3.7 Microscopic Exit Ramp and Entrance Ramp Characteristics

Characteristic	Description	Variable Type	Values
Exit Lighting	The presence of external lighting at the exit ramp terminal	Categorical	Yes, No
Exit Intersection	The type of intersection at the exit ramp terminal	Categorical	3 Leg, 4 Leg, Merge, Other
Exit Control	The type of traffic control present at the exit ramp terminal	Categorical	Signal, Sign, None
Exit Lane Number	Number of travel lanes for exiting vehicles on the exit ramp at the exit ramp terminal	Integer	1, 2, 3, 4, 5
Exit Right Angle	Indicates if the exit ramp terminal makes a right angle with the crossing street	Categorical	Yes, No

Characteristic	Description	Variable Type	Values
Exit Separated Right Turn	Indicates if exiting vehicles making a right turn onto the crossing street merge at a separate location from through or left-turning vehicles	Categorical	Yes, No
Exit Opposing	The direction of right-way vehicles on the approach opposing the exit ramp terminal	Categorical	Away, Toward, Two-Way, None
Right Way Turns	Indicates if vehicles on the crossing street are allowed to make right-way turns onto the approach containing the exit ramp	Categorical	Allowed, Not Allowed
Crossing Median Type	Indicates the type of median present for crossing street vehicles which could potentially turn left to go WW on the exit ramp	Categorical	Paved, Raised, Grass, Other, None
Crossing Median Extension	Indicates whether the crossing median extends into the ramp terminal intersection	Categorical	Yes, No
Entrance Lighting	The presence of external lighting at the entrance ramp opening	Categorical	Yes, No, No Entrance Ramp (i.e., exit ramp only)
Entrance Lane Number	Number of travel lanes for vehicles entering the entrance ramp at the entrance ramp opening	Integer	0, 1, 2, 3
Entrance Wider	Indicates whether the entrance ramp opening is wider than the exit ramp terminal	Categorical	Yes, No, No Entrance Ramp
Entrance Location	The location of the entrance ramp opening relative to the exit ramp terminal	Categorical	Opposing, Adjacent, Other, No Entrance Ramp

- Exit Lighting: This variable was considered since most WWCs happen at night and it is expected that lighting will make it easier for potential WW drivers to see the exit ramp before turning onto it. However, proper signage and pavement markings are also important for lighting to have the desired impact. Without these, drivers might be more likely to turn onto exit ramps with lighting because drivers think the lights are indicating where they need to go. Lighting will also likely not have an impact on daytime WWCs. Therefore, care is needed when considering the potential impact of exit lighting on WWCs. Overall, 198 of the 341 exits (58.1%) had lighting at the exit ramp terminal. It is recommended to deploy lighting at the 42% of exits without lighting if possible, unless there are other reasons why certain exits do not have lighting.

- Exit Intersection: This variable was considered since the type of intersection at the exit ramp terminal affects the number of potential ways drivers could go WW on the exit ramp. Figure 3.17 shows an example of a 4-leg exit intersection, Figure 3.18 shows an example of a 3-leg exit intersection, Figure 3.19 shows an example of a "Merge" exit intersection (the exit ramp merges directly onto the crossing street), and Figure 3.20 shows an example of an "Other" exit intersection (one intersection underneath I-84 for all exit and entrance ramps at the interchange). The exit ramps are shown in a yellow box or oval and labeled in all four of these figures. It is expected that exit ramp terminals with fewer approaches (such as direct merge exit ramps or 3-leg intersections) would have less WWD. The most common exit intersection type was 4 leg (254 exits or 74.5%), followed by 3 leg (39 exits or 11.4%), other (30 exits or 8.8%), and merge (18 exits or 5.3%).

Figure 3.17 Example of "4 Leg" exit intersection (I-90 EB at Pleasant View Road)

Figure 3.18 Example of "3 Leg" exit intersection (I-90 EB at S. Latour Creek Road)

Figure 3.19 Example of "Merge" exit intersection (I-84 EB at W. Overland Road)

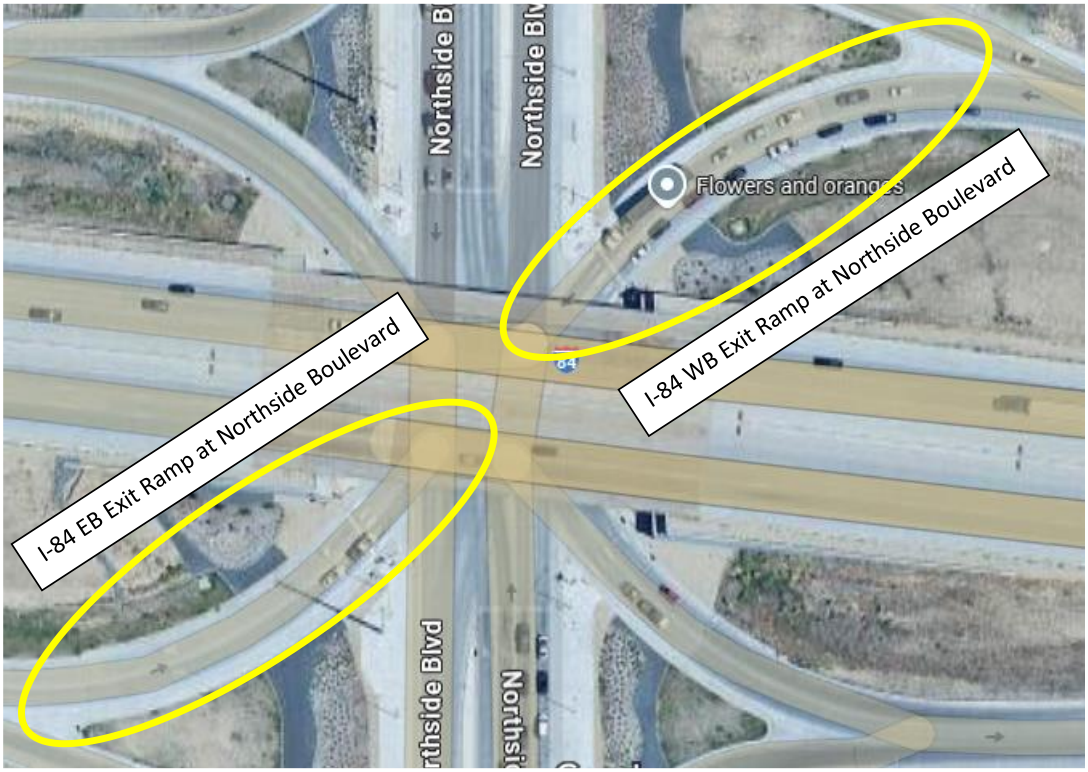

Figure 3.20 Example of "Other" exit intersection (I-84 EB and WB at Northside Blvd.)

- Exit Control: This variable was considered since the type of traffic control present at the exit ramp terminal intersection could make it easier or harder for drivers to turn WW onto the exit ramp. Exit ramp intersections with no traffic control could be more susceptible to WWD, while exit ramp intersections with traffic signals could be less susceptible to WWD (since the traffic signals help drivers identify the proper direction of traffic flow). Overall, 224 of the 341 studied exits (65.7%) had stop and/or yield signs as traffic control, 69 exits (20.2%) had traffic signal control, and 48 exits (14.1%) had no traffic control.

- Exit Lane Number: This variable was considered since having more lanes on the exit ramp terminal could make drivers more likely to turn WW onto the exit ramp. Only the number of exit ramp lanes at the exit ramp terminal intersection were counted in this value, meaning that exit ramp turn lanes which meet the crossing street at a different location than the exit ramp terminal intersection were not counted. The 341 Idaho exits contained either 1, 2, 3, 4, or 5 lanes at their exit ramp terminals, with 213 exits (62.5%) having 1 lane, 94 (27.6%) having 2 lanes, 29 (8.5%) having 3 lanes, 4 (1.2%) having 4 lanes, and 1 (0.3%) having 5 lanes.

- Exit Right Angle: This variable was considered since exit ramps with sharp angles could be more difficult for WW drivers to enter. Overall, 213 of the 341 exits (62.5%) did not have a right angle at the exit ramp terminal.

- Exit Separated Right Turn: This variable was considered since exit ramps with separated right turns could have less WWD than traditional exit ramps due to one entry lane for potential WW

drivers being moved away from the exit ramp terminal. Only 31 of the 341 exits (9.1%) contained a separated right turn, with one example shown in Figure 3.21.

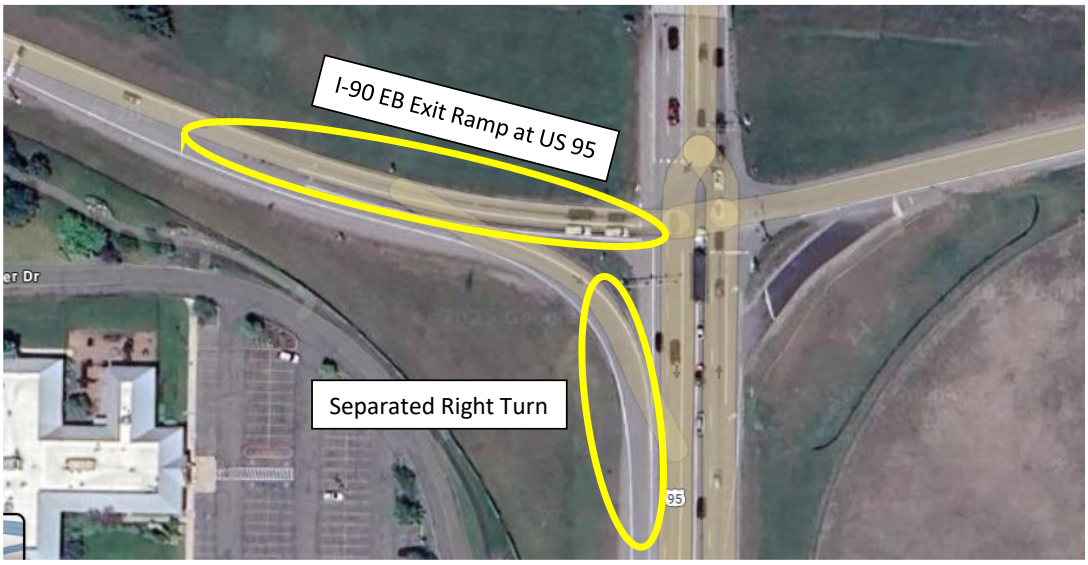

Figure 3.21 Example of exit ramp with separated right turn (I-90 EB at US 95)

- Exit Opposing: This variable was considered since the type of approach opposing the exit ramp terminal could increase or decrease the potential for WWD. It is possible that exits with opposing approaches where right-way drivers can go toward the exit ramp (values of "Toward" or "Two-Way") could have more WWD than exits with opposing approaches where right-way drivers can only travel away from the exit ramp (value of "Away") or exits with no opposing approaches (value of "None"). Most exits had Exit Opposing values of "Away" (243 exits or 71.3%), followed by "None" (73 exits or 21.4%), "Two-Way" (15 exits or 4.4%), and "Toward" (10 exits, or 2.9%). Figures 3.22, 3.23, and 3.24 shows examples of "Away", "Toward", and "Two-Way" respectively, with the yellow arrows indicating the directions right-way vehicles can travel on the approach opposing the exit ramp.

Figure 3.22 Example of exit ramp with "Away" exit opposing value (I-90 EB at Pleasant View Road)

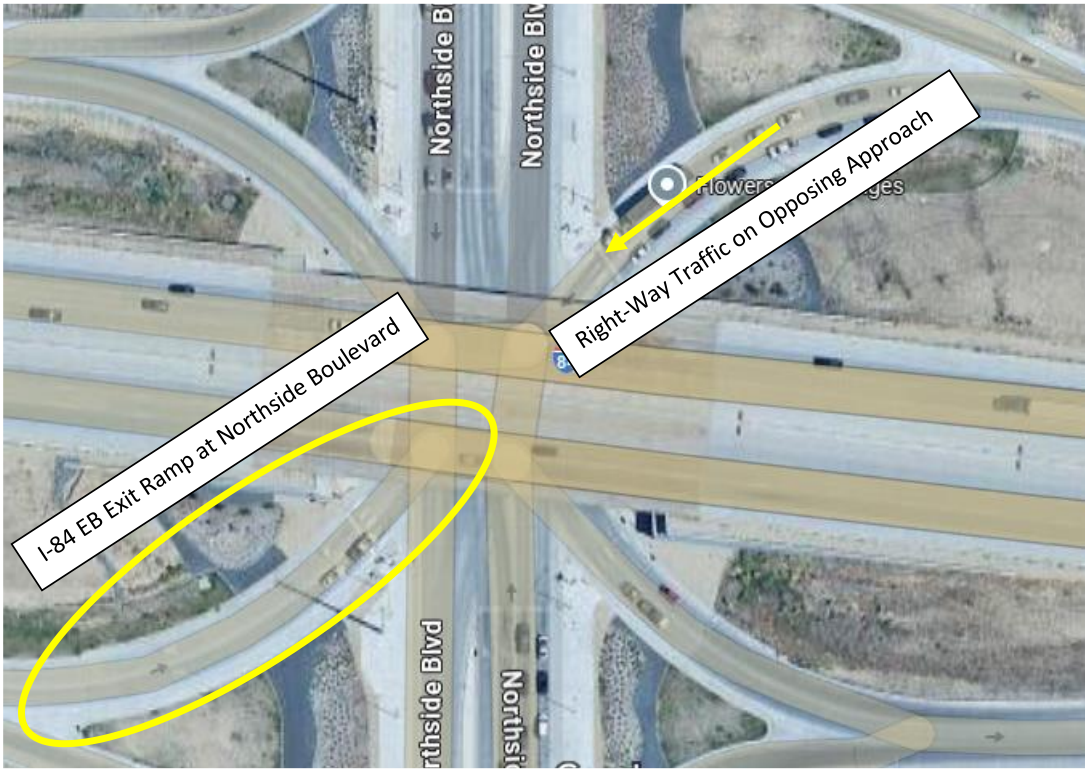

Figure 3.23 Example of exit ramp with "Toward" exit opposing value (I-84 EB at Northside Boulevard)

Figure 3.24 Example of exit ramp with "Two-Way" exit opposing value (I-90 EB at North 23rd Street)

- Right Way Turns: This variable was considered since exit ramps located on approaches where right-way drivers can turn onto the approach containing the exit ramp (due to there being an entrance ramp or road parallel to the exit ramp) could be more likely to have WWD, due to these drivers incorrectly turning onto the exit ramp rather than the parallel roadway. Only 32 of the 341 exits (9.4%) allowed drivers to make right-way turns onto the approach containing the exit ramp. Figure 3.25 shows an example of an exit where drivers on the crossing road can make right-way turns onto the approach containing the exit ramp. In this figure, the entrance ramp is shown in a yellow box and the exit ramp is shown in a red box, with right-way turns indicated by yellow arrows and WW turns indicated by red arrows.

Figure 3.25 Example of exit ramp with right way turns allowed (I-90 EB at S. Latour Creek Road)

- Crossing Median Type: This variable was considered since different crossing street median types could have different impacts on the ability of crossing street drivers to make WW left turns on the exit ramp. It is expected that crossing streets with physical medians (values of "Raised" or "Grass") would have less WWD than crossing street with Crossing Median Types of "Paved" or "None". Most exits had a Crossing Median Type of "None" (204 exits or 59.8%), followed by "Paved" (86 exits or 25.2%), "Raised" (43 exits, or 12.6%), "Grass" (5 exits or 1.5%), and "Other" (3 exits or 0.9%). The "Other" median cases were at exits between two limited access facilities where a barrier and steep elevation drop separated the travel directions on the crossing roadway.

- Crossing Median Extension: This variable was considered since having the crossing street median extend into the exit ramp terminal intersection could make it more difficult for drivers to make WW left turns onto the exit ramp. Figure 3.26 shows an example of an exit with a crossing median extension with the median extension in the yellow box and the exit ramp in the red box. Median extensions were present at 32 of the 341 exits (9.4%).

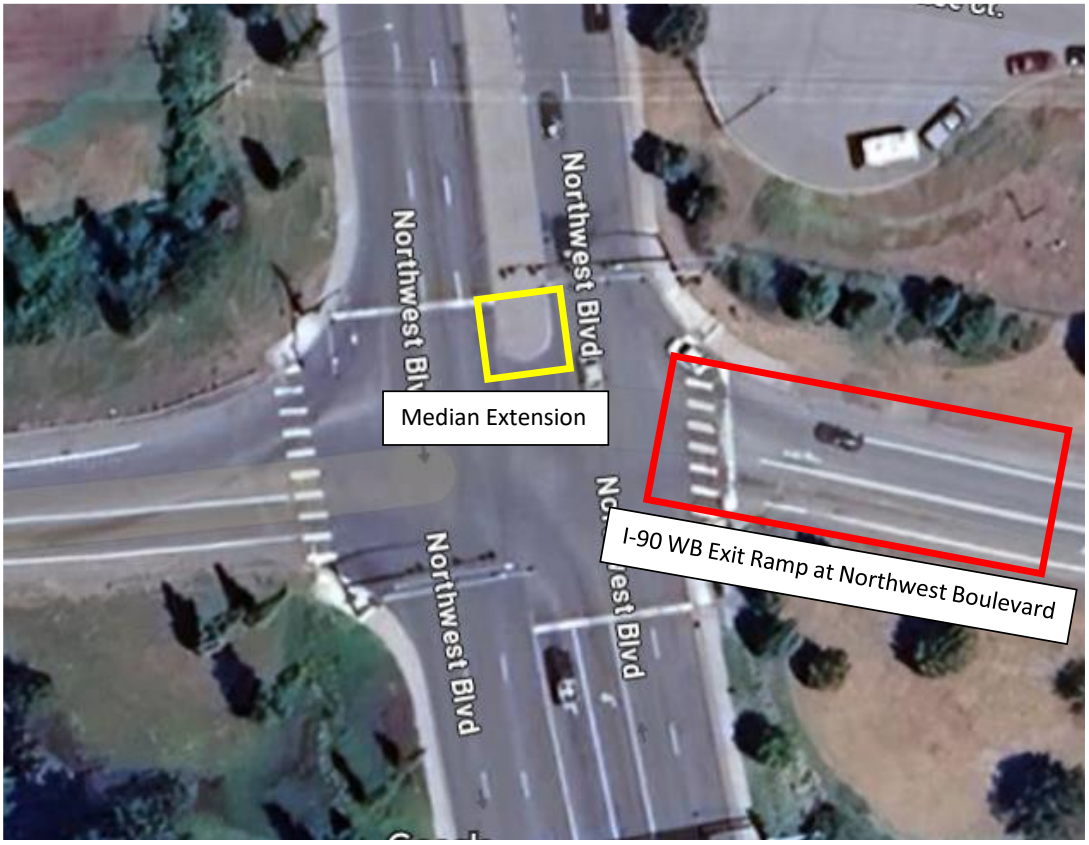

Figure 3.26 Example of a crossing median extension (I-90 WB at Northwest Blvd.)

- Entrance Lighting: This variable is the same as the Exit Lighting variable, but for the entrance ramp rather than the exit ramp. Like the Exit Lighting variable, it was considered since most WWCs happen at night and it is expected that lighting will make it easier for drivers to correctly identify the entrance ramp. Since not all exit ramps have an associated entrance ramp, a value of "No Entrance Ramp" was added to differentiate between exits with no associated entrance ramp and exits with an associated entrance ramp, but no lighting on the entrance ramp. The absence of entrance ramps for some exits can make it difficult to accurately determine the impacts of entrance ramp characteristics on WWD, so care is needed when considering this or any other entrance ramp variable when modeling. Overall, 322 of the 341 studied exits (94.4%) had an associated entrance ramp, with 184 of these 322 exits (57.1%) having lighting at the entrance ramp opening.

- Entrance Lane Number: This variable was considered since having more lanes on the entrance ramp opening could make drivers more likely to turn right way onto the entrance ramp rather than turning WW onto the exit ramp. The 322 Idaho exits with entrance ramps contained entrance ramp openings with either 1, 2, or 3 lanes, with 278 entrance ramp openings (86.3%) having 1 lane, 42 (13.0%) having 2 lanes, and 2 (0.6%) having 3 lanes.

- Entrance Wider: This variable was considered since wider entrance ramp openings relative to the exit ramp terminals can help direct drivers to the entrance ramp, thereby discouraging

WWD on the exit ramp. The throat widths for each exit ramp terminal and its associated entrance ramp opening were measured and compared. For the 322 exits with associated entrance ramps, 174 (54.0%) had the entrance ramp narrower than the exit ramp, which could potentially result in more WWD.

- Entrance Location: This variable was considered since the location of the entrance ramp relative to the exit ramp could potentially cause drivers to go WW on the exit ramp. It is possible that exits where the entrance ramp is adjacent to or opposing the exit ramp could have more WWD than exits where the entrance ramp is accessed at a different point from the exit ramp. The 322 exits with associated entrance ramps included 245 (76.1%) with opposing entrance ramps, 23 (7.1%) with adjacent entrance ramps, and 54 (16.8%) with an Entrance Location of "Other". Figure 3.25 shows an example of an "Adjacent" entrance ramp, while Figures 3.27 and 3.28 show examples of "Opposing" and "Other" entrance ramps, respectively. In these figures, the entrance ramps are circled in yellow and the exit ramps are circled in red.

Figure 3.27 Example of "Opposing" entrance location (I-90 EB at Pleasant View Rd.)

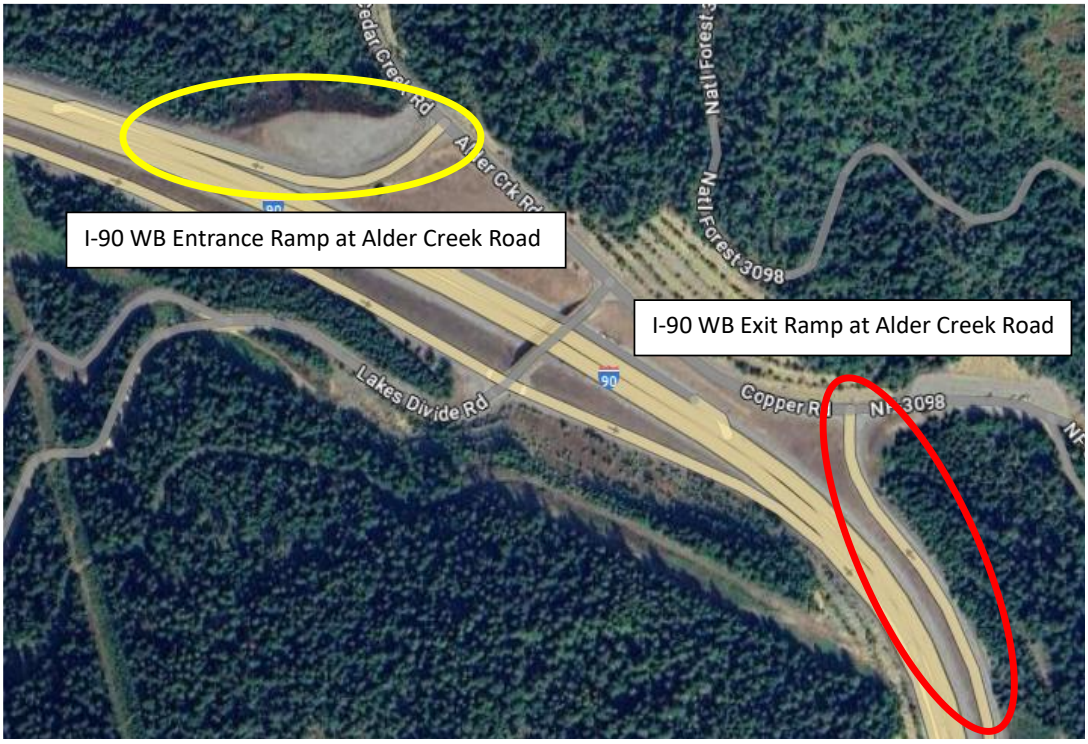

Figure 3.28 Example of "Other" entrance location (I-90 WB at Alder Creek Rd.)

Existing WWD Signage and Pavement Marking Countermeasures

Sufficient signage and pavement markings on exit ramps and crossing roads can be effective low-cost countermeasures to reduce WWD on limited access facilities. The UCF research team reviewed and documented the existing signage and pavement markings at Idaho limited access exit ramps which could help reduce WWD to understand the quality and quantity of these WWD countermeasures in Idaho,. The type, number, and location of various signs and pavement markings designed to reduce WWD were collected from two different sources. The first source was the Idaho Statewide Asset Attribute Inventory (SWAAI) database (ITD D5 GIS 2021). This database contained GIS layers with information on multiple roadway aspects (including signage and pavement markings) which were collected in 2020. It is important to note that the data from 2020 were used for this task as the 2023 data were not available when the UCF research team collected these data, even though the 2023 data are now available through the SWAAI database. This means that any changes or additions to the signage or pavement markings after 2020 are not considered in this report. The second data source was Google Maps Satellite and StreetView images, which were used to verify and supplement the data included in the SWAAI database.

Using these data sources, the UCF research team collected information on WW signage and pavement markings present at limited access exit ramps and crossing streets. All possible signs in Idaho were reviewed and the following signs were identified as being related to WWD (with their MUTCD sign codes shown in parentheses): Keep Right (R4-7, R4-7c), DNE (R5-1), WW (R5-1a), One Way (R6-1 and R6-2), No

Right Turn (R3-1), No Left Turn (R3-2), Left Turn Only (R3-5), Through Movement Only (R3-5a), Through and Left Movement Only (R3-6_Modified), Left Movement (R3-6L), Right Movement (R3-6R), Advance Intersection Lane Control (R3-8 and R3-8b), Keep Left (R4-8), and Divided Highway (R6-3). Only Keep Right, DNE, WW, and One Way signs on exit ramps which would be seen by vehicles going WW or attempting to turn WW on the exit ramp were considered. For the remaining sign types, only those which were visible to vehicles which could potentially turn from the crossing street or opposing approach to go WW on the exit ramp were considered. The locations and quantity of each sign type were determined for each exit ramp and crossing street. Additionally, the locations of pavement markings which could reduce WWD (such as arrows, messages, stop bars, yield markings, and turning lane guidelines) were also collected for the exit ramps and crossing streets. The details of the collected signage and pavement marking data can be found in the supplementary spreadsheet file submitted to ITD along with this report.

These signage and pavement marking data were collected for 346 Idaho limited access exit ramps (same 352 exit ramps mentioned previously minus the six exit ramps not located in Idaho). A total of 2,024 exit ramp signs were counted at these ramps, with 36.0% being One Way signs, 31.6% being DNE signs, and 31.2% being WW signs. However, WW signs were present at the most ramps (92.2%), followed by DNE signs (91.6%) and One Way signs (75.1%). This is because there were typically only one or two WW or DNE signs per ramp when they were present, while ramps with One Way signs often had four One Way signs. Approximately 5% of ramps had no WWD-related signage, with most of these being exits from one limited access roadway to another. For exit ramp pavement markings, stop bars were the most common (82.9% of ramps), followed by arrows (59.5%) and messages (22.5%). These pavement markings were found in all lanes for 79.1% of ramps. WWD-related signage and pavement markings on crossing streets were much less common than on exit ramps, with 83.8% of crossing streets having no WWD-related signage and 57.5% of crossing streets having no WWD-related pavement markings. The most common crossing street signs were No Right Turn (8.4% of ramps) and No Left Turn (7.2%) and the most common crossing street pavement markings were arrows (34.7% of ramps) and stop bars (29.2%). These findings suggest that improving and adding signage and pavement markings on crossing streets near exit ramp terminals could potentially help reduce WWD frequency on Idaho limited access roadways.

Limited Access Roadway Data Collection Summary and Conclusions

This chapter shows the extensive efforts conducted by the UCF research team to collect accurate and reliable roadway data for ITD limited access facilities. These high-quality data were important to ensure that the analyses and modeling efforts discussed in subsequent chapter were accurate. The ITD limited access roadway network studied for this project contained 341 exits with 352 exit ramps (including six exits outside of Idaho from which WW vehicles could enter Idaho). These exits were primarily diamonds (especially full diamonds), with PC interchanges and rest areas also being common. The mainline, exit ramp, and crossing AADT volumes varied by roadway depending on location, with urban roadways like I-184 having the highest volumes.

The UCF research team also collected a variety of microscopic exit and entrance ramp characteristics. Over 40% of exit ramp terminals did not have external lighting, which could result in more WWD during nighttime hours. It is recommended to add lighting at these ramps, if possible, to potentially reduce WWD. Almost 75% of exit ramp terminal intersections were 4-leg intersections, which could potentially have more WWD than 3-leg or direct merge intersections. Most of these intersections (66%) were controlled by stop or yield signs and had one or two exit ramp lanes. Over 62% of exit ramps did not make a right angle with the crossing street, which could help reduce WWD. Almost 60% of crossing streets did not contain a median to potentially reduce WWD by left-turning vehicles, with less than 10% of crossing streets having a median that extended into the exit ramp terminal intersection. It is recommended to consider adding medians, median extensions, striping, or other delineators on crossing streets where possible to make it harder for vehicles to make WW left turns. Over 94% of exit ramps had an associated entrance ramp, with these entrance ramps typically having one lane and being narrower than the exit ramps (which could increase the potential for WWD). More than 76% of these entrance ramps were located directly opposite the exit ramp, with 7% being adjacent to the exit ramp. These microscopic characteristics are discussed in more detail in Chapter 5 as they were considered in the WWD hotspots modeling process to identify which ones significantly impacted WWC frequency and identify potential changes which could help mitigate WWD on exit ramps.

Existing low-cost WWD countermeasures (signage and pavement markings) on Idaho limited access exit ramps and crossing streets were also reviewed to identify potential improvements. WW, DNE, and One Way signs were present on almost all exit ramps, with only 5% of ramps having no WWD-related signage. It is recommended to consider the use of additional pavement arrows and messages on exit ramps as these could help confused drivers realize that they are going WW. It is also recommended to consider installing more WWD-related signage on crossing streets since almost 84% of ramps do not have any WWD-related signs on the crossing street. These signs can help potential WW drivers differentiate between exit and entrance ramps and reduce driver confusion. Checking that signs are properly oriented towards potential WW drivers and that signage and pavement markings are sufficiently visible at nighttime is also recommended to ensure that they are seen by potential WW drivers (especially at nighttime when most WWD occurs) and do not confuse right-way drivers.

4. WWD Event Identification and Analysis on Idaho Limited Access Roadways

Previous studies have shown that WWCs are rare, but are more severe than other types of crashes. Therefore, it is important to study both WWCs and non-crash WWD events to obtain a better understanding of WWD behavior. Locations with limited WWCs in the past could still have high WWD behavior which could lead to increased WWCs in the future if not properly treated. Conducting detailed analyses of historical WWCs and non-crash WWD events on Idaho limited access roadways can show ITD where and when these WWD events are most likely to occur and how their frequency has changed in recent years.

This chapter discusses how the UCF research team identified and analyzed WWCs and non-crash WWD events (law enforcement citations and Idaho State Police [ISP] dispatch reports) on ITD limited access roadways, along with the major findings from these analyses and recommendations. Detailed WWD event data were submitted in a supplementary spreadsheet file to ITD along with this report.

WWD Event Data Collection and Filtering

The UCF research team worked with the ITD management team to obtain three types of WWD event data: WWCs, law enforcement citations for WWD, and ISP dispatch reports for WW drivers. The procedures to collect and filter these data, including the procedures used to identify overlap within and between the data sets, are discussed in this section.

WWC data

WWCs are the most severe outcome of WWD, often resulting in injuries or fatalities on limited access roadways. Therefore, it is important to properly identify WWCs on the ITD limited access network for analysis and modeling. This section discusses the data sources and procedures used to collect potential WWCs, the filter procedures used to identify actual WWCs, and the results of various analyses on these data regarding time, location, and circumstances.

Three data sources were used to obtain ITD crash data. The first source was the ITD AASHTOWare Safety database. This database contains details on all traffic crashes in Idaho from 2008 through approximately one month before the present day. Users can develop queries to filter for crashes based on various characteristics, such as crash severity, contributing circumstances, and roadway type. The second source was the ITD WebCARS database. From this database, narratives and diagrams for each crash can be obtained. The final data source was digital crash reports obtained from ITD. These were used for cases where narratives and/or diagrams were not available on WebCARS. Once the actual WWCs were identified using these three sources, their location details (including roadway, direction, and nearest exit) were identified using the information obtained from these three sources along with IPLAN and Google Maps as needed.

To obtain WWC data, the UCF research team made two different crash queries in the AASHTOWare Safety database. Queries were initially only made for crash data through 2022, as that was the most recent year with complete crash data when making the queries. Additional queries for crashes from 2023 were made at a later time. Due to the UCF research team obtaining 2023 crashes at a later date, these crashes were not considered for the WWD hotspot modeling in Chapter 5. However, the 2023 crashes were considered for the analyses in this chapter. The results from these queries were reviewed to identify all potential WWCs on limited access roadways based on their roadway functional classification and geographical coordinates. The crash report diagrams and narratives were then obtained for each of these potential WWCs using WebCARS (and digital crash reports from ITD as needed) and reviewed to ensure that they were actually WWCs.

The first query (query #1) used to identify potential WWCs was based on the reported contributing circumstances. In this query, the following filters were initially used to obtain crashes from the AASHTOWare Safety database: Contributing Circumstances (All) = Wrong Side or Wrong Way and Date & Time (Year) ≠ 2023. This resulted in 1,145 crashes from 2011 through 2022, with zero crashes identified for 2009 and 2010. Based on the Road Functional Class and coordinates (latitude and longitude) for each of these crashes, 138 crashes were identified as possible WWCs on limited access roadways. The WebCARS database was then used to obtain crash diagrams and narratives for these 138 crashes. After reviewing these narratives and diagrams for each crash, 20 of these 138 crashes were identified as not being WWCs and 16 were identified as not occurring on a limited access roadway. This left 102 potential WWCs on Idaho limited access roadways, with 8 of these crashes not having crash report diagrams on WebCARS. Digital crash reports for these 8 crashes were provided by ITD and review of these reports indicated that all 8 were WWCs on limited access roadways. Therefore, 102 actual WWCs on ITD limited access roadways from 2011-2022 were identified from query #1. This same query was conducted at a later time for only crash data from 2023, resulting in 130 crashes. After filtering by Road Functional Class and coordinates, 12 crashes were identified as possible limited access WWCs. Review of the narratives and diagrams for these 12 crashes showed that 2 were not WWCs, resulting in 10 Idaho limited access WWCs in 2023 from query #1 and a total of 112 Idaho limited WWCs from 2011-2023 using query #1.

The second query (query #2) used to identify potential WWCs was based on the type of crash. In this query, the following filters were initially used to obtain crashes from the AASHTOWare Safety database: All Events = Head-On and Date & Time (Year) ≠ 2023. This resulted in 4,376 crashes from 2009 through 2022. Based on the identified Road Functional Class and coordinates, 256 crashes were identified as possible WWCs on limited access roadways. Comparison of these crashes with the crashes identified from query #1 showed that 41 of these 256 crashes were in the 112 actual WWCs on Idaho limited access roadways identified from query #1 and 3 of these 256 crashes were identified as either not being WWCs or not being on a limited access roadway from query #1, leaving 212 new possible WWCs on limited access roadways. After reviewing the WebCARS narratives and diagrams for these 212 crashes, 100 were identified as not being WWCs and 33 were identified as not occurring on a limited access roadway. This left 79 potential new WWCs on Idaho limited access roadways which were not identified from query #1, including 3 crashes with missing or incomplete information on WebCARS. Crash reports

for these 3 crashes were provided by ITD and review of these reports indicated that 2 of these 3 crashes were actual WWCs on limited access roadways, with 1 crash unclear if it was caused by WWD. Therefore, this unclear crash was removed from the data set, resulting in a total of 78 actual WWCs on ITD limited access roadways from 2009-2022 identified from query #2. This same query was conducted at a later time for only crash data from 2023, resulting in 351 crashes. After filtering by Road Functional Class and coordinates, 23 crashes were identified as possible limited access WWCs, with 5 of these already identified as WWCs from query #1. Review of the narratives and diagrams for the remaining 18 crashes showed that 5 were not WWCs and 2 were not on limited access roadways, resulting in 11 Idaho limited access WWCs in 2023 from query #2 and a total of 89 Idaho limited WWCs from 2009-2023 using query #2. Adding this total to the actual WWCs from query #1 resulted in 201 actual WWCs on Idaho limited access roadways from 2009-2023. One additional WWC was identified after reviewing the WWD citation data, resulting in 202 total WWCs on Idaho limited access roadways from 2009-2023.

WWD non-crash data

While WWCs are the most severe outcome of WWD behavior, many WWD events do not result in a crash. Understanding the frequency and characteristics of WWD non-crash data (and their relationship with WWC data) is important to fully comprehend the magnitude and influencing factors of WWD. Two types of WWD non-crash data were collected during this project: ISP citation data and ISP WWD complaint reports from ITD District 1.

ISP citation data were obtained by ITD and provided to the UCF research team. The provided raw data spreadsheet contained 2,335 potential WWD citations on all types of roadways in Idaho for the period from April 19th, 2018, through January 26th, 2024 (over 5.5 years of data). These citations were for vehicles violating any of the following six Idaho statutes identified by the UCF research team as potentially being related to WWD: 49-630 (drive on right side of roadway – exceptions), 49-634 (limitations on overtaking on the left), 49-635 (further limitations on driving on left of center of highway), 49-636 (one-way highways), 49-645 (limitations on turning around), and 49-1421 (driving on divided highways – restricted access) (Idaho State Legislature 2025). The raw data file contained various information, such as the date and time the citation was issued, location of the citation, what statutes the cited driver violated, and notes about the situation. One important piece of information missing from the raw citation data was geographical coordinates (latitude and longitude). Without these coordinates, citations could not be mapped unless they had enough details in the location information (including roadway, direction, and nearest mile marker or interchange) to accurately determine where they occurred.

The raw citation data were filtered to remove citations not on limited access roadways and citations which could not be mapped due to not having detailed enough location information. Then, the notes included in the raw data were reviewed to remove additional citations that were not actually WWD. Two common types of non-WWD citations included in the raw ISP citation data were for non-authorized vehicles using emergency median crossovers to turn around on the mainline and vehicles making passing violations (such as crossing solid white lines). After applying these filters, 139 WWD citations

remained for three Idaho statutes: 49-630, 49-636, and 49-645. The citations for statutes 49-634 and 49-635 were all filtered out since they were primarily issued on non-limited access roadways and were issued for passing violations (not WWD) when they were issued on limited access roadways. The citations for statute 49-1421 were all filtered out since they were issued for unauthorized vehicles using median crossovers and not for WWD.

ITD also provided the UCF research team with ISP WWD complaint reports from the District 1 office in Coeur d'Alene. These are reports of WW drivers received by ISP for which law enforcement officers were dispatched to investigate, leading to either the WW driver being involved in a crash, being stopped by law enforcement, or law enforcement unable to find the reported WW vehicle. The provided file contained 38 unique ISP WWD complaint reports from January 3rd, 2019, through September 18th, 2023. All of these complaints occurred on I-90 between mile markers 36 and 73. Manual review of these reports showed that 2 were for a WWD bicycle, so these were excluded, resulting in 36 ISP WWD complaint reports.

Collecting additional details for WWD events

Once all the WWD events were identified, the UCF research team collected the following additional details on location and circumstances for all these events: Limited Access Roadway, WWD Direction, WWD Origin Point, Origin ID, and Distance from Exit. Descriptions of each of these variables and how their values were collected are discussed in the following list. All these values were determined based on the location information obtained from the AASHTOWare database, the WebCARS database, and crash reports (for WWCs) or the provided location information in the raw data (for WWD citations and dispatch reports).

- Limited Access Roadway: This is the limited access roadway (number and direction) where the WWD event occurred, with the list of potential values shown in the first column of Table 3.1.
- WWD Direction: This is the direction that the WW vehicle was going when the WWC occurred, with potential values being "NB in SB", "SB in NB", "EB in WB", and "WB in EB". This value is related to the direction shown in the Limited Access Roadway value. For example, if the Limited Access Roadway value was "I-90 EB", the WWD Direction value would be "WB in EB".
- WWD Origin Point: This indicates how the WW vehicle started going WW on the limited access roadway, with potential values being "Exit Ramp", "Mainline", "Construction", "Unknown", and "Other". Cases when each potential value was used are discussed below.
    - A value of "Exit Ramp" was used for WWD events where it was known that the WW vehicle came from a specific exit ramp.
    - A value of "Mainline" was used for either WWCs caused by a right-way vehicle crossing the median on the mainline to the opposite side or non-crash WWD events where the vehicle turned WW on the mainline or entrance ramp.

- A value of “Construction” was used for either WWCs where a right-way vehicle crossed the temporary dividing line in a construction crossover with both directions of travel on the same side of the limited access roadway or non-crash WWD events where the vehicle went WW in a construction zone.
- A value of “Unknown” was used for WWD events where the vehicle was going WW on the mainline, but it was unknown how the vehicle started going WW.
- A value of “Other” was used for WWD events which do not meet any of the previous values. One such example is vehicles that were going right way on an exit ramp, then crossed over the median to go WW on an entrance ramp.

- Origin ID: This is either the exit ID or mainline segment ID corresponding to the location where the WW vehicle definitely or likely started going WW. The exact meaning of this value depends on the value of the WWD Origin Point, as discussed below.
  - For WWD events where the WWD Origin Point value was “Exit Ramp”, the Origin ID value was the exit ID of the exit ramp where the WW vehicle was known to have entered the mainline from.
  - For WWD events where the WWD Origin Point value was “Unknown”, the Origin ID value was the exit ID of the nearest exit ramp where the WW vehicle could have entered the mainline from. This nearest exit is the next downstream exit which would be reached by right-way vehicles.
  - For WWD events where the WWD Origin Point value was “Mainline” or “Construction”, the Origin ID value was the mainline segment ID of the mainline segment where the vehicle started going WW.
  - For WWD events where the WWD Origin Point value was “Other”, the Origin ID value was either the exit ID of the exit ramp where the WW vehicle was known to have entered the mainline from, the exit ID of the nearest exit from which it could have entered the mainline from, or the mainline segment ID of the mainline segment where the vehicle started going WW, as appropriate based on the circumstances of the event.
- Distance from Exit: This is the distance between the WWD event location and the exit ID listed in the Origin ID column, to the nearest 0.1 mile. These distances were only calculated for WWD events with WWD Origin Point values of “Exit Ramp” or “Unknown” since “Mainline”, “Construction”, and “Other” origin WWCs typically occurred right near where the WWD started. Additionally, these distances were used to distribute WWD events to the nearest exits before modeling (as discussed in Chapter 5) and only “Exit Ramp” and “Unknown” origin WWD events were considered for modeling, so there was no need to calculate these distances for the other WWD origin types.

Identifying and removing overlap within and between WWD event data sets

Before conducting detailed analyses of the Idaho limited access WWD event data, all three WWD event data sets were examined to identify overlap within and between each data set. Overlap within a data set occurs when there are multiple data points of the same type for the same WWD situation, while overlap between data sets occurs when there are one or more data points in different sets that correspond to the same WWD event. An example of overlap within a data set is when multiple vehicles get citations for turning WW on a highway mainline and exiting down an entrance ramp to avoid the same congestion on the highway. An example of overlap between data sets is when a WW driver causes a WWC and also gets a WWD citation. By removing all overlap, each data set will be independent. This independence is important for the hotspot modeling (to prevent the model from being biased towards events with multiple data points) and ensures that the WWD citation and ISP dispatch report data sets only contain unique non-crash WWD events. For cases with overlap between different data sets, the WWD event was only counted in the most severe data set (WWCs, then citations, then ISP dispatch reports). For example, a WWD event with a crash and citation would be counted as a WWC while a WWD event with a WWD citation and dispatch report would be counted as a WWD citation.

To identify overlapping WWD events, the date, time, location, latitude, longitude, and comments were compared for all data points in all three data sets. Data points with similar information for all these aspects were counted as overlapping events. Table 4.1 shows the number of events with and without overlap for each data set. The 202 WWC events included 195 where there was only a single WWC, 6 where there was a WWC and at least one WWD citation, and 1 where there was a WWC and at least one WWD dispatch report. The 102 WWD citation events after removing overlap included 93 with one WWD citation and 9 with multiple WWD citations for the same event (total of 39 WWD citations for these 9 events). The 32 WWD ISP dispatch report events included 30 with one dispatch report and 2 with multiple dispatch reports for the same event (total of 4 WWD dispatch reports for these 2 events). The analyses in this chapter use the 202 WWC events, 102 WWD citation events, and 32 ISP dispatch report events after removing overlap.

Table 4.1 WWD Event Overlap

Type of Overlap	Number of WWC Events	Number of WWD Citation Events	Number of WWD ISP Dispatch Report Events
No Overlap	195	93	30
WWD Citation Overlap	6	9	0
WWD ISP Dispatch Report Overlap	1	0	2
Total Before Removing Overlap	**202**	**139**	**36**
Total After Removing Overlap	**202**	**102**	**32**

WWC Analyses

Multiple analyses were conducted on the collected WWC data for Idaho limited access roadways. These include analyses of all WWCs from 2009-2023 (both counts and rates based on Idaho's population and number of licensed drivers to account for exposure); comparisons with Florida WWCs from 2018-2023; analyses of only WWCs with exit ramp or unknown origin points; and analyses of only WWCs originating from mainline crossovers, construction crossovers, or other unique cases. Based on these analyses, some suggestions are made for potential treatments to reduce WWD, with additional recommendations made in Chapter 5 based on the modelling and optimization results.

All Idaho limited access WWCs

Figure 4.1 shows the number of WWCs per year from 2009-2023. This figure shows that the number of WWCs has generally been increasing, with 2020 through 2023 having the most WWCs. According to the US Census Bureau (2023), Idaho had a 6.8% increase in population from April 1, 2020, to July 1, 2023, which was the greatest percentage increase in population among all states. This increase corresponds with the increased WWC frequency shown in Figure 4.1, suggesting that WWCs could remain high as Idaho's population continues to grow without improved mitigation efforts. Higher populations result in higher traffic volumes, which have been shown by many studies to increase all types of traffic crashes, including WWCs. Therefore, it is important for ITD to properly identify effective methods to reduce WWD so the problem does not keep growing as more people move to Idaho.

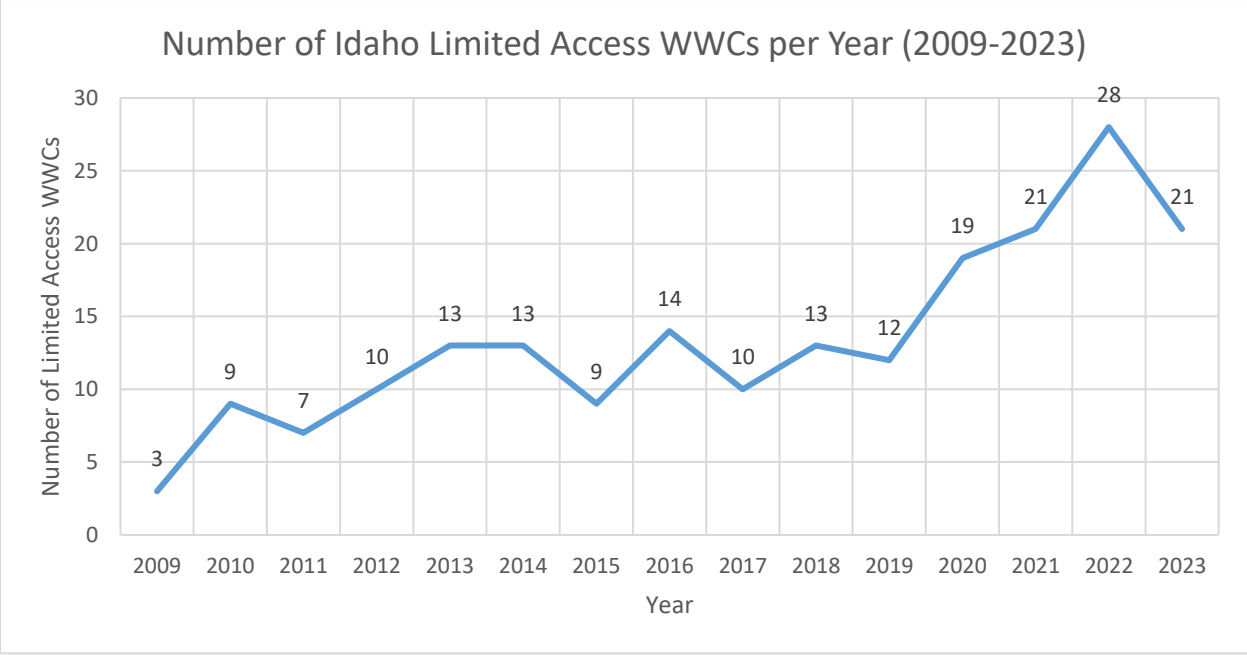

Figure 4.1 WWCs per year from 2009 through 2023

Figure 4.2 shows the number of WWCs by hour of the day. In this figure (and all figures for hourly analyses of WWD events), hour 0 corresponds to 12:00 AM through 12:59 AM, hour 1 corresponds to 1:00 AM through 1:59 AM, and so on. WWCs were generally most frequent from 3:00 PM through 4:59 AM (hours 15 through 4), with hours 1, 16, 17, and 21 having the most WWCs. Previous WWC research in other states typically found that WWCs were most common during nighttime hours. The Idaho data generally supports this finding (since the daytime hours from 5:00 AM through 2:59 PM had relatively low WWC counts), but it is interesting that the WWC counts during the late afternoon and early evening hours were higher than most nighttime hours. These high WWC counts during the afternoon and evening hours are mainly due to mainline crossover WWCs, as discussed later in this section.

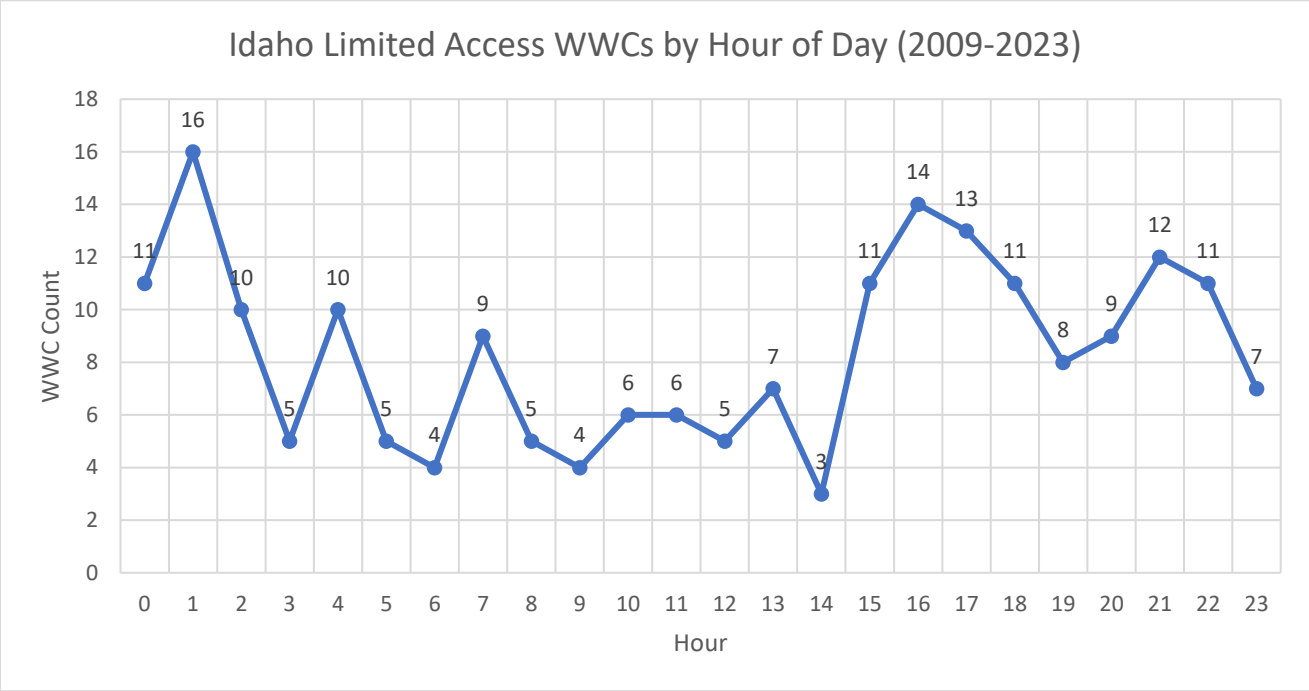

Figure 4.2 WWC counts by hour of the day

Figure 4.3 shows the number of WWCs by month. In general, October through March had the highest monthly WWC counts, possibly due to more hours of darkness during these months reducing drivers' visibility and increasing their chances of going WW. Additionally, snowy and icy road conditions during these months could result in more mainline crossover WWCs or could cause WW signage and pavement markings to be obscured and therefore less effective in warning WW drivers. A detailed analysis of likely causes for mainline crossover WWCs is discussed later in this section to show how weather conditions can contribute to these types of WWCs.

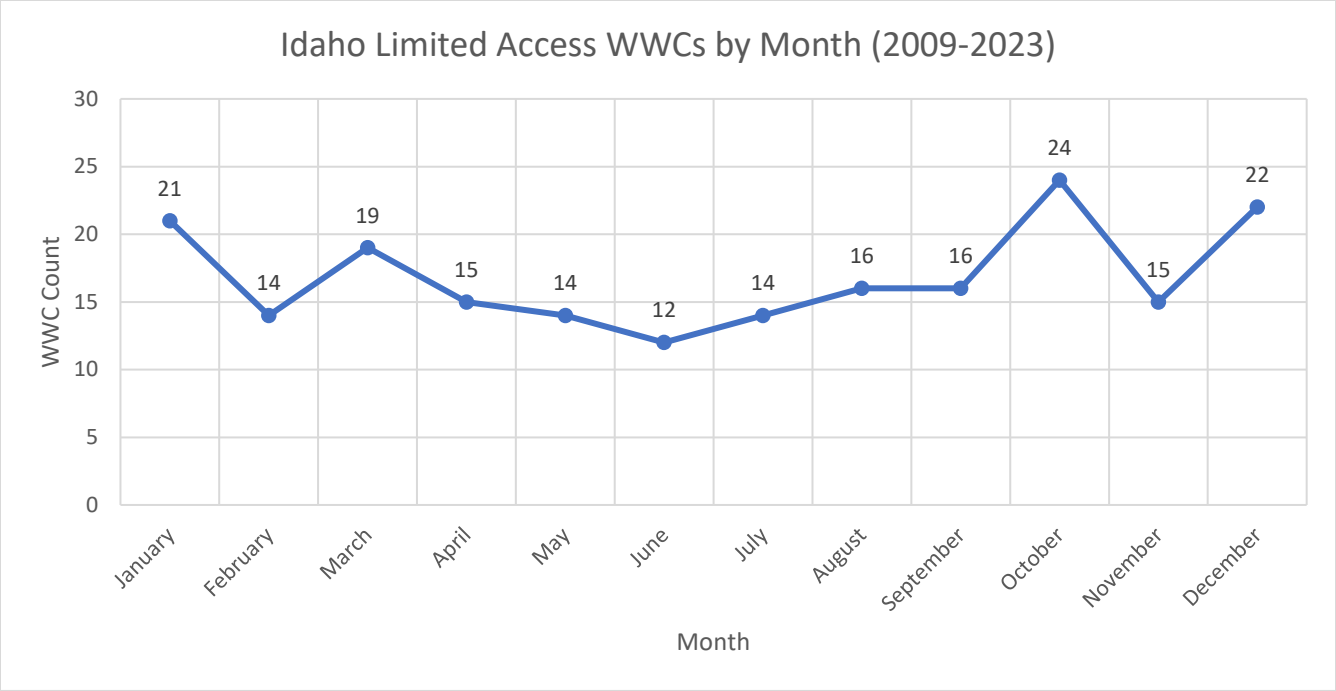

Figure 4.3 WWC counts by month

Since Idaho's population has increased a lot in recent years, WWC rates were calculated based on Idaho's population and number of licensed drivers to account for greater exposure which could increase the chance of WWCs. Data on vehicle miles traveled are commonly used to calculate crash rates, but vehicle miles traveled counts for Idaho limited access roadways were not available. Idaho population estimates were obtained from data tables released by the US Census Bureau, Population Division (2011, 2021, 2023) and licensed driver estimates were obtained from the FHWA (2023, 2024, n.d.). Table 4.2 shows the annual WWC rates per million people and per million licensed drivers, while Figures 4.4 and 4.5 show these annual rates and how they compare with the overall averages for the entire study period of 7.83 WWCs per million people and 10.93 WWCs per million licensed drivers. Note that Idaho licensed driver counts were not available for 2023, so Figure 4.5 only shows these rates through 2022. These results show that the WWC rates have drastically increased and been much higher than average since 2019. The COVID-19 pandemic is a likely reason for the increase in 2020, but it does not explain the large increase in 2022. These trends show that WWCs are increasing more than Idaho's population, so effective treatment strategies are needed to ensure that WWC rates do not continue to increase as Idaho's population continues to grow. The years 2011, 2015, 2017, and 2023 experienced substantial decreases in WWC rates (although 2023's rate is still the third highest rate since 2009); these decreases could be due to calmer winters or other unknown factors.

Table 4.2 Idaho Annual WWC Rates by Population and Licensed Driver

Year	WWCs	Idaho Population (millions)	Annual WWCs per Million People	Idaho Licensed Drivers (millions)	Annual WWCs per Million Licensed Drivers
2009	3	1.554	1.93	1.055	2.84
2010	9	1.571	5.73	1.070	8.41
2011	7	1.584	4.42	1.084	6.46
2012	10	1.596	6.27	1.093	9.15
2013	13	1.612	8.06	1.111	11.70
2014	13	1.632	7.96	1.128	11.52
2015	9	1.652	5.45	1.135	7.93
2016	14	1.684	8.31	1.161	12.06
2017	10	1.720	5.81	1.190	8.40
2018	13	1.752	7.42	1.253	10.38
2019	12	1.789	6.71	1.253	9.58
2020	19	1.849	10.27	1.285	14.78
2021	21	1.905	11.03	1.343	15.63
2022	28	1.939	14.44	1.393	20.11
2023	21	1.965	10.69	N/A	N/A
Total	**181**	**25.805**	**7.83**	**16.555**	**10.93**

N/A = not applicable

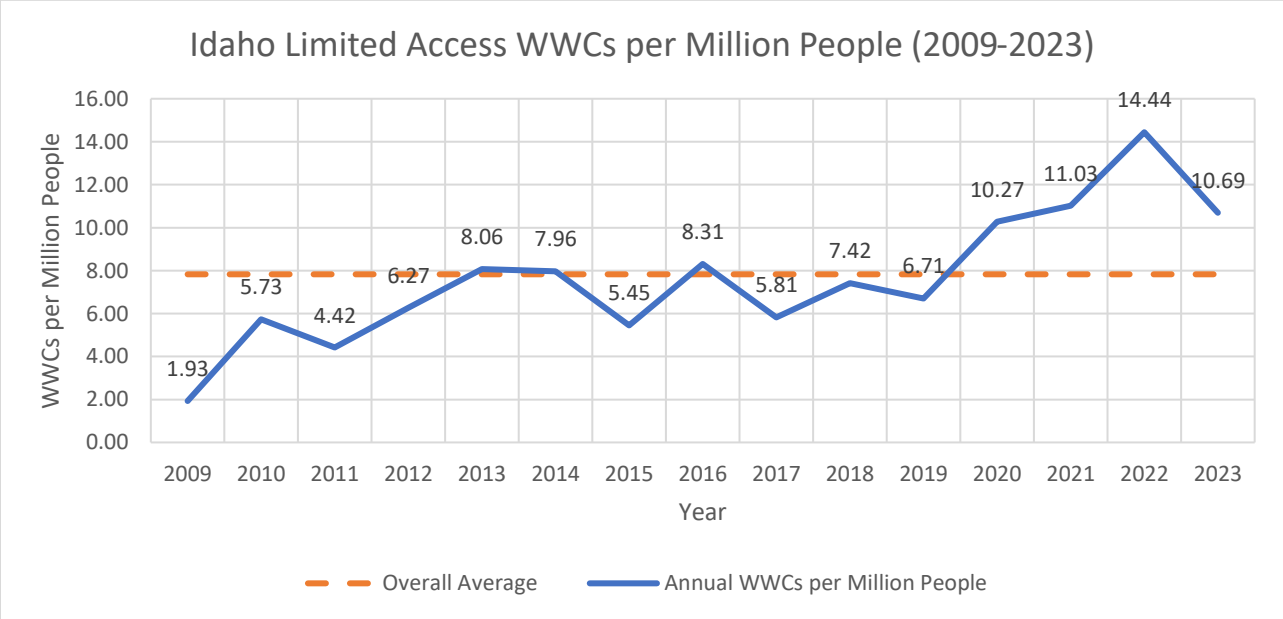

Figure 4.4 Idaho annual WWC rates per million people

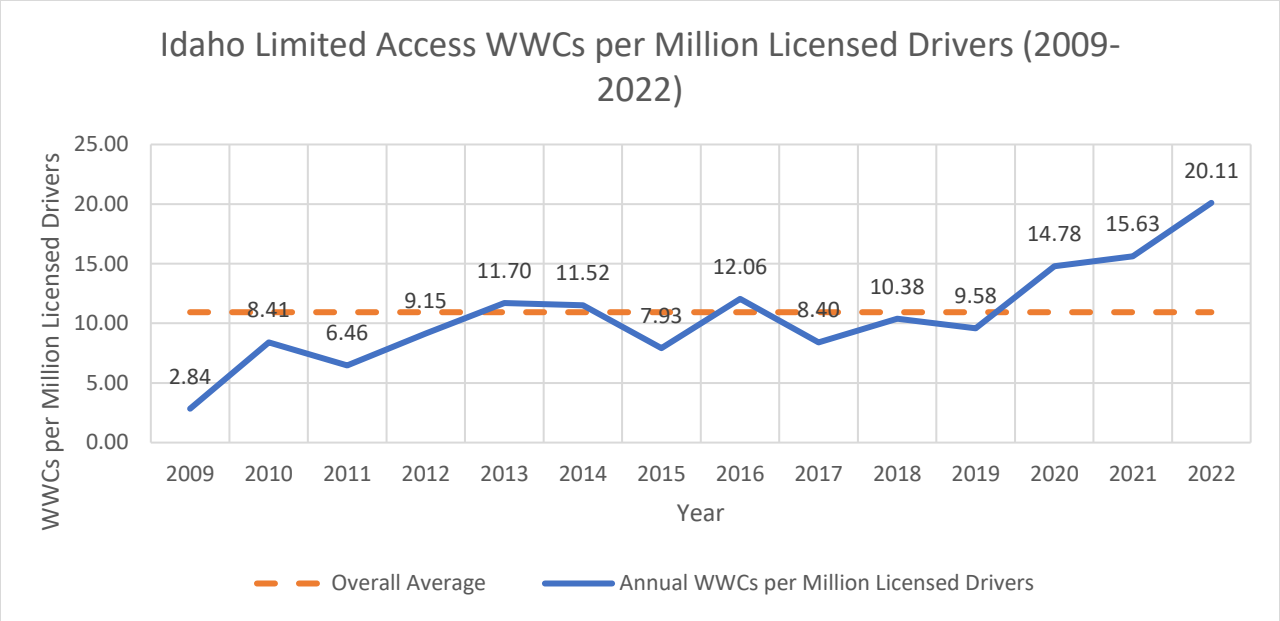

Figure 4.5 Idaho annual WWC rates per million licensed drivers

Table 4.3 and Figure 4.6 show the number of WWCs by severity per year. ITD uses the KABCO scale to classify crash severity, with K crashes having at least one fatal injury, A crashes having at least one suspected serious injury, B crashes having at least one suspected minor or visible injury, C crashes having at least one possible injury or complaint of an injury, and O crashes having no injuries (property damage only crashes). Approximately 25% of WWCs were fatal (K crashes), 48% had fatalities or serious injuries (K or A crashes), and 80% had at least one injury (K, A, B, or C crashes). Over 49% of the fatal WWCs occurred from 2020 through 2023, indicating the pressing need to effectively combat WWD and reduce these fatal crashes in the future.

Table 4.3 WWCs by Severity per Year

Year	K WWCs	A WWCs	B WWCs	C WWCs	O WWCs	Total
2009	2	1	0	0	0	**3**
2010	4	3	0	0	2	**9**
2011	2	1	2	1	1	**7**
2012	2	0	2	4	2	**10**
2013	2	6	2	2	1	**13**
2014	3	4	2	2	2	**13**
2015	1	2	1	1	4	**9**
2016	4	6	1	2	1	**14**
2017	2	3	1	4	0	**10**
2018	2	2	3	3	3	**13**

Year	K WWCs	A WWCs	B WWCs	C WWCs	O WWCs	Total
2019	2	0	4	2	4	**12**
2020	6	3	2	3	5	**19**
2021	6	4	5	1	5	**21**
2022	7	6	4	6	5	**28**
2023	6	5	1	3	6	**21**
Total	**51**	**46**	**30**	**34**	**41**	**202**

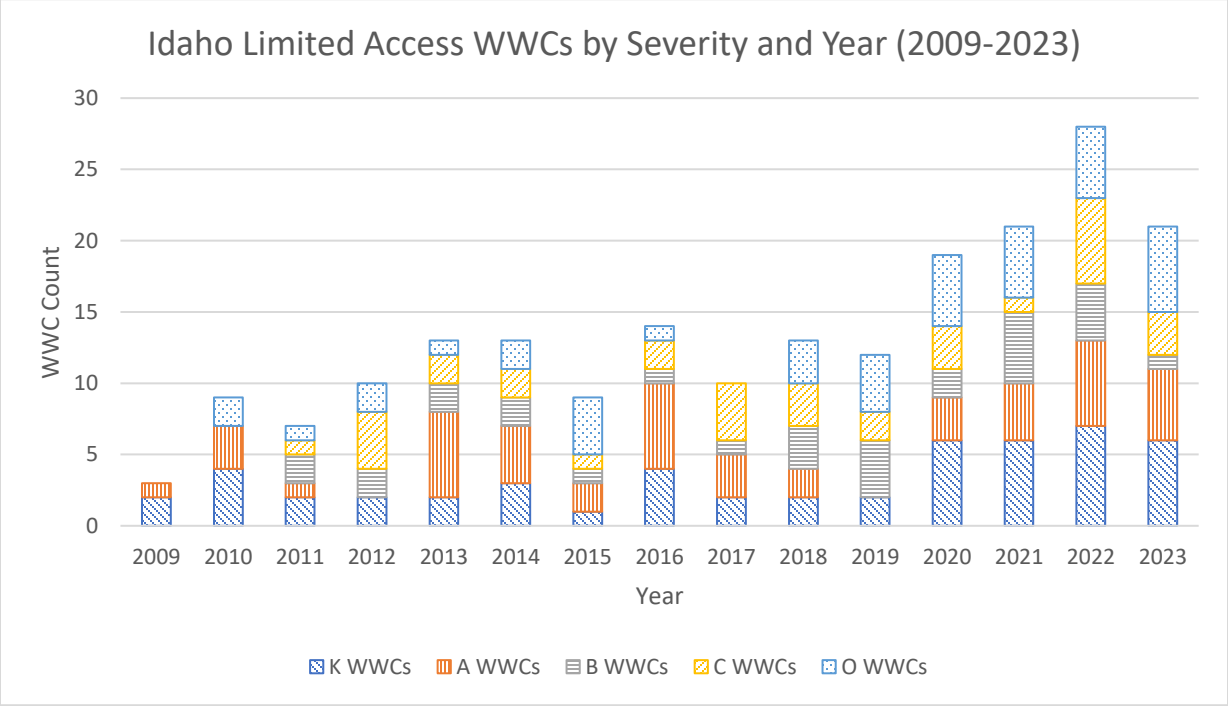

Figure 4.6 Number of WWCs by severity per year

Table 4.4 shows the number of fatalities, serious injuries, and people involved in Idaho limited access WWCs each year from 2009-2023. It also includes the percentage of people involved in WWCs who experienced fatal or serious injuries and the fatality and serious injury rates. The fatality rates were calculated by dividing the number of fatalities by the number of fatal WWCs (K crashes) while the serious injury rates were calculated by dividing the number of serious injuries by the number of fatal or serious injury WWCs (K or A crashes). Overall, the 202 WWCs involved 697 people of which 70 (10.0%) experienced fatal injuries and 110 (15.8%) experienced serious injuries. On average, each fatal WWC resulted in 1.37 fatalities and every fatal or serious injury crash resulted in 1.13 serious injuries.

Table 4.4 WWC Fatality and Serious Injury Summaries by Year

Year	Fatalities	Serious Injuries	Total People Involved	Fatality Percentage	Fatality Rate	Serious Injury Percentage	Serious Injury Rate
2009	4	4	19	21.1%	2.00	21.1%	1.33
2010	9	8	30	30.0%	2.25	26.7%	1.14
2011	2	3	22	9.1%	1.00	13.6%	1.00
2012	3	4	35	8.6%	1.50	11.4%	2.00
2013	3	13	40	7.5%	1.50	32.5%	1.63
2014	5	5	41	12.2%	1.67	12.2%	0.71
2015	1	5	29	3.4%	1.00	17.2%	1.67
2016	4	7	48	8.3%	1.00	14.6%	0.70
2017	3	9	30	10.0%	1.50	30.0%	1.80
2018	3	7	62	4.8%	1.50	11.3%	1.75
2019	3	2	38	7.9%	1.50	5.3%	1.00
2020	8	8	83	9.6%	1.33	9.6%	0.89
2021	7	9	81	8.6%	1.17	11.1%	0.90
2022	7	16	78	9.0%	1.00	20.5%	1.23
2023	8	10	61	13.1%	1.33	16.4%	0.91
Total	**70**	**110**	**697**	**10.0%**	**1.37**	**15.8%**	**1.13**

Table 4.5 and Figure 4.7 show the number of WWCs by origin type (Exit Ramp, Mainline, Construction Crossover, Unknown, or Other) per year from 2009-2023. These data show that 105 crashes (52.0%) definitely or likely originated from an exit ramp (origin types of “Exit Ramp” or “Unknown”) and 92 crashes (45.5%) were caused by a crossover on the mainline (origin types of “Mainline” or “Construction Crossover”). While it is not known for sure that WWD events with unknown origins actually originated from an exit ramp, it is reasonable to make this assumption since many previous studies found that exit ramps are the most common origin for WW drivers. Additionally, the typical characteristics of the unknown origin WWCs (a vehicle is already going WW on the mainline before crashing into another vehicle) do not fit the typical characteristics of the mainline crossover WWCs (a right-way vehicle on the mainline loses control and crosses the median, then immediately crashes into another vehicle). These results suggest that WWD mitigation efforts are needed at mainline locations and not just at exit ramps. Since vehicles which start going WW on the mainline or in construction crossovers would not be impacted by exit ramp WWD countermeasures, these WWCs (along with the “Other” origin WWCs) were not considered in the WWD hotspot modeling, as discussed in Chapter 5. However, these mainline crossovers are analyzed later in this section to determine common causes, identify high-frequency locations, and recommend treatments which could help reduce these WWCs. Unknown origin WWCs

were especially high in 2022 and mainline crossover WWCs were especially high in 2023. Installing WWD detection devices at exit ramps could help reduce these unknown origin WWCs and help ITD obtain more non-crash WWD event data, while installing median barriers or similar treatments on the mainline could help reduce mainline crossovers. Specific mainline segments with high mainline crossover WWC counts are discussed later in this chapter.

Table 4.5 WWCs by Origin Type per Year

Year	Exit Ramp	Unknown	Mainline Crossover	Construction Crossover	Other	Total
2009	0	0	3	0	0	**3**
2010	1	2	5	0	1	**9**
2011	3	2	2	0	0	**7**
2012	1	3	5	0	1	**10**
2013	3	3	7	0	0	**13**
2014	3	4	4	1	1	**13**
2015	2	4	3	0	0	**9**
2016	1	9	4	0	0	**14**
2017	0	3	5	2	0	**10**
2018	3	5	2	3	0	**13**
2019	2	5	5	0	0	**12**
2020	3	7	9	0	0	**19**
2021	5	4	8	2	2	**21**
2022	4	15	7	2	0	**28**
2023	2	6	11	2	0	**21**
Total	**33**	**72**	**80**	**12**	**5**	**202**

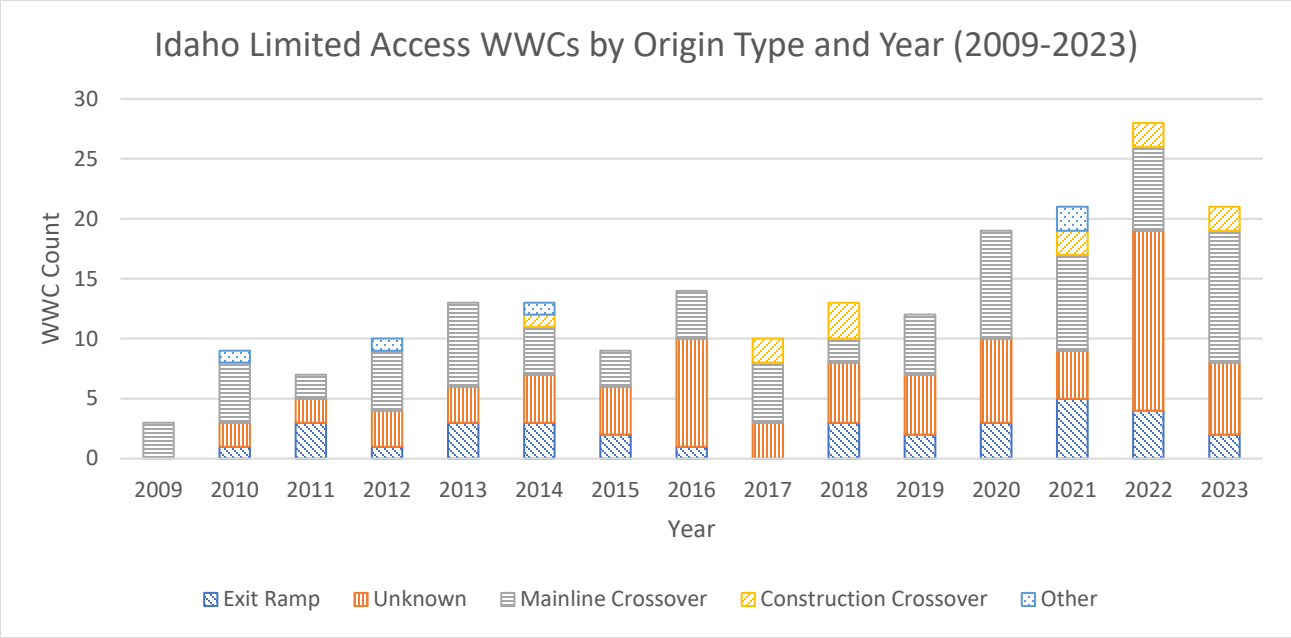

Figure 4.7 Number of WWCs by origin type per year

WWCs were also analyzed with respect to the Idaho limited access roadways they occurred on. Table 4.6 and Figure 4.8 show the severity distribution for each roadway based on all WWCs from 2009-2023. Overall, I-84 had the most WWCs during this period, which is expected since it is the limited access roadway with the most centerline miles in Idaho. However, I-90 had the second highest number of WWCs, even though it is less than half the length of I-15 in Idaho, suggesting that WWD is problematic on I-90. Approximately 49% of the fatal WWCs and 53% of the fatalities occurred on I-84, with I-84 WB having more fatal WWCs and fatalities than I-84 EB. Therefore, focusing WWD mitigation efforts on I-84 would likely help save the most lives. The hotspot modeling and optimization efforts in Chapter 5 identify specific segments and exits on I-84 and other Idaho limited access roadways where countermeasure deployments would likely provide the most WWD reduction.

Table 4.6 WWCs by Roadway and Severity

Roadway	K WWCs	A WWCs	B WWCs	C WWCs	O WWCs	Total
I-84 EB	11	8	6	6	8	**39**
I-84 WB	14	9	8	5	9	**45**
I-90 EB	7	7	5	4	7	**30**
I-90 WB	5	5	4	4	1	**19**
I-15 NB	6	3	3	2	2	**16**
I-15 SB	5	3	2	4	7	**21**
US 20 EB	1	3	1	4	4	**13**
US 20 WB	1	4	1	1	3	**10**

Roadway	K WWCs	A WWCs	B WWCs	C WWCs	O WWCs	Total
I-184 EB	0	1	0	3	0	**4**
I-184 WB	0	1	0	0	0	**1**
I-86 EB	1	2	0	0	0	**3**
I-86 WB	0	0	0	1	0	**1**
Total	**51**	**46**	**30**	**34**	**41**	**202**

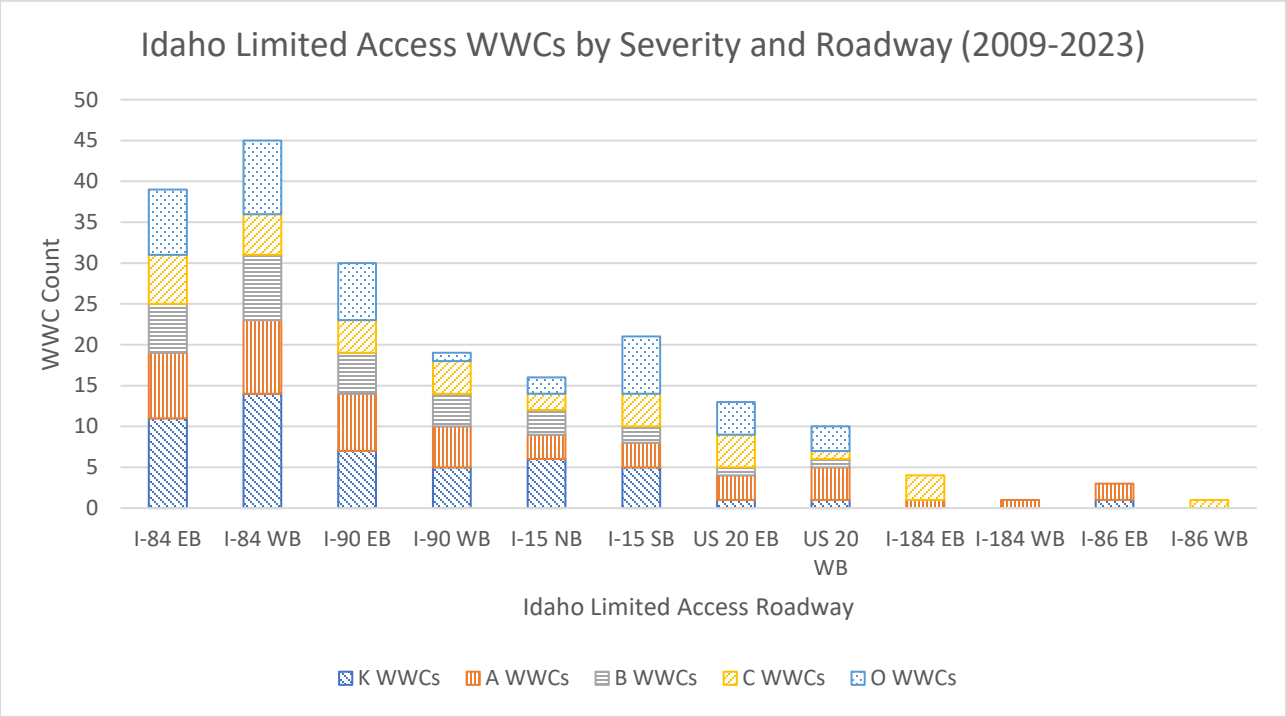

Figure 4.8 Number of WWCs by severity on each Idaho limited access roadway

Table 4.7 and Figure 4.9 show the number of WWCs for each origin type category on each roadway. Almost 40% of the WWCs on I-84 EB and WB had unknown origins, with another 39% due to mainline crossovers. These results suggest that WWD detection at I-84 exit ramps and median barriers on the I-84 mainline could help ITD better understand and reduce WWCs on I-84. Over 45% of WWCs on I-15 NB and SB had unknown origins, suggesting that WWD detection could be beneficial at I-15 exit ramps, while 61% of WWCs on US 20 EB and WB were mainline crossovers, suggesting that median barriers could be useful at reducing WWCs on this roadway.

Table 4.7 WWCs by Roadway and Origin Type

Roadway	Exit Ramp	Unknown	Mainline Crossover	Construction Crossover	Other	Total
I-84 EB	3	16	14	5	1	**39**
I-84 WB	6	17	19	1	2	**45**
I-90 EB	10	7	10	3	0	**30**
I-90 WB	6	4	7	2	0	**19**
I-15 NB	1	8	7	0	0	**16**
I-15 SB	2	9	9	1	0	**21**
US 20 EB	2	3	7	0	1	**13**
US 20 WB	1	2	7	0	0	**10**
I-184 EB	1	3	0	0	0	**4**
I-184 WB	0	0	0	0	1	**1**
I-86 EB	1	2	0	0	0	**3**
I-86 WB	0	1	0	0	0	**1**
Total	**33**	**72**	**80**	**12**	**5**	**202**

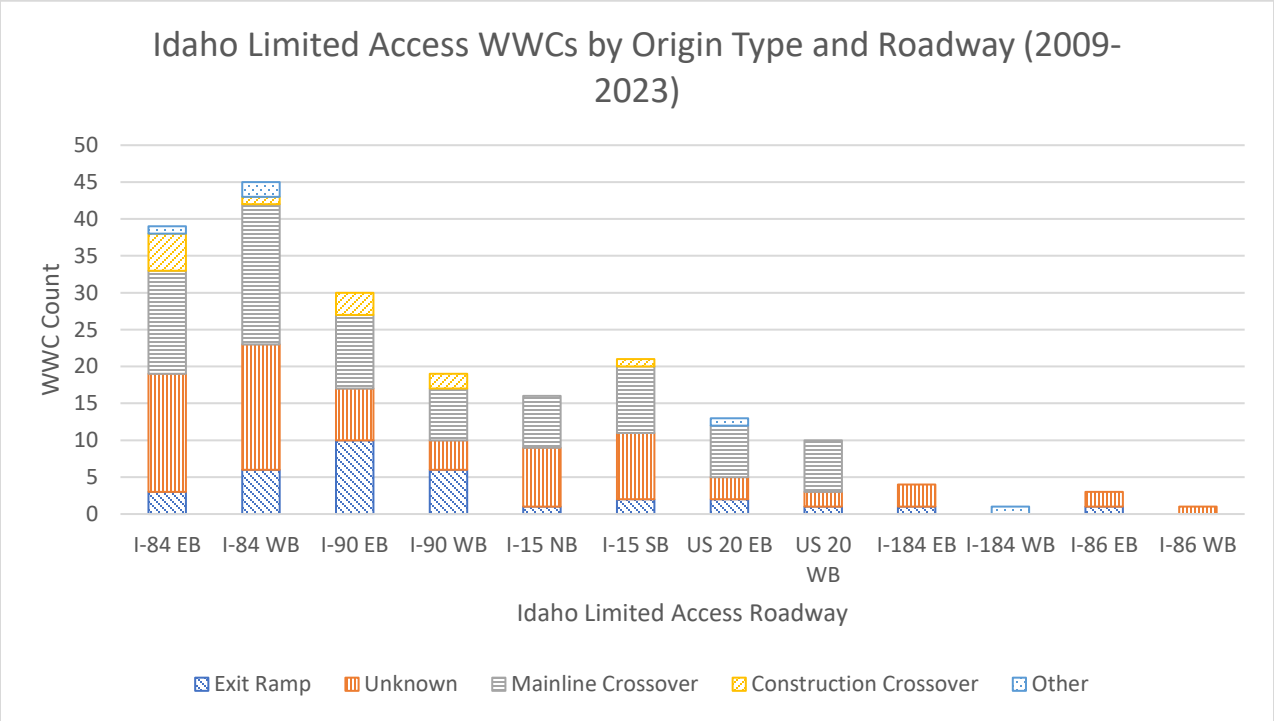

Figure 4.9 Number of WWCs by origin type on each Idaho limited access roadway

Since longer roadways are expected to have more WWCs (due to higher exposure), the number of WWCs per roadway mile were calculated for each Idaho limited access roadway. Table 4.8 and Figure 4.10 show these WWC per roadway mile rates. In Table 4.8, the five roadways with the highest WWC per roadway mile rates are highlighted in gray. The mileage for each roadway was estimated using the IPLAN General Information App (ITD 2021). I-184 EB, I-90 EB and WB, and US 20 EB and WB have the highest WWC per roadway mile rates, indicating that these roadways have the highest potential for WWCs. Since I-184 is very short compared to the other roadways and only had 5 WWCs over the entire 15-year study period, it might not be the best candidate for WWD treatment efforts. The high WWC per roadway mile rates for I-90 (which is the roadway with the second-most total WWCs and fatal WWCs) suggest that this is a problematic roadway for WWD which could benefit from WWD treatments. Hotspot segments and optimal exits for WWD mitigation efforts on this roadway are identified in Chapter 5 to help ITD most effectively combat WWD. These results generally agree with the findings from Rogers et al. (2015) that longer roadways have more WWD events and shorter roadways have higher WWD event densities.

Table 4.8 Idaho WWC Rates per Limited Access Roadway Mile

Roadway	WWCs	Idaho Mileage	WWCs per Roadway Mile
I-84 EB	39	275.6	0.142
I-84 WB	45	275.6	0.163
I-90 EB	30	73.9	0.406 (2nd highest rate)
I-90 WB	19	73.9	0.257 (5th highest rate)
I-15 NB	16	196	0.082
I-15 SB	21	196	0.107
US 20 EB	13	38	0.342 (3rd highest rate)
US 20 WB	10	38	0.263 (4th highest rate)
I-184 EB	4	4.3	0.930 (highest rate)
I-184 WB	1	4.3	0.233
I-86 EB	3	62.5	0.048
I-86 WB	1	62.5	0.016
Total	**202**	**1300.6**	**0.155**

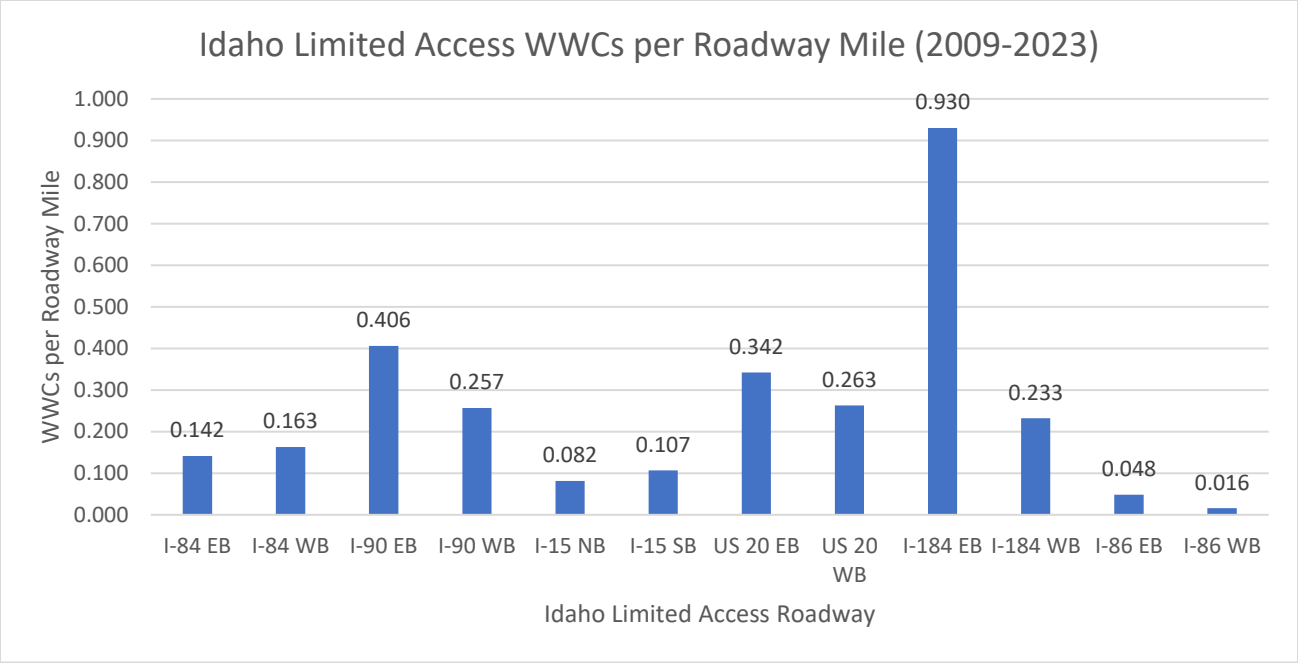

Figure 4.10 Idaho WWCs per limited access roadway mile

Comparisons between Idaho and Florida WWC rates

To better quantify the extent of WWD in Idaho, the UCF research team compared Idaho and Florida WWC data from 2018-2023. WWC counts and rates on limited access roadways in Idaho for these years are shown in Table 4.2, while Florida data are shown in Table 4.9. Figures 4.11, 4.12, and 4.13 show the yearly WWC counts and rates in both states. The number of licensed drivers was not available for Florida in 2023 (as was the case for Idaho), so these rates are only shown through 2022. Even though Florida typically had three to five times more WWCs than Idaho each year, Idaho had over two to four times higher WWC rates than Florida based on both total population and licensed drivers each year. Florida WWC counts and rates peaked in 2021 (87 WWCs, 3.99 WWCs per million people, and 5.39 WWCs per million licensed drivers) while Idaho WWC counts and rates peaked in 2022 (28 WWCs, 14.44 WWCs per million people, and 20.11 WWCs per million licensed drivers). Compared to the lowest yearly WWC counts and rates, the Florida peaks were increases of 33.8% for WWC counts, 32.5% for WWCs per million people, and 29.0% for WWCs per million licensed drivers. For Idaho, the peaks were increases of 133.3% for WWC counts, 115.3% for WWCs per million people, and 109.9% for WWCs per million licensed drivers. These large increases and high rates for Idaho compared to Florida indicate that WWD is a growing problem in Idaho for which effective treatments are urgently needed.

Table 4.9 Florida Annual WWC Rates by Population and Licensed Driver

Year	Florida WWCs	Florida Population (millions)	Annual WWCs per Million People	Florida Licensed Drivers (millions)	Annual WWCs per Million Licensed Drivers
2018	71	21.255	3.34	15.369	4.62
2019	65	21.492	3.02	15.561	4.18
2020	67	21.591	3.10	15.715	4.26
2021	87	21.831	3.99	16.144	5.39
2022	70	22.246	3.15	16.496	4.24
2023	68	22.611	3.01	N/A	N/A
Total	**428**	**131.025**	**3.27**	**79.285**	**5.40**

N/A = not applicable

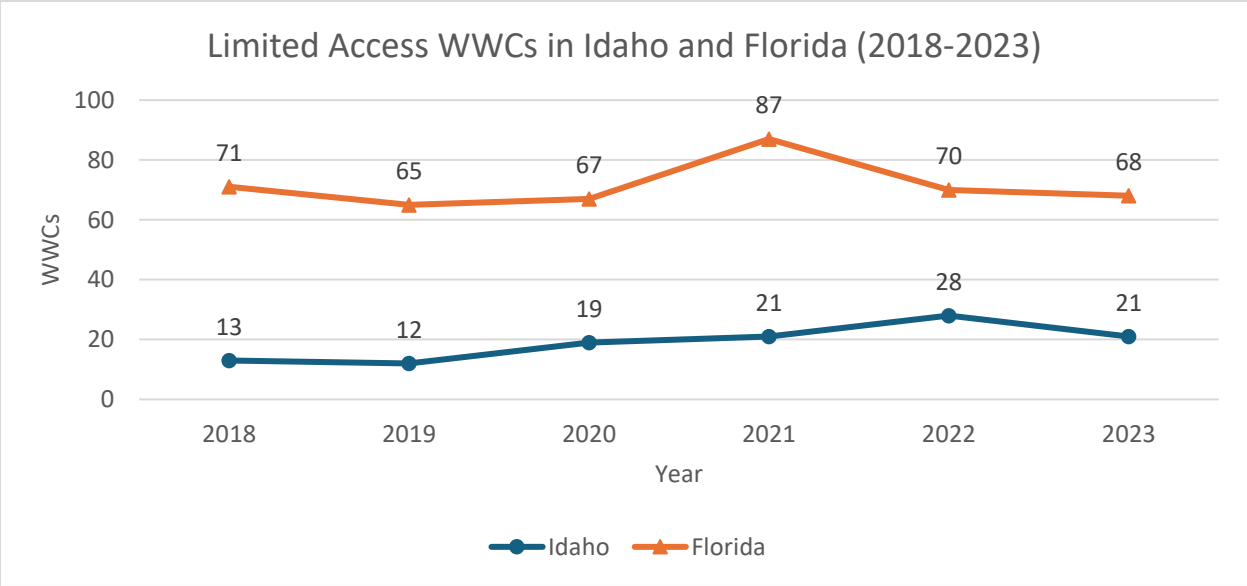

Figure 4.11 Annual limited access WWC counts in Idaho and Florida from 2018-2023

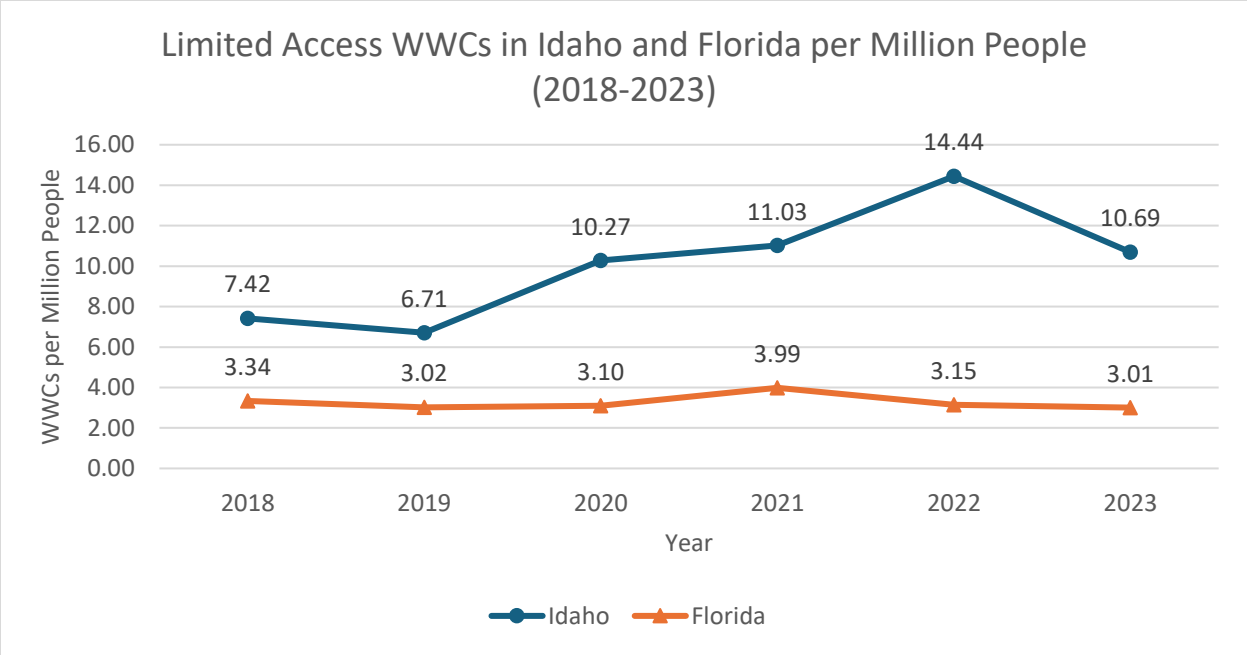

Figure 4.12 Annual WWCs per million people in Idaho and Florida from 2018-2023

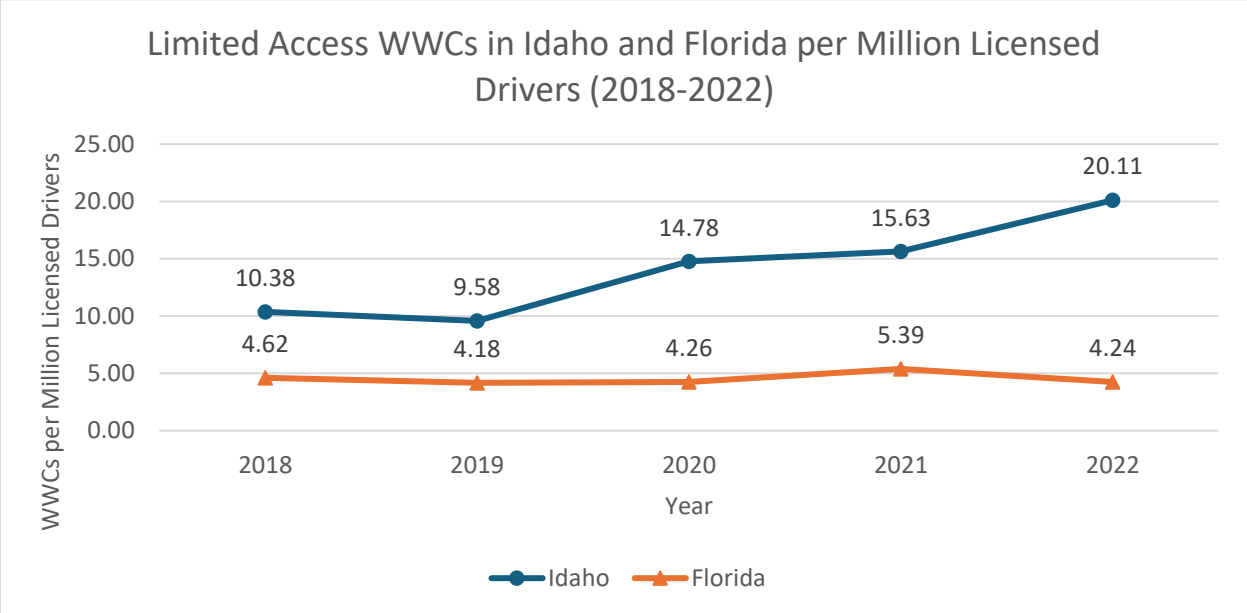

Figure 4.13 Annual WWCs per million licensed drivers in Idaho and Florida from 2018-2022

The number of WWCs per limited access roadway mile were also compared between Idaho and Florida, as shown in Figure 4.14. When counting each roadway direction separately, Idaho has approximately 1,300 miles of limited access roadway and Florida has approximately 4,300 miles of limited access

roadways. Figure 4.14 shows that Florida had higher annual WWC per roadway mile rates from 2018 through 2021, but Idaho's rates were higher in 2022 and 2023. This further emphasizes that WWD has become more prevalent in Idaho over the past few years.

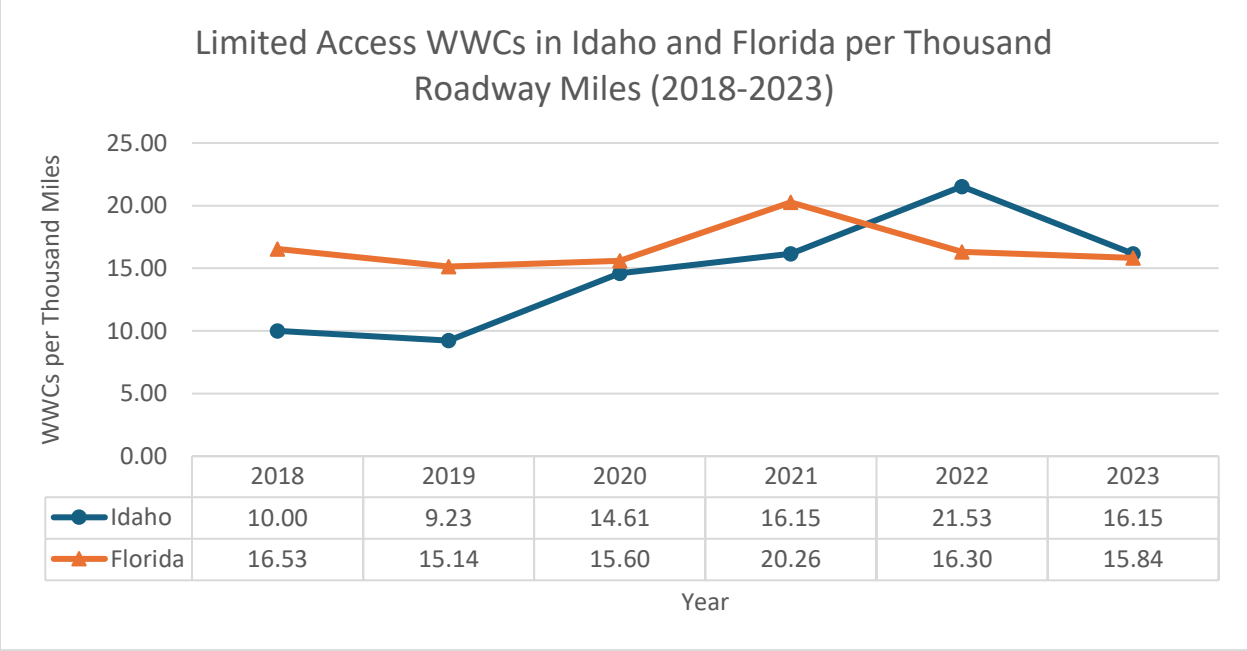

Figure 4.14 Annual WWCs per thousand roadway miles in Idaho and Florida from 2018 through 2023

Exit ramp and unknown origin WWCs

The 33 WWCs which were known to have originated from an exit ramp and the 72 WWCs with unknown origin (total of 105 WWCs) were studied in more detail to understand their characteristics. As previously mentioned, it is reasonable to assume that unknown origin WWCs started at an exit ramp, so it makes sense to study both of these origin types together. Figures 4.15 and 4.16 show the number of exit ramp and unknown origin WWCs by hour of the day and month, respectively. Every hour from 5:00 AM through 5:59 PM experienced 3 or less WWCs during the study period, while every other hour except for hour 3 experienced 4 or more WWCs. This indicates that these types of WWCs are not as common during daytime hours compared to nighttime hours. Hours 0, 1, 2, 4, 19, 21, and 22 all had 7 or more WWCs. These findings agree with previous research that most WWD from exit ramps occurs during nighttime hours. Figure 4.16 shows that there is not much monthly variation in the number of exit ramp and unknown origin WWCs (except for a sharp decline in June), especially when compared to Figure 4.3 for all WWCs.

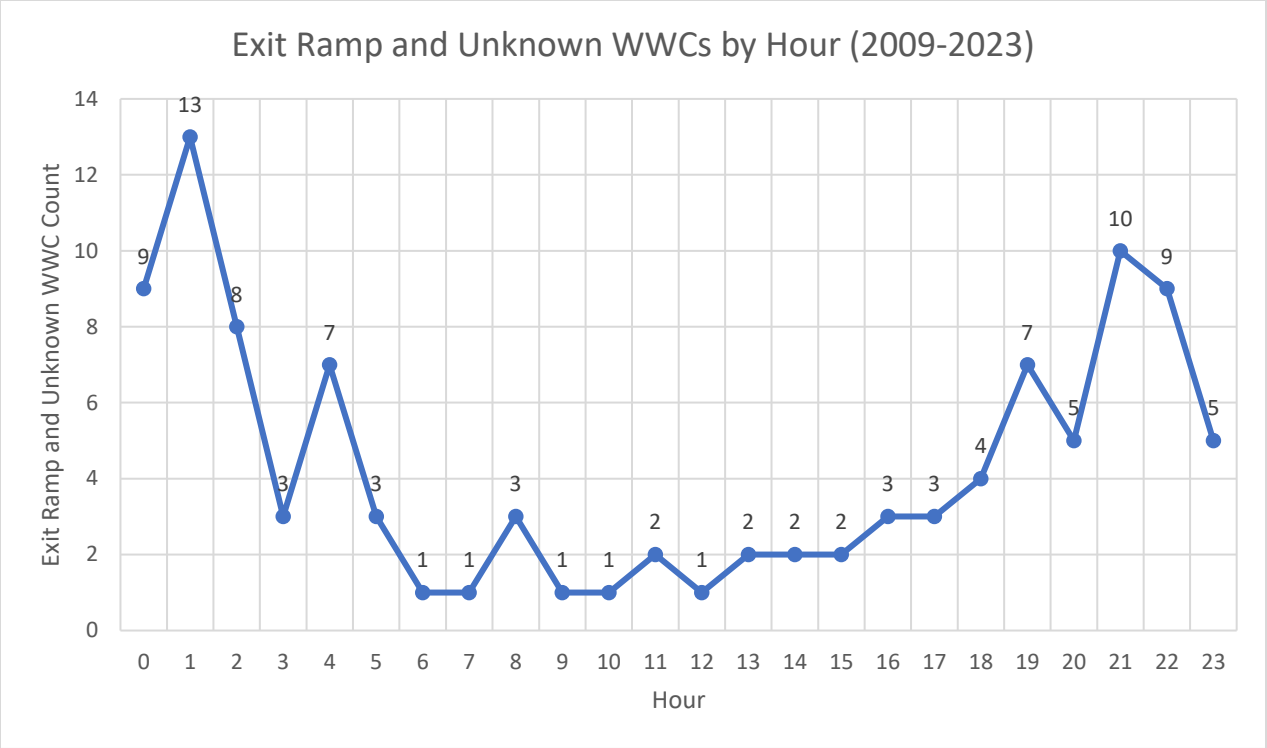

Figure 4.15 Exit ramp and unknown origin WWCs by hour of the day

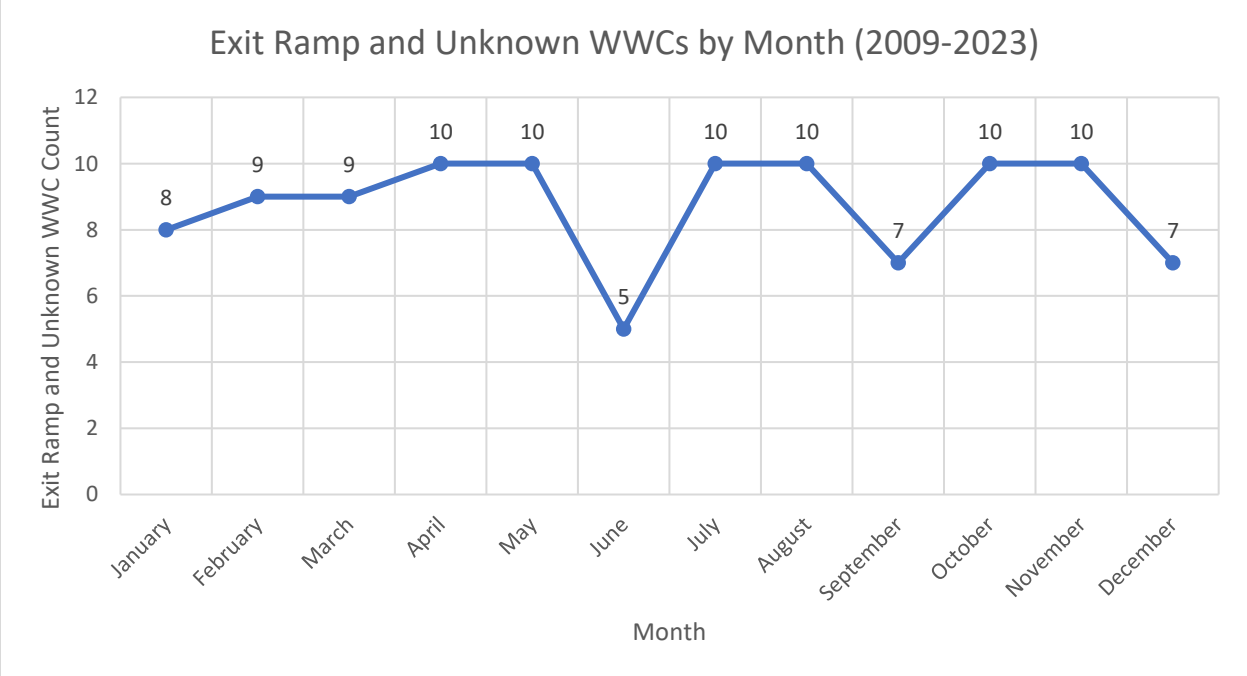

Figure 4.16 Exit ramp and unknown origin WWCs by month

Table 4.10 shows the number of exit ramp or unknown WWCs for each crash severity level, while Table 4.11 shows the number of fatalities and serious injuries, percentage of total people involved who experienced fatal or serious injuries, and fatal and serious injury rates for the exit ramp or unknown origin WWCs. Approximately 29% of the unknown origin WWCs were fatal, compared to only 6% of the exit ramp WWCs. This difference is likely because most of the exit ramp origin WWCs occurred on an exit ramp whereas most of the unknown origin WWCs occurred some distance away from exit ramps on the mainline where vehicles would likely be traveling at higher speeds than on the exit ramp. Therefore, being able to detect and stop WW vehicles before they enter the mainline could help reduce WWD fatalities. The fatality and serious injury percentages and rates are very close to, but slightly lower than, the fatality and serious injury percentages and rates for all WWCs, suggesting that exit ramp and unknown origin WWCs represent typical WWCs.

Table 4.10 Exit Ramp and Unknown Origin WWCs by Severity Level

Crash Severity	Exit Ramp WWC Count	Unknown Origin WWC Count	Total
Fatal (K)	2	21	**23**
Serious Injury (A)	10	12	**22**
Minor Injury (B)	8	5	**13**
Possible Injury (C)	5	18	**23**
No Injury (O)	8	16	**24**
Total	**33**	**72**	**105**

Table 4.11 Fatality and Serious Injury Summaries for Exit Ramp and Unknown Origin WWCs

Parameter	Value
Fatalities	31
Serious Injuries	50
Total People Involved	327
Fatality Percentage	9.5%
Fatality Rate	1.35
Serious Injury Percentage	15.3%
Serious Injury Rate	1.11

The 33 exit ramp WWCs were further examined to identify any exit ramps where multiple WWCs originated from. Four exit exits were known origin points for multiple WWCs from 2009 through 2023, with I-90 EB Exit 11 at Northwest Blvd. (exit ID of A7) and I-90 WB Exit 7 at E. Seltice Way (exit ID of B5) both being origin points for 6 WWCs, while I-84 WB Exit 168 at Golf Course Rd. (exit ID of D46) and I-15 SB Exit 116 at US 26 (exit ID of J27) were both origin points for 2 WWCs. Therefore, these exit ramps

could be prime candidates for advanced WWD countermeasure deployment. The hotspot modeling and optimization in Chapter 5 consider both the known and unknown origin WWD events at each exit, along with other statistically significant factors, to estimate the WWCR at each of these exits (and all other Idaho limited access exits) and show how they compare with other exits to identify the best locations for WWD countermeasures.

Mainline crossover, construction crossover, and other origin WWCs

The 80 mainline crossover WWCs, 12 WWCs in construction crossovers, and 5 WWCs with other origin points (total of 97 WWCs) were also examined in more detail. These categories were combined since they are all WWCs that definitely did not originate from a typical WW vehicle on an exit ramp. Figures 4.17 and 4.18 show the number of mainline crossover, construction crossover, and other WWCs by hour of the day and month, respectively. These WWCs were more frequent during daytime hours, especially the late afternoon and evening hours between 3:00 PM and 6:59 PM. Every hour from 9:00 PM through 6:59 AM experienced 3 or less WWCs during the study period while most hours between 7:00 AM and 8:59 PM experienced 4 or more WWCs. These findings are the opposite of the findings from the exit ramp and unknown origin WWC analysis, indicating that different treatment strategies might be needed to address these different types of WWCs. One possible reason for these differences is low traffic volumes at night and high traffic volumes during the day. When traffic volumes are low, confused drivers could be more likely to enter the highway WW since there are few right-way vehicles to indicate the correct direction of travel, thus increasing the number of WWCs originating from exit ramps. Since the mainline crossover, construction crossover, and other WWCs are mainly caused by drivers losing control and crossing the median, higher traffic volumes both increase the chances of there being a right-way driver that loses control and there being an opposing right-way vehicle to be hit by the WW driver that lost control. Figure 4.18 shows that the months from October through March typically had more of these WWCs than other months, possibly due to snowy or icy conditions causing drivers to lose control. This agrees with the findings from the monthly distribution of all WWCs as shown in Figure 4.3.

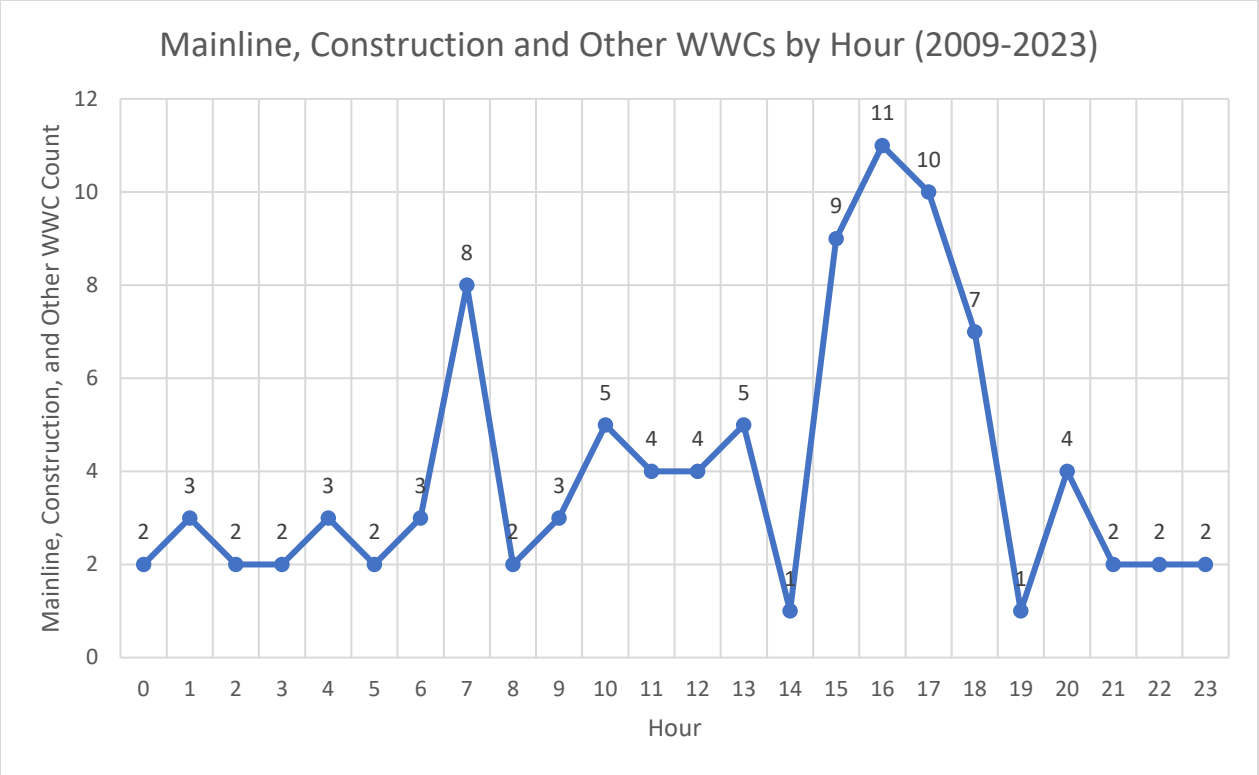

Figure 4.17 Mainline, construction, and other WWCs by hour of the day

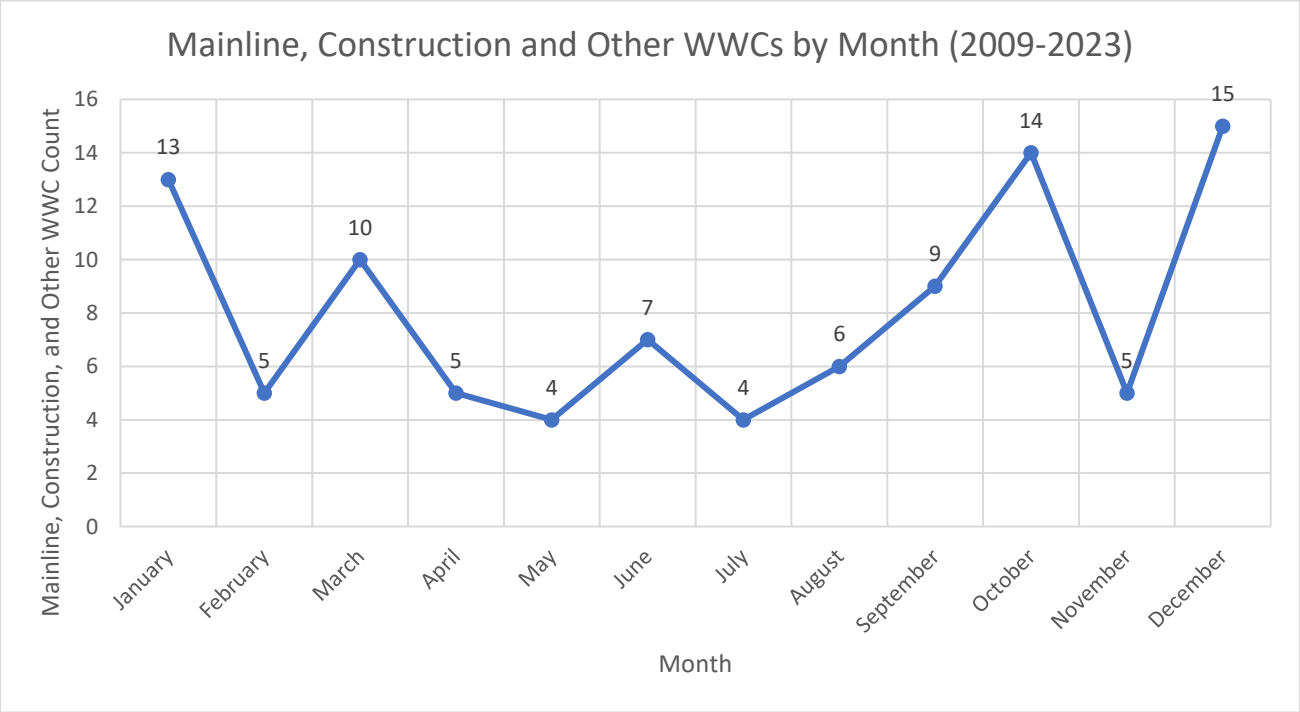

Figure 4.18 Mainline, construction, and other WWCs by month

Table 4.12 shows the number of mainline crossover, construction crossover, or other WWCs for each crash severity level, while Table 4.13 shows the number of fatalities and serious injuries, percentage of total people involved who experienced fatal or serious injuries, and fatal and serious injury rates for these WWCs. Approximately 29% of these WWCs were fatal, including 5 of the 12 construction crossover crashes (41.7%). Alternative construction practices (such as increasing the separation between opposing directions of travel) could help reduce WWCs in construction crossovers. The fatality and serious injury percentages and rates are very close to, but slightly higher than, the fatality and serious injury percentages and rates for all WWCs, suggesting that there is not much of a difference between these types of WWCs and WWCs originating from exit ramps.

Table 4.12 Mainline, Construction, and Other WWCs by Severity Level

Crash Severity	Mainline Crossover WWC Count	Construction Crossover WWC Count	Other WWC Count	Total
Fatal (K)	23	5	0	**28**
Serious Injury (A)	22	1	1	**24**
Minor Injury (B)	14	2	1	**17**
Possible Injury (C)	9	1	1	**11**
No Injury (O)	12	3	2	**17**
Total	**80**	**12**	**5**	**97**

Table 4.13 Fatality and Serious Injury Summaries for Mainline, Construction, and Other WWCs

Parameter	Value
Fatalities	39
Serious Injuries	60
Total People Involved	370
Fatality Percentage	10.5%
Fatality Rate	1.39
Serious Injury Percentage	16.2%
Serious Injury Rate	1.15

The 80 mainline crossover WWCs were further examined to identify likely causes and mainline segments where multiple mainline crossover WWCs occurred. Table 4.14 shows the likely causes for the mainline crossover WWCs. Note that some WWCs had multiple likely causes, which is why the counts add up to more than 80 and the percentages add up to more than 100%. Over 42% of the WW vehicles in these crashes lost control due to unknown reasons, while almost 28% lost control due to ice, snow, or slush on the road (with the WW drivers also going too fast for the conditions in some of these cases). These

findings suggest that treatment methods such as warning upstream drivers of slick road conditions and/or lowering speed limits during bad weather through the use of variable speed limits could potentially help reduce mainline crossover WWCs.

Table 4.14 Likely Causes of Mainline Crossover WWCs

Likely Cause	Mainline Crossover WWC Count	Percentage
Unknown Loss of Control	34	42.5%
Ice/Snow/Slush	22	27.5%
Right-Way Crash	6	7.5%
Tire Blowout/Mechanical Issue	6	7.5%
Too Fast	4	5.0%
Unsafe Lane Change	4	5.0%
Overcorrected and Lost Control	3	3.8%
Failure to Stop for Traffic/Emergency Lights	3	3.8%
Driver Fatigue/Asleep	2	2.5%
Driver Seizure	1	1.3%
Detached Trailer	1	1.3%
Inattentive Driving	1	1.3%
Drugs	1	1.3%
Parked in Travel Lanes	1	1.3%
Hit Animal	1	1.3%

Table 4.15 shows the 18 mainline segments which experienced multiple mainline crossover WWCs during the study period. For this table, only the mainline segment where each WWC occurred was considered and not where exactly within the segment. This means that a segment could have multiple WWCs which occurred miles apart depending on the length of the segment. I-84 contained 10 segments with multiple mainline crossover WWCs, I-90 and US 20 each contained 3 segments with multiple mainline crossover WWCs (with one segment on US 20 having 4 mainline crossover WWCs), and I-15 contained 2 segments with multiple mainline crossover WWCs. These segments should be priority considerations for median barriers or other treatment methods to reduce median crossovers, especially when the road is icy.

Table 4.15 Idaho Limited Access Mainline Segments with Multiple Mainline Crossover WWCs from 2009-2023

Roadway	Segment ID	Starting Point	Ending Point	Number of Mainline Crossover WWCs
I-90	M5	Pleasant View Rd EB	N Spokane St WB	2
I-90	M6	N Spokane St WB	N Spokane St EB	2
I-90	M8	E Seltice Way EB	Ross Point Rd WB	2
I-84	N4	US 95 EB	US 30 WB	2
I-84	N6	US 30 EB	Black Canyon Rd WB	3
I-84	N10	Oasis Rd EB	State Road 44 WB	2
I-84	N20	US 26 EB	Midland Blvd WB	3
I-84	N55	Simco Rd EB	Old U.S. 30 WB	2
I-84	N61	Old Oregon Trail Rd EB	Hammett Hill Rd WB	2
I-84	N64	Cold Springs Rd EB	N Bannock St WB	2
I-84	N73	Bliss Rest Area EB	US 30 WB	2
I-84	N83	State Road 46 EB	State Road 25 WB	2
I-84	N95	Ridgeway Rd EB	S 1250 W WB	2
I-15	Q35	Northgate Pkwy NB	E Ross Fork Rd SB	2
I-15	Q43	W 450 N NB	North Blackfoot Rest Area SB	3
US 20	R11	25th E EB	105th N WB	2
US 20	R15	E County Line Rd EB	S State St WB	3
US 20	R20	Main St EB	W 5000 S WB	4

WWD Citation and Dispatch Report Analyses

The results of the WWC analyses in the previous section show where and when these crashes are most common. However, WWCs do not fully represent the extent of WWD as many WWD events do not result in a crash. Analyzing these non-crash WWD events provides a better understanding of WWD frequency and characteristics to help ITD more effectively combat this problem. This section discusses the various analyses conducted on the 102 non-crash WWD citation events and the 32 non-crash ISP dispatch report events.

All WWD citations

The 102 non-crash WWD citations events on Idaho limited access roadways occurred from June 2018 through December 2023. Figure 4.19 shows the number of WWD citations per year from 2018 through

2023. The WWD citation count was highest in 2020 (21 WWD citations) and has been relatively consistent since 2019. Comparing this figure to Figure 4.1 shows that there were 114 WWCs during this same six-year period, with there being more WWD citations than WWCs in 2019 and 2020. Since the number of WWCs has increased in recent years while the number of WWD citations has remained steady, increased law enforcement presence could be beneficial in reducing WWCs by helping to apprehend more WW drivers before they cause a crash.

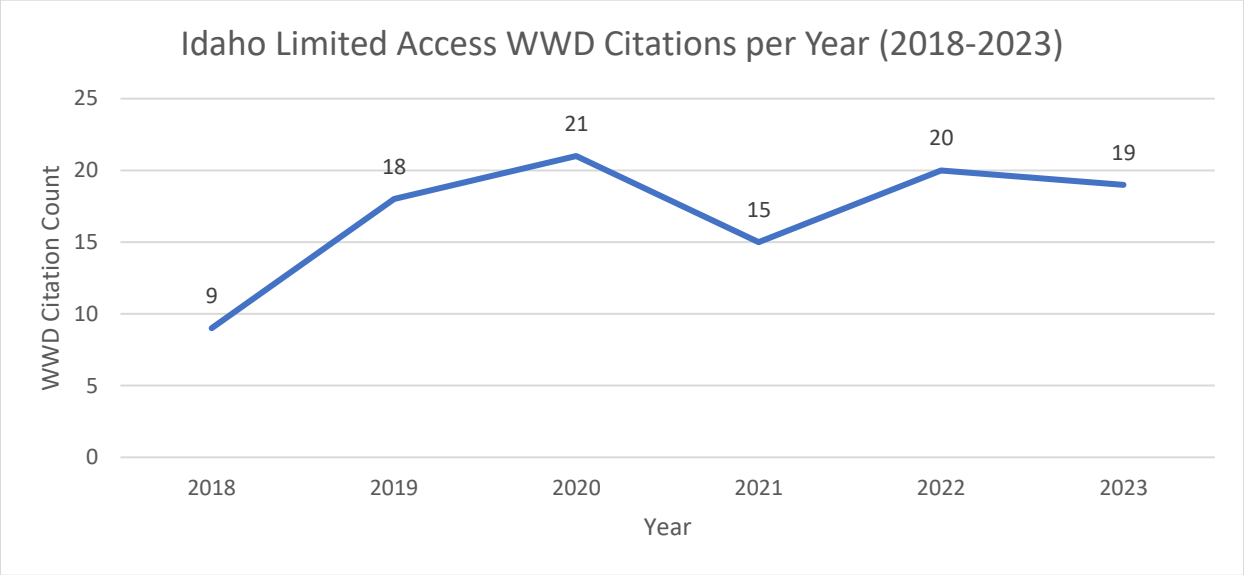

Figure 4.19 Idaho limited access WWD citations per year from 2018 through 2023

Table 4.16 shows the number and percentage of WWD citations by Idaho statute (49-630, 49-636, or 49-645) for the entire period from June 2018 through December 2023. As previously mentioned, these were the only three statutes with WWD citations after filtering. Almost two-thirds of the citations were issued to drivers violating Idaho statute 49-636. Based on these findings, the UCF research team recommends having one of these three statutes (or a subsection within one of these statutes) specifically mention limited access WWD events. This could help ITD and ISP better collect and document limited access WWD citations in the future.

Table 4.16 Number of WWD Citations by Violated Idaho Statute from 2018 through 2023

Idaho Statute	Number of WWD Citations	Percentage of WWD Citations
49-630 (drive on right side of roadway – exceptions)	21	20.6%
49-636 (one-way highways)	67	65.7%
49-645 (limitations on turning around)	14	13.7%
Total	**102**	**100%**

Figures 4.20 and 4.21 show the number of Idaho limited access WWD citations by hour of the day and month, respectively. In general, WWD citations were more common during daytime hours than nighttime hours, especially from 9:00 AM through 11:59 AM and 2:00 PM through 8:59 PM. This could be due to more law enforcement being present during daytime hours and traffic congestion being more likely during daytime hours, which could cause drivers to turn WW on the mainline. The monthly counts show that December had the most WWD citations, with late spring and summer months also having high counts. The high December counts could be due to poor weather conditions resulting in congestion (with drivers turning WW to avoid this congestion) and more driver confusion, while the high counts in spring/summer could be due to increased traffic volumes during these months, including potential tourists who are unfamiliar with the area.

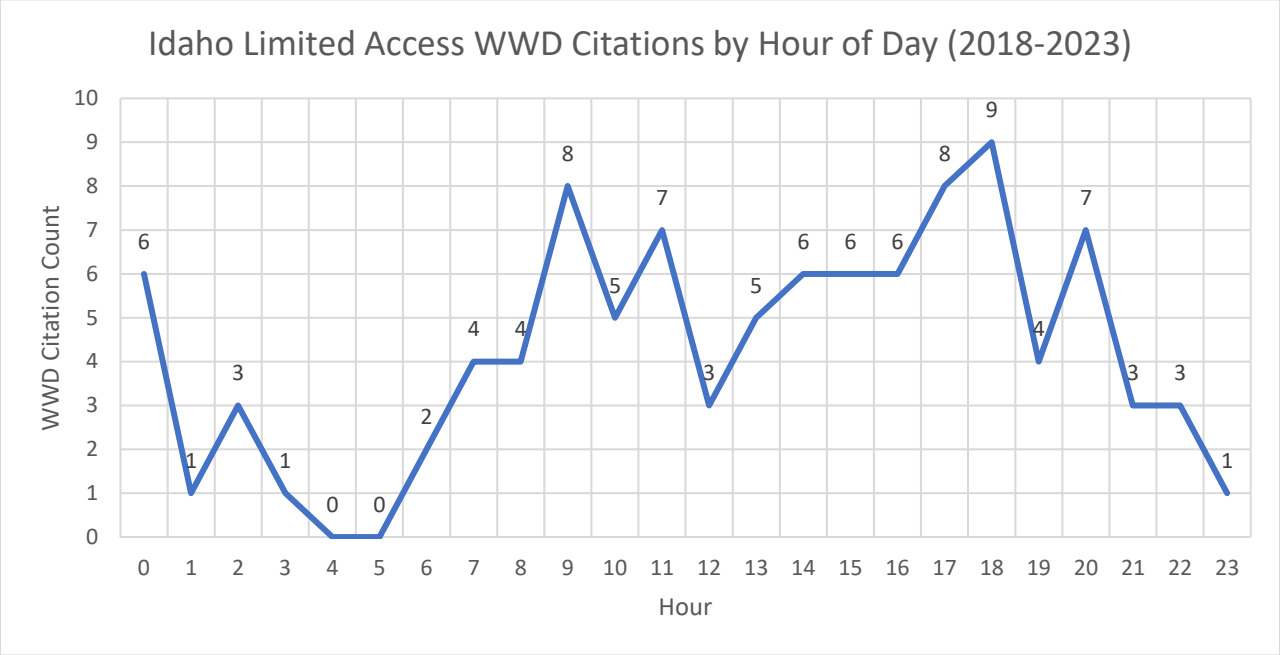

Figure 4.20 WWD citation counts by hour of the day

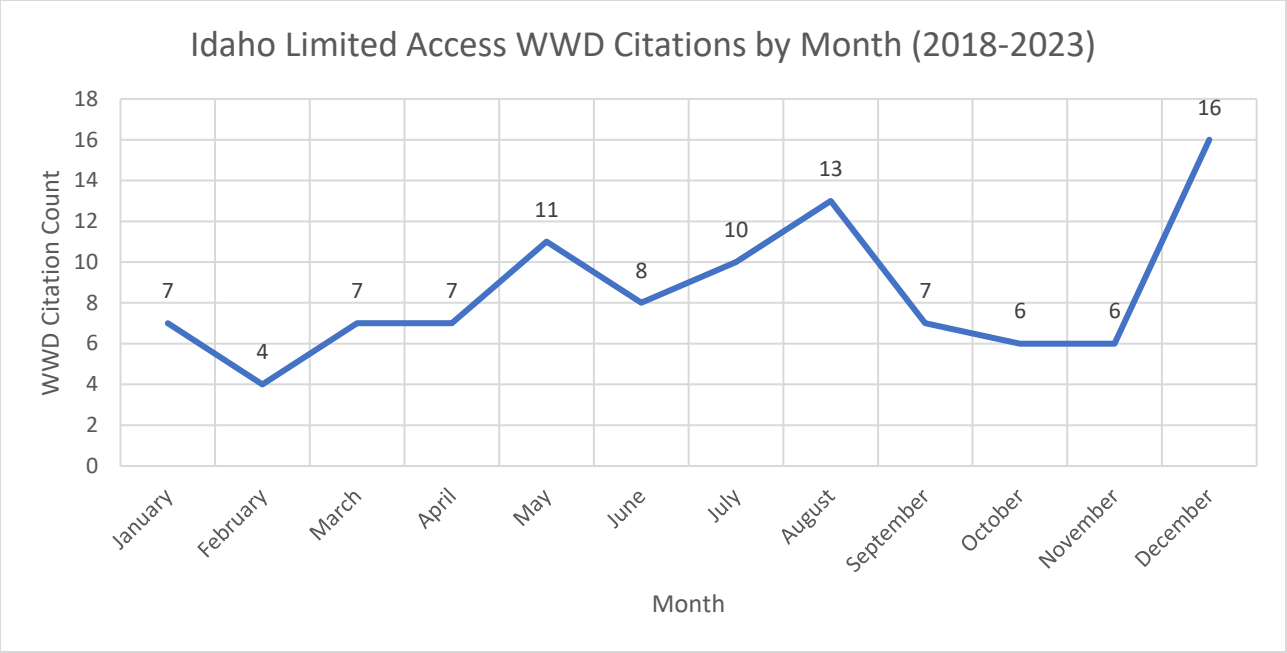

Figure 4.21 WWD citation counts by month

Table 4.17 and Figure 4.22 show the number of WWD citations by origin type per year. The exit ramp, unknown, and other origin types are the same as for WWCs, meaning that the exit ramp and unknown origin WWCs and citations can be included in the same models. The "Other" category only contained one WWD citation caused by a driver reversing on the mainline after missing an exit. Mainline turnaround citations are ones where a right-way driver turned WW on the mainline or entrance ramp (usually to avoid congestion), while construction zone citations are ones where a right-way driver ended up going WW in a construction zone (usually due to confusion). Therefore, these two categories of citations differ from the mainline crossover and construction crossover WWC origin categories. Unknown origin and exit ramp WWD citations were the most common (63% of citations), with exit ramp citations being more common than exit ramp WWCs (due to law enforcement often observing where the driver started going WW for these citations).

Table 4.17 WWD Citations by Origin Type per Year

Year	Exit Ramp	Unknown	Mainline Turnaround	Construction Zone	Other	Total
2018	1	6	1	1	0	**9**
2019	6	4	6	2	0	**18**
2020	7	4	6	4	0	**21**
2021	7	5	3	0	0	**15**
2022	3	9	7	0	1	**20**
2023	7	5	5	2	0	**19**
Total	**31**	**33**	**28**	**9**	**1**	**102**

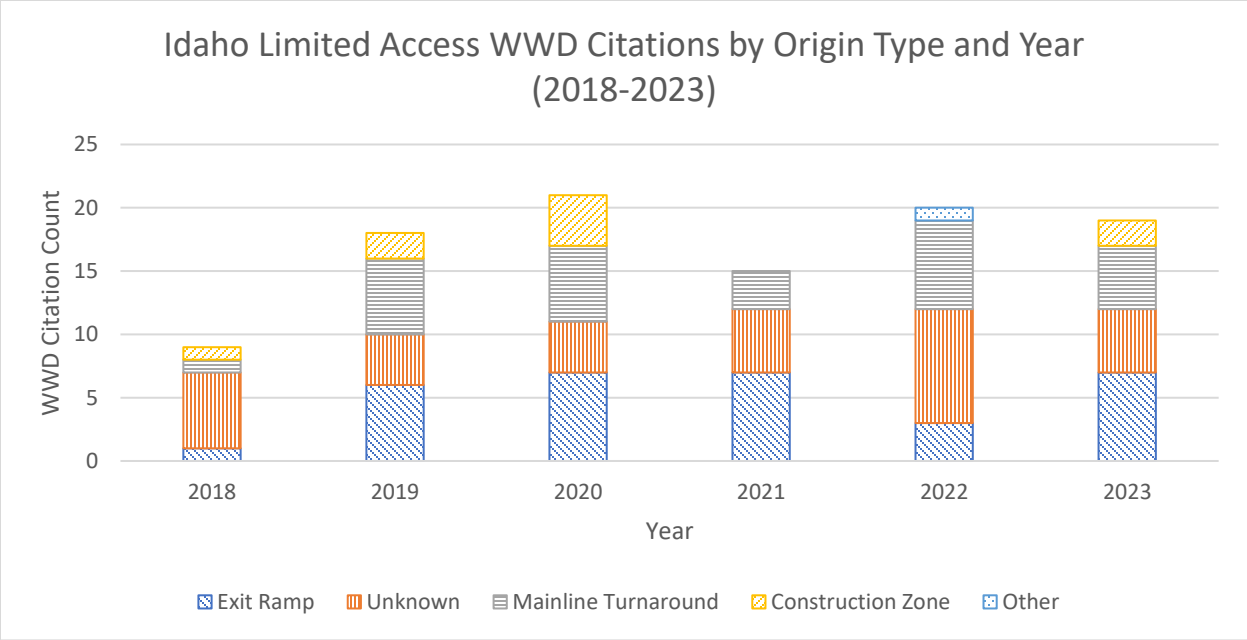

Figure 4.22 Number of WWD citations by origin type per year

The WWD citations were also analyzed with respect to the Idaho limited access roadways they occurred on. Table 4.18 and Figure 4.23 show the number of WWD citations by origin type on each roadway. I-84 WB and I-84 EB had the most WWD citations (like they did for the WWCs), but I-15 NB and SB had the second-most WWD citations, whereas I-90 EB and WB had the second-most WWCs. This suggests that increased law enforcement on I-90 could potentially reduce WWCs. Additionally, only 3 of the 11 WWD citations on I-90 had exit ramp or unknown origins (even though over half of the I-90 WWCs had exit ramp or unknown origins), suggesting that increased law enforcement or other efforts are needed to stop WW drivers that enter I-90 from exit ramps before they cause WWCs.

Table 4.18 WWD Citations by Origin Type and Roadway

Roadway	Exit Ramp	Unknown	Mainline Turnaround	Construction Zone	Other	Total
I-84 EB	8	9	10	6	1	34
I-84 WB	14	6	4	3	0	27
I-15 NB	3	4	2	0	0	9
I-15 SB	3	3	2	0	0	8
I-90 EB	0	1	6	0	0	7
I-90 WB	1	1	2	0	0	4
US 20 EB	1	3	0	0	0	4
US 20 WB	0	2	2	0	0	4
I-86 EB	0	1	0	0	0	1
I-86 WB	1	2	0	0	0	3
I-184 EB	0	1	0	0	0	1
I-184 WB	0	0	0	0	0	0
Total	**31**	**33**	**28**	**9**	**1**	102

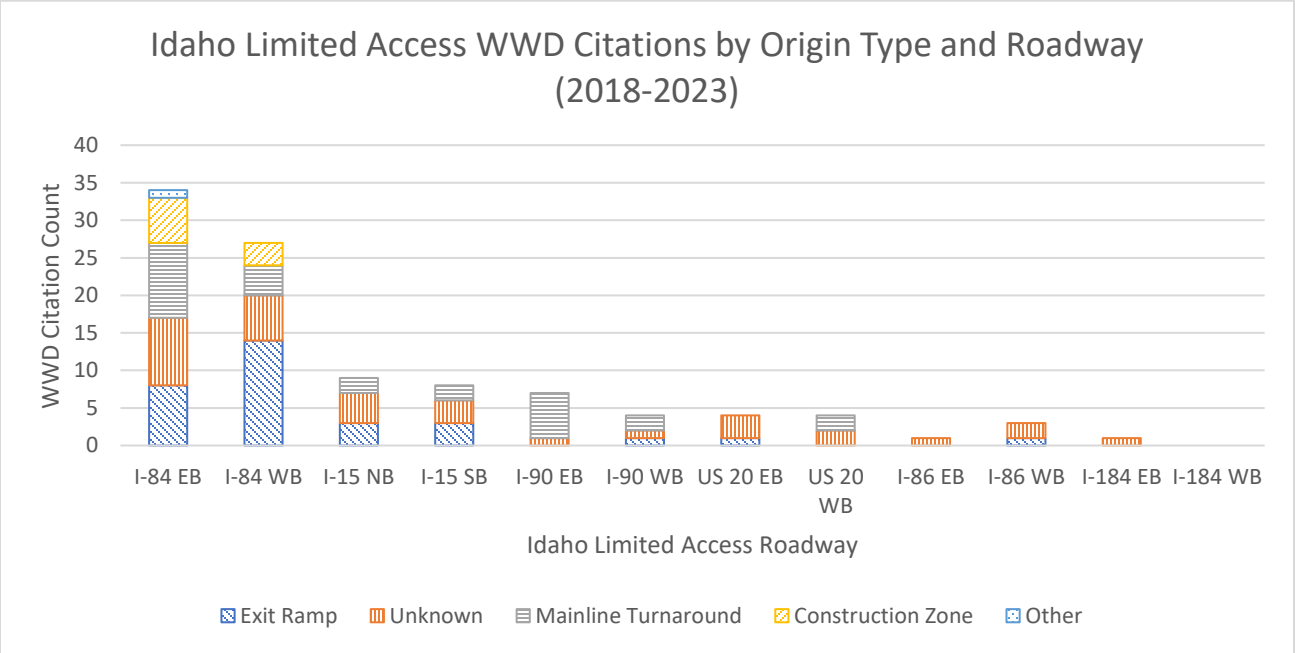

Figure 4.23 Number of WWD citations by origin type on each Idaho limited access roadway

Figure 4.24 shows the WWD citation rates per roadway mile for each Idaho limited access roadway. I-184 EB and both directions of I-15, I-84, and US 20 all have high rates, suggesting that they have many

law enforcement officers to cite WW drivers. Conversely, I-90 and I-86 have low rates, suggesting that additional law enforcement coverage could be needed on these roadways (especially I-90) to apprehend more WW drivers.

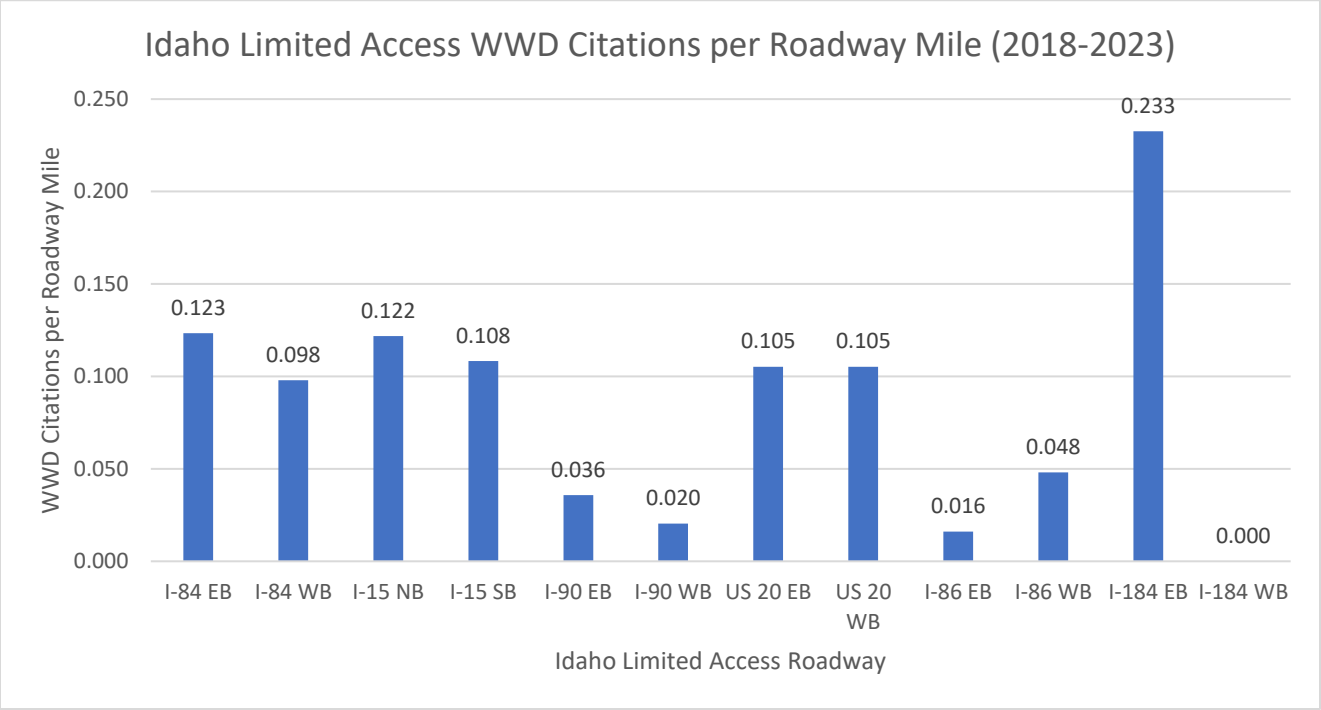

Figure 4.24 WWD citations per Idaho limited access roadway mile

Exit ramp and unknown origin WWD citations

The 31 WWD citations which were known to have originated from an exit ramp and the 33 WWD citations with unknown origin (total of 64 WWD citations) were examined in more detail to understand their characteristics. Figure 4.25 shows the number of exit ramp and unknown origin citations by hour of the day. These citations were generally more common during daytime hours (with hours 9 and 18 having the highest counts), but there were often large fluctuations between consecutive hours. These fluctuations make it hard to determine any consistent trends based on time of day. Compared to the exit ramp and unknown origin WWCs (Figure 4.15), citations were more common during daytime hours. This suggests that increased law enforcement presence during nighttime hours could potentially allow law enforcement officers to apprehend WW drivers before they cause a crash, thereby helping to reduce nighttime WWCs.

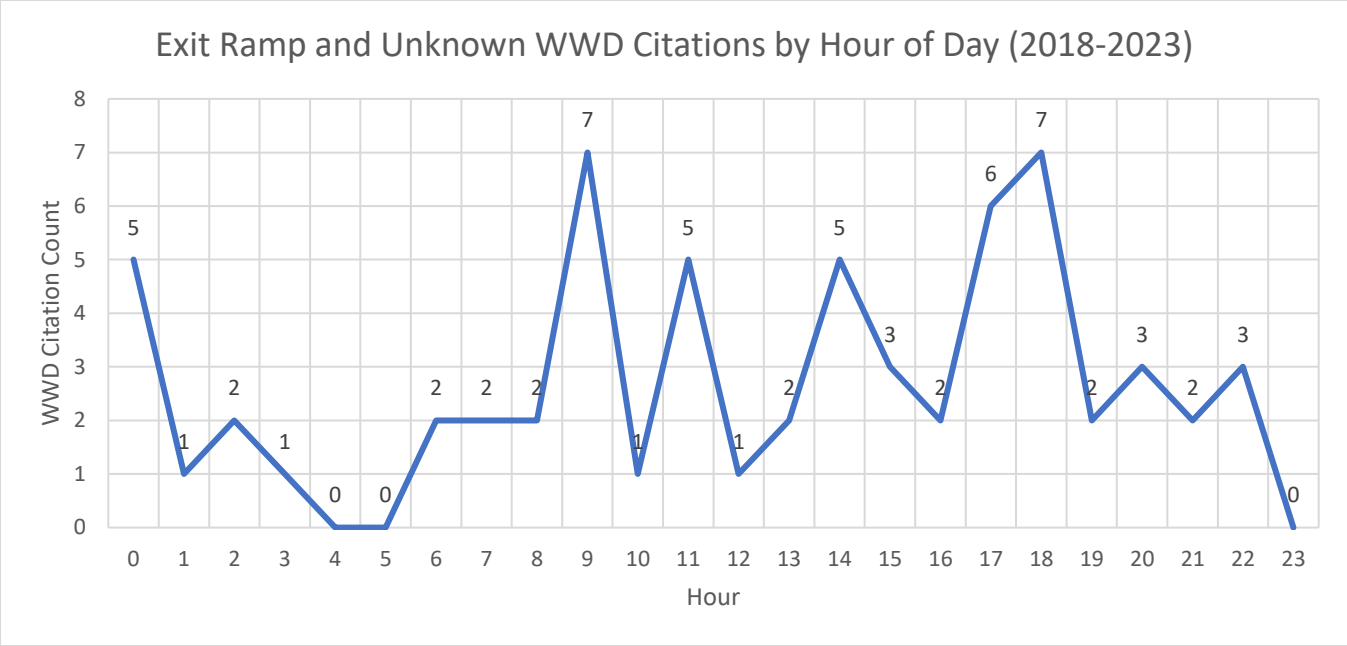

Figure 4.25 Exit ramp and unknown origin WWD citations by hour of the day

The 31 exit ramp WWD citations were further examined to identify any exit ramps where multiple WWD citation events originated from. Five exit ramps were known origin points for multiple WWD citation events from 2018 through 2023, with I-84 WB Exit 168 at Golf Course Rd. (exit ID of D46) having 5 WWD citations and I-84 EB Exit 52 at N Orchard St. (exit ID of C21), I-84 EB Exit 168 at Golf Course Rd. (exit ID of C46), I-84 WB Exit 33 at W Karcher Rd. (exit ID of D11), and I-84 WB Exit 35 at Northside Blvd. (exit ID of D12) all having 2 WWD citations. I-84 WB Exit 168 also had multiple exit ramp WWCs, suggesting that this exit is susceptible to WWD. The modeling and optimization efforts in Chapter 5 utilize both WWC and non-crash WWD citation data to find out how they relate to each other and which exits have the highest WWCR based on these events and other significant factors.

ISP WWD dispatch reports

The 32 ISP WWD dispatch reports from January 2019 through September 2023 which did not overlap with the WWC or WWD citation data were all located on I-90 in District 1 between mile markers 36 and 73. Almost all of these WWD events (29 reports, or 90.6%) had unknown origins, with the remaining 3 known to have originated from exit ramps. These 3 exit ramp events originated from I-90 EB Exit 49 at Bunker Ave. (exit ID of A21), I-90 EB Exit 51 at N Division St. (exit ID of A23), and I-90 EB Exit 68 at I-90 Business Loop (exit ID of A32). Figure 4.26 shows the number of ISP WWD complaint reports in District 1 per year from 2019 through 2023. There were the most ISP WWD complaint reports in 2023 (even though the data only contained reports through September 2023), indicating that WWD has become more frequent on I-90 in District 1 in recent years. This trend could potentially be related to Idaho's population growth.

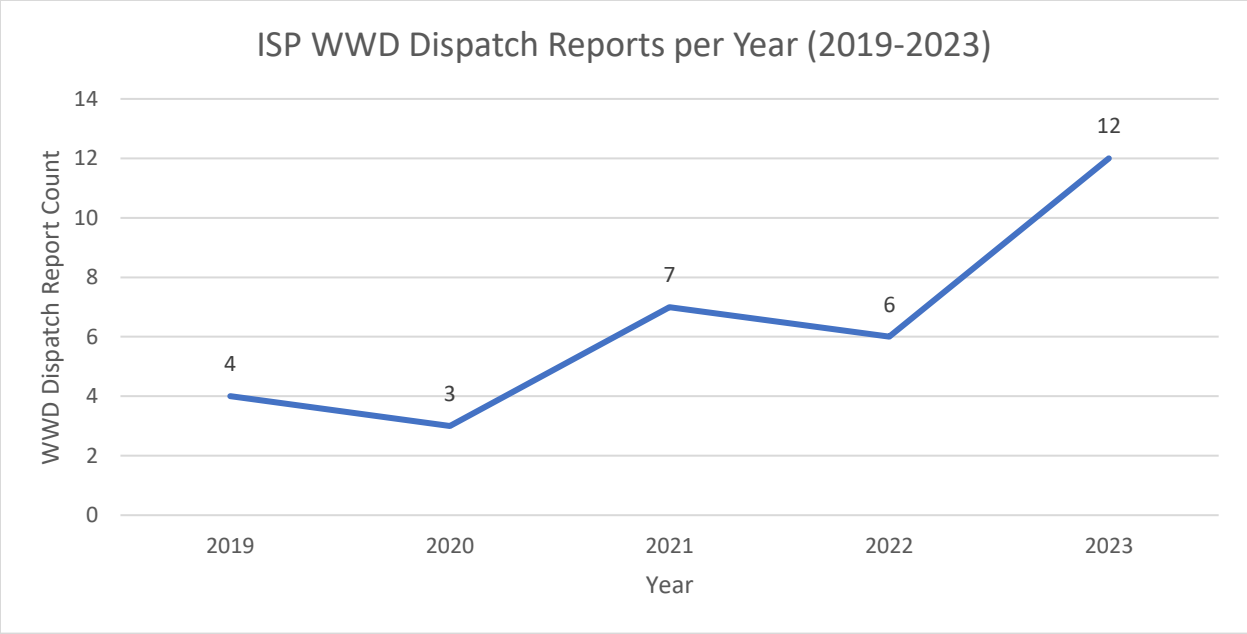

Figure 4.26 ISP District 1 WWD complaint reports per year from 2019 through 2023

Due to the limited scope of these dispatch reports, they were only analyzed with respect to time of day and month, as shown in Figures 4.27 and 4.28, respectively. Most of these reports occurred during nighttime and early morning hours, specifically 9:00 PM through 5:59 AM, with hour 10 also having multiple reports. The higher counts during nighttime hours agree with the trends for the exit ramp and unknown origin WWCs. The monthly counts are varied and do not show any specific trends, with April having the most reports. Due to the limited scope of these reports (only about 40 miles on I-90), they were not considered during the modeling process in Chapter 5 as they would bias the model by making it seem like WWD was more common on I-90. However, it is recommended to expand the collection of these reports to other ITD districts and limited access roadways throughout Idaho as these reports can be a valuable source of non-crash WWD event data. If these expansions are made, these reports could be considered in future updates to the WWD hotspot model to obtain a more accurate understanding of locations with high WWD frequency.

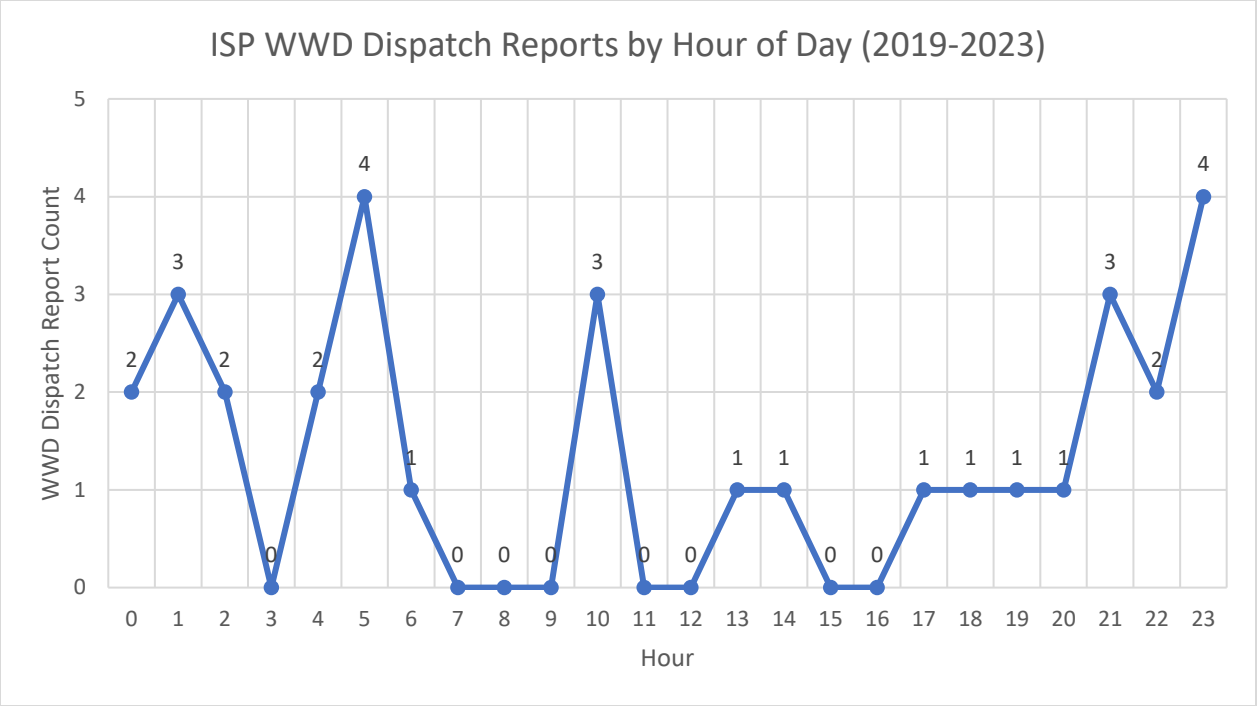

Figure 4.27 ISP WWD dispatch reports by hour of the day

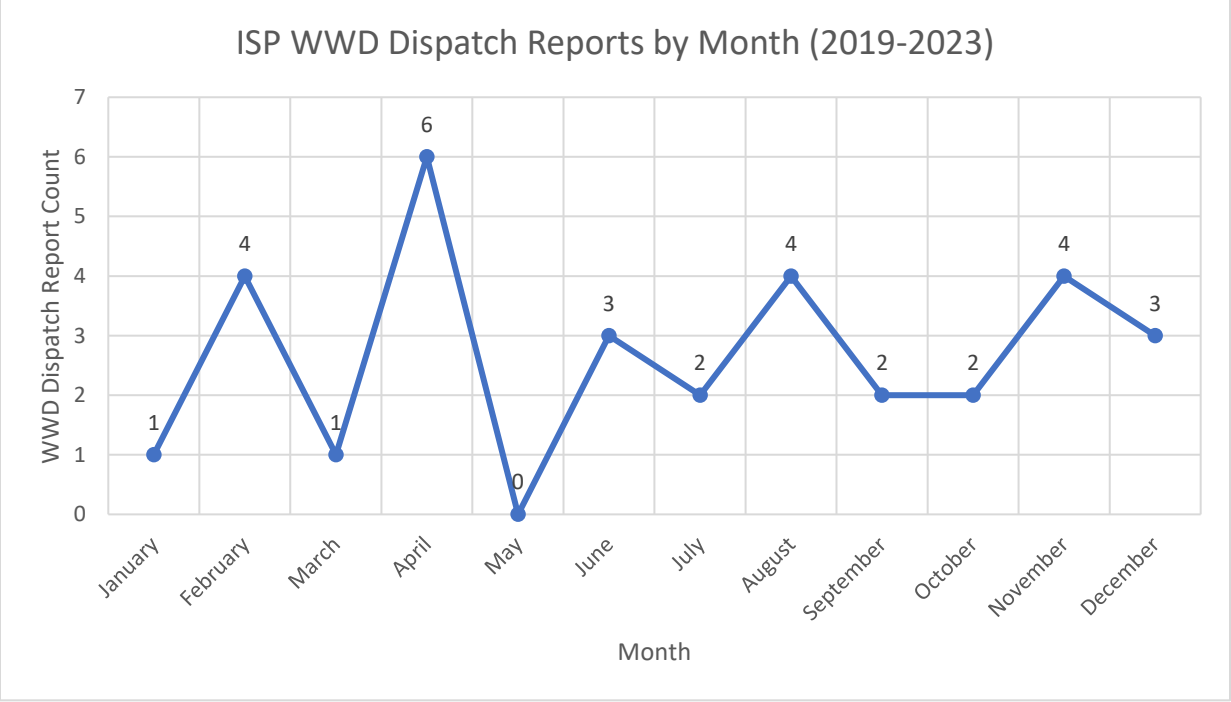

Figure 4.28 ISP WWD dispatch reports by month

WWD Event Analysis Summary, Conclusions, and Recommendations

The collection and analysis of WWD event data (WWCs, WWD citations, and ISP WWD dispatch reports) discussed in this chapter provided useful insights to help ITD improve data quality and better treat WWD in the future. WWC data were collected through ITD's AASHTOWare Safety database. Multiple queries were used to obtain potential WWC data with either a contributing circumstance of "Wrong Side or Wrong Way" or an event type of "Head-On". After filtering these queries to remove crashes not on limited access facilities and non-WWD crashes (based on crash report narratives and diagrams), there were 202 total WWCs from 2009-2023 on Idaho limited access roadways. Only 112 of these WWCs were reported as having a contributing circumstance of "Wrong Side of Wrong Way". To address this, it is recommended for ITD to work with ISP officers to improve the reporting consistency of WWCs in the future.

WWD citation and ISP dispatch reports were also collected, as these types of non-crash WWD data can provide a better representation of the WWD problem than WWCs. ISP citation data for six Idaho statutes potentially related to WWD were reviewed, resulting in 139 non-crash WWD citations on limited access roadways from 2018-2023 (after removing overlap). Only three of the six considered statutes actually had WWD citations, with statute 49-636 being the most common. Consistently citing WWD incidents in the future will help make it easier to collect and analyze these data. A major shortcoming of these citation data was the lack of latitude and longitude coordinates to map them, making it hard to determine exactly where the WWD citation was issued. It is recommended to collect latitude and longitude information for citations in the future to improve their accuracy. The ISP WWD dispatch reports were only available for a 37-mile stretch of I-90 in ITD District 1 (total of 32 reports from 2019-2023 after removing overlap), limiting their usefulness in determining WWD characteristics. It is recommended to collect these dispatch reports throughout the state to obtain meaningful insights into WWD behaviors.

WWC analyses showed that WWC counts (including fatal crashes) and WWC rates have increased since 2019, with I-84 and I-90 having the most WWCs. These increases have occurred while Idaho has been experiencing rapid population growth, so proactive measures in the form of effective treatments are needed to ensure that WWD does not continue to grow at a greater rate than population growth. Idaho WWC rates per million people and million licensed drivers have been higher than Florida rates since 2018 (even though Idaho WWC counts were much lower), with the Idaho WWC rate per thousand limited access roadway miles also higher than Florida's rate for 2022 and 2023. These comparisons suggest that deployments of advanced WWD countermeasures are likely to be useful in Idaho (like they were in Florida) to make roads safer and save lives.

Approximately 10% of people involved in WWCs experienced fatal injuries and 16% experienced serious injuries. There were similar counts of WWCs with unknown or exit ramp origins and WWCs which originated from the mainline, indicating that exit ramp countermeasures are not enough to eliminate WWD without mitigation efforts on the mainline. Unknown origin WWCs were especially common on I-84 and I-15, so it is recommended to deploy WWD detection devices at exit ramps on these roadways.

Exit ramp and unknown origin WWCs were more common during nighttime than daytime, with I-90 EB Exit 11 and I-90 WB Exit 7 experiencing many exit ramp WWCs and therefore being potential candidates for advanced WWD countermeasure deployments. Mainline and construction crossover WWCs were most common in the afternoon and evening on I-84 and US 20, so median barriers, alternative construction practices, or other mainline treatments are recommended for these roadways. Icy roadways were a common cause of these crossovers, so strategies to help improve driver awareness and reduce speeding when roadways are slick could be effective treatments. However, additional research efforts are needed to fully understand mainline and construction crossover WWCs and potential treatment strategies. Crossover WWCs were not considered in the modeling and optimization efforts discussed in the next chapter since they differ greatly from exit ramp or unknown origin WWCs.

Analyses of the WWD non-crash data showed that WWD citations on Idaho limited access roadways have not increased as much as WWCs in recent years. This suggests that increased law enforcement presence could potentially reduce WWCs by stopping WW drivers before they cause a crash. Increased law enforcement could be especially useful during nighttime hours and on I-90, as this time period and roadway had low WWD citation counts compared to WWC counts. Exit ramp and unknown origin WWD citations were more common than mainline turnarounds, with five exits on I-84 being the origin points for multiple WWD crashes. These included I-84 WB Exit 168, which was also the origin point for multiple WWCs. The limited available ISP dispatch data did not provide much insight into WWD behavior, but similar data from other parts of the state could help ITD better understand the full scope of WWD. The insights, findings, and recommendations discussed in this chapter can help ITD decide on future treatment strategies to reduce WWCs and their associated injuries and fatalities, with more detailed insights and recommendations obtained from the hotspot modeling and optimization discussed in the next chapter.

5. WWD Hotspot Modeling and Optimization

The data analyses in Chapter 4 showed some potential locations with high WWD frequency and allowed for some recommendations to be made which could help reduce limited access WWD. However, modeling efforts are needed to accurately predict WWCs, identify statistically significant influencing factors for limited access roadway segments, and locate high-risk segments and exits. The model predictions can be added to historical WWC counts to obtain WWCR values which consider both actual WWC history and potential WWCs due to the significant factors. These WWCR values can be used to identify WWD hotspot segments with a high risk of WWCs. Optimization techniques can be applied to the modeling results to identify specific exits with high potential WWCR reduction for priority treatment of advanced or improved WWD countermeasures. These could include hotspot exits within the identified hotspot segments and lone wolf exits outside of the identified hotspot segments. With these efforts, ITD can most effectively combat WWD in the future to reduce the frequency of WWCs, which will help prevent injuries and save lives. This modeling and optimization approach has been used by Professor Al-Deek and his UCF research team with great success in Florida, as discussed in Chapter 2.

This chapter discusses the modeling and optimization methods that the UCF research team used to identify WWD hotspot segments and the optimal exits for priority implementation of WWD countermeasures on Idaho limited access roadways. These methods are similar to the ones used for previous applications in Florida, but modified and improved to account for differences in data between Idaho and Florida and help identify additional factors which could influence WWCs in Idaho. Multiple models were developed and compared to ensure that the final model was the most accurate and reliable based on the available data. This WWD hotspots model was used to identify WWD hotspot segments based on WWCR values. The WWCR reduction lone wolf optimization algorithm was then developed and used to prepare a priority listing of Idaho exit ramps for WWD countermeasure implementation based on their estimated potential WWCR reduction. These optimization results were also used to determine the optimal number of exits for WWD countermeasure deployment, identify improved WWCR reduction and resource utilization compared to only deploying countermeasures at the exits in the identified hotspot segments, and estimate life-cycle benefits and costs for different types of advanced WWD countermeasures. ITD can use the recommendations from this chapter to start cost-effectively combatting WWD.

Data Preparation for WWD Hotspots Modeling

Before developing the WWD hotspots model, the UCF research team had to prepare the collected roadway and WWD event data to make them suitable for modeling. These data preparation efforts were important to ensure that the developed models were accurate and reliable.

Determining scope of WWD events and WWD event counts for each exit

The analyses of the WWC and non-crash WWD data in Chapter 4 showed that there were two main types of WWD events: those that definitely or likely originated from an exit ramp, and those that originated on the mainline. Since the purpose of the WWD hotspots modeling and optimization is to identify exit ramps with high WWCR for priority deployment of WWD countermeasures, WWD events which originated on the mainline were excluded. Further research is needed on these mainline crossover WWD events to better understand them and identify effective treatment measures and locations as part of a separate future research project. This means that only WWD events with origins of Exit Ramp or Unknown were considered. The findings and recommendations discussed in Chapter 4 regarding the mainline WWD events can be used by ITD to understand the general characteristics of these mainline crossover WWD events, but a separate research effort is needed to fully understand them and determine appropriate deterrence methods. Additionally, ISP dispatch reports were not considered in the modeling process since they only included data for I-90 in ITD District 1.

From the exit ramp and unknown origin WWC and WWD citation data, the five years from 2018-2022 were selected for modeling, as these years were present in both the WWC and citation data sets (since complete 2023 WWC data were not available when these data preparation steps were being conducted). This resulted in 53 WWCs (17 with known entry points and 36 with unknown entry points) and 52 WWD citations (24 with known entry points and 28 with unknown entry points) after removing overlap within and between these data sets. Using the assigned entry points for each of these events (as discussed in Chapter 4), the number of known origin and unknown origin WWCs and citations were determined for each exit during each year from 2018-2022, as well as the total number of WWCs and citations for each exit during the entire 5-year period. For modeling, there is no need to differentiate between known and unknown origin events as only the total WWC and citation counts are important. However, separating between known and unknown origin events is important for the optimization, as events with unknown origins will be distributed to the nearest potential exits to obtain WWD entry values for each exit, whereas exits with known origins will only be assigned to the known exit.

Preparing roadway segment data

For the WWD hotspots modeling, the UCF research team modeled multi-exit roadway segments instead of individual exits. This segment modeling approach provided many advantages compared to modeling individual exits. The main advantage was that using roadway segments helped account for the uncertainty in knowing exactly where a WW driver entered the limited access facility. Over two-thirds of the WWCs and half of the WWD citations had unknown origin points. While it is likely that these events originated from the nearest possible exit, assuming this for all unknown origin events would be inaccurate. Using roadway segments made it more likely that a WWD event was located in at least one segment which contained its actual origin point. Modeling roadway segments also helped to better identify how specific exit and roadway characteristics influence WWC frequency by allowing for comparison between neighboring segments which only differed by one exit. Combining the exit WWC

counts into segment WWC counts also reduced the number of data points with zero WWCs, thereby improving the model's ability to identify statistically significant factors which influence WWC frequency.

Using roadway segments to develop a WWD hotspots model also introduced some limitations, but these were addressed by UCF's innovative modeling and optimization approach. The main limitation was that the segments needed to be selected carefully to ensure that the segment selection method could be applied consistently to all roadways and did not bias the model. Each segment should contain the same number of exits across all roadways to allow for data consistency. Having segments with a different number of exits would make it difficult to accurately interpret and compare results across different roadways. Since each roadway had a different number of exits, the best way to ensure this consistency was to have roadway segments overlap with each other. Figures 5.1 and 5.2 show an example of the overlapping approach used to segment the Idaho limited access roadways. Figure 5.1 shows the segment containing the six exits on I-90 WB from N. 4th St. to E. Seltice Way, while Figure 5.2 shows the next segment containing the six exits on I-90 WB from US 95 to N. Spokane St. These two segments share five of the same exits (US 95, Northwest Blvd., Huetter Rest Area, State Road 41, and E. Seltice Way), but each have a different sixth exit (N. 4th St. in Figure 5.1 and N. Spokane St. in Figure 5.2). With this overlapping approach, segments could be consistently created for each roadway. This overlapping approach also made it easier for the model to identify significant influential factors by increasing the sample size compared to using non-overlapping segments and allowing the model to see how changing one exit in a segment affects the WWC frequency and segment characteristics.

Figure 5.1 Example 6-exit segment on I-90 WB from N. 4th St. to E. Seltice Way

Figure 5.2 Example 6-exit segment on I-90 WB from US 95 to N. Spokane S

While this overlapping segmentation method ensured that the segmentation method was consistent and would not impact the modeling results, it brought about another issue by causing neighboring segments to be correlated with each other. Since neighboring segments shared exits, they were not fully independent from each other. Traditional modeling methods require data points to be independent for these methods to be accurate. However, this correlation can be handled with the use of GEEs, which can model correlated data using typical modeling distributions (such as Poisson or negative binomial) while also accounting for the correlation between data points. Using GEEs, a model was developed to predict WWCs on multi-exit overlapping roadway segments based on WWD citations, traffic volumes, area, and design characteristics while accounting for segments on the same roadway being correlated with each other.

Another limitation of modeling roadway segments was the difficulty in identifying which specific exits had high WWCR since model predictions were obtained for each segment rather than each exit. The innovative WWCR reduction optimization algorithm developed by Professor Al-Deek and his UCF research team addressed this issue. This algorithm considered the segment WWCR values and the distribution of WWD events to multiple nearest entry points to identify which exits had the highest potential WWCR reduction and are therefore priority candidates for WWD countermeasure deployment. Determining the distribution of WWD events was a crucial component for this algorithm to be effective. The details of this optimization algorithm, including how the distribution of WWD events was determined, are discussed later in this chapter, with the end result being that the optimization algorithm could identify specific exits with high potential WWCR reduction.

Using this roadway segmentation approach, each of the ITD limited access roadways were divided into multi-exit roadway segments. Each segment was assigned an alphanumeric ID consisting of the letter corresponding to the roadway containing the segment (as shown in Table 3.1) and a number corresponding to its position on the roadway. These segment numbers started at 1 for the westernmost segment on EB roadways, the easternmost segment on WB roadways, the southernmost segment on NB roadways, and the northernmost segment on SB roadways. Multiple size segments were developed (3-

exit segments, 4-exit segments, 5-exit segments, and 6-exit segments) and modeled. After developing multiple models for each of these different segment sizes, it was determined that 6-exit segments were the best as this size resulted in the models being more accurate and containing more significant variables. Therefore, only the details for 6-exit segments are discussed in this report and only the data for 6-exit segments were included in the data spreadsheet submitted to ITD. The processes to obtain data for the 3-exit segments, 4-exit segments, and 5-exit segments were the same as the processes for the 6-exit segments discussed in this document, with only the actual segments and associated data values differing between the different sized segments.

Splitting the ITD limited access roadways into overlapping 6-exit segments resulted in 282 segments. Since I-184 EB and I-184 WB only contained four and five exits, respectively, they were not included in the 6-exit segment data. These 282 segments had a total WWC count of 277 (with 124 segments having zero WWCs and 158 segments having at least one WWC) and a total WWD citation count of 285 (with 134 segments having zero WWD citations and 148 segments having at least one WWD citation) for the entire five-year study period.

For each segment, the collected exit data were used to develop segment variables. Table 5.1 shows the segment variables which were considered during the modeling process, with details about some of these variables discussed after the table. For variables related to the microscopic exit ramp and entrance ramp data, Table 3.7 and its corresponding discussion contains details about these microscopic data. Many variables which were categorical when collected for exits (such as interchange type) were changed to variables for each category when combined into segment variables. This made it easier for the model to identify the influence of each category and allowed for only significant categories to be included in the model. The segment variables which had separate variables for each category are highlighted in gray in Table 5.1, with the number of categories mentioned in the "Description" column and all categories listed in the discussion of the respective categorical variable following the table. For all binary variables with values of 0 and 1, a value of 1 indicated that the specified feature was present and a value of 0 indicated that the specified feature was not present. As an example, a value of 1 for the FD presence variable indicated that the segment contained at least one FD exit. For the integer variables, the values shown represented the actual values present in the data, even if additional values were theoretically possible. As an example, the "Exit Separated Right Turn Count" variable only contained integer values of 0 through 5, even though a value of 6 was theoretically possible since each segment contained six exits. However, no segment in the data had a value of 6 for this variable. For continuous variables, the minimum, median, maximum, mean, and standard deviation (St. d.) values are shown.

Table 5.1 Segment Variables Considered During the Modeling Process

Segment Variable	Description	Variable Type	Values
Interchange Type Count	The count of exits with a specific interchange type in the segment (11 categories)	Integer	0, 1, 2, 3, 4, 5, 6
Interchange Type Presence	The presence of at least one exit with a specific interchange type in the segment (11 categories)	Binary	0, 1
Segment Length	Length of the segment, in miles	Continuous	Minimum = 5.1, Median = 19.3, Maximum = 47.9, Mean = 19.6, St. d. = 10.1
Average Exit Density	Average number of exits per mile in the segment	Continuous	Minimum = 0.125, Median = 0.311, Maximum = 1.176, Mean = 0.415, St. d. = 0.241
Area Type	Primary area type of the segment	Binary	R (Rural), U (Urban)
Exit Intersection Type Count	The count of exits with a specific exit intersection type in the segment (4 categories)	Integer	0, 1, 2, 3, 4, 5, 6
Exit Intersection Type Presence	The presence of at least one exit with a specific exit intersection type in the segment (4 categories)	Binary	0, 1
Exit Control Type Count	The count of exits with a specific exit control type in the segment (3 categories)	Integer	0, 1, 2, 3, 4, 5, 6
Exit Control Type Presence	The presence of at least one exit with a specific exit control type in the segment (3 categories)	Binary	0, 1
Maximum Exit Ramp Lane Count	The maximum number of exit ramp lanes for any exit in the segment	Integer	1, 2, 3, 4
Mean Exit Ramp Lane Count	The average number of exit ramp lanes for all exits in the segment	Continuous	Minimum = 1, Median = 1.333, Maximum = 2.833, Mean = 1.475, St. d. = 0.482
Exit Right Angle Count	The count of exits with right-angle exit ramp terminals in the segment	Integer	0, 1, 2, 3, 4, 5, 6
Majority Exit Right Angle	Indicates whether more than half of the exits in the segment had right-angle exit ramp terminals	Binary	Yes, No

Segment Variable	Description	Variable Type	Values
Exit Separated Right Turn Count	The count of exits with separated right turns in the segment	Integer	0, 1, 2, 3, 4, 5
Exit Opposing Type Count	The count of exits with a specific opposing approach type in the segment (4 categories)	Integer	0, 1, 2, 3, 4, 5, 6
Exit Opposing Type Presence	The presence of at least one exit with a specific opposing approach type in the segment (4 categories)	Binary	0, 1
Right Way Turns Allowed Count	The count of exits in the segment where right-way drivers are allowed to turn onto the approach containing the exit ramp	Integer	0, 1, 2, 3, 4
Crossing Median Type Count	The count of exits with a specific crossing median type at the exit ramp terminal in the segment (5 categories)	Integer	0, 1, 2, 3, 4, 5, 6
Crossing Median Type Presence	The presence of at least one exit with a specific crossing median type at the exit ramp terminal in the segment (5 categories)	Binary	0, 1
Crossing Median Extension Count	The count of exits with a crossing median extension at the exit ramp terminal in the segment	Integer	0, 1, 2, 3
Entrance Location Type Count	The count of exits with a specific entrance ramp location in the segment (4 categories)	Integer	0, 1, 2, 3, 4, 5, 6
Entrance Location Type Presence	The presence of at least one exit with a specific entrance ramp location in the segment (4 categories)	Binary	0, 1
Average Mainline AADT	The mean mainline AADT for all exits in the segment (in thousands of vehicles per day)	Continuous	Minimum = 1.685, Median = 9.898, Maximum = 56.950, Mean = 13.779, St. d. = 11.962
Average Exit Ramp AADT	The mean exit ramp AADT for all exits in the segment (in thousands of vehicles per day)	Continuous	Minimum = 0.144, Median = 1.643, Maximum = 14.667, Mean = 2.446, St. d. = 2.747
Average Crossing AADT	The mean crossing street AADT for all exits in the segment (in thousands of vehicles per day)	Continuous	Minimum = 0.076, Median = 5.227, Maximum = 29.883, Mean = 7.480, St. d. = 7.676

Segment Variable	Description	Variable Type	Values
WW Citations 2018-2022	The total number of WWD citations in the segment from 2018-2022	Integer	0, 1, 2, 3, 4, 5, 6, 7
WW Citation Presence	Indicates whether at least one WWD citation occurred in the segment from 2018-2022	Binary	0, 1
WW Crashes 2018-2022	The total number of WWCs in the segment from 2018-2022	Integer (Dependent)	0, 1, 2, 3, 4, 5, 6

- Interchange Type Count: One interchange type count variable was created for each of the 11 interchange design categories shown in Table 3.3: FD, PD, SD, OD, PC, 2L, 3L, RA, SR, UI, and Other. Since each segment has six exits, each of these variables can have a maximum value of 6 for an individual segment and all 11 values for a segment add up to 6.

- Interchange Type Presence: Like the interchange type count, one interchange type presence variable was created for each of the 11 interchange design categories. These variables are related to the interchange type count variables, as segments with zero exits of a certain type will have a value of 0 for both the count and presence variables of that specific interchange type and segments with 1 or more exits of a certain type will have a presence value of 1 for that specific interchange type. Due to this relationship, only the interchange type count variables or interchange type presence variables were considered in the same model at the same time. For instance, a model would be developed using the statistically significant interchange type count variables (with other significant variables as applicable). Then, a second model would be developed where the statistically significant interchange type count variables were replaced with the statistically significant interchange type presence variables (with other significant variables as applicable). These models would then be compared using various performance measures (as discussed later in this chapter) to determine which variables resulted in a more accurate model. Any future iterations of the model would then only use the variables which performed better. This same process was also applied to all other pairs of related variables highlighted in gray in Table 5.1, along with other related variables as discussed later in this list. FD was the most common interchange design (present in 99.3% of segments), followed by PC (50.0%) and RA (27.3%). SR was the least common interchange design, being present in only 2.8% of segments.

- Segment Length and Average Exit Density: Since these variables are related (Average Exit Density = 6/Segment Length), only one of these variables was considered in a model at once.

- Area Type: The primary area type for each segment was determined based on the number of exits in the segment located in either a rural or urban area. Segments with four, five, or six rural exits were classified as rural and segments with zero, one, or two rural exits were classified as urban. For segments with three urban and three rural exits, the proportion of the segment

length in each area type was used to determine the primary area type. Overall, 78.4% of the segments were primarily rural.

- Exit Intersection Type Count and Exit Intersection Type Presence: One exit intersection type count and one exit intersection type presence variable were created for each of the four exit intersection values shown in Table 3.7 (3 Leg, 4 Leg, Merge, and Other). All segments contained at least one 4-leg intersection, with 55.3% containing at least one 3-leg intersection, 38.3% containing at least one other intersection, and 22.7% containing at least one merge intersection.

- Exit Control Type Count and Exit Control Type Presence: One exit control type count and one exit control type presence variable were created for each of the three exit control values shown in Table 3.7 (Signal, Sign, and None). Almost all segments (92.9%) contained at least one exit with sign control, 51.4% contained at least one exit with no control, and 42.2% contained at least one exit with signal control.

- Maximum Exit Ramp Lane Count and Mean Exit Ramp Lane Count: Since these variables were both used to represent the exit ramp lane count, only one of these variables was considered in a model at once. The most common value for the maximum exit ramp lane count was 2 (49.3% of segments), followed by 1 (24.8%), 3 (19.5%), and 4 (6.4%).

- Exit Right Angle Count and Majority Exit Right Angle: Since these variables were both used to represent the frequency of exit ramp terminals which meet the crossing street at right angles, only one of these variables was considered in a model at once. The majority exit right angle variable was used to see if segments where more than half of the exits (i.e., 4 or more exits) met the crossing streets at a right angle had a greater or lesser impact on WWD than segments which had fewer than 4 exits with these right angles. Only 12.4% of segments had a majority exit right angle value of “Yes” (i.e., an exit right angle count of 4 or more), with an exit right angle count of 2 (39.0%) being the most common.

- Exit Separated Right Turn Count: Most segments (69.9%) contained zero exits with separated right turns, with 14.2% containing one such exit, 8.9% containing two such exits, 5.0% containing three such exits, 1.8% containing four such exits, and 0.4% containing five such exits.

- Exit Opposing Type Count and Exit Opposing Count Presence: One exit opposing type count and one exit opposing type presence variable were created for each of the four exit opposing values shown in Table 3.7 (Away, Toward, Two-Way, and None). All but one segment (99.6%) contained at least one exit with an “Away” opposing approach, 74.1% contained at least one exit with no opposing approach, 18.8% contained at least one exit with a “Two-Way” opposing approach, and 12.1% contained at least one exit with a “Toward” opposing approach.

- Right Way Turns Allowed Count: Most segments (58.5%) contained zero exits where right-way drivers were allowed to turn onto the approach containing the exit ramp, with 35.5% containing one such exit, 3.9% containing two such exits, 0.7% containing three such exits, and 1.4% containing four such exits.

- Crossing Median Type Count and Crossing Median Type Presence: One crossing median type count and one crossing median type presence variable were created for each of the five crossing median type values shown in Table 3.7 (Paved, Raised, Grass, Other, and None). The most common crossing median type was “None” (present in 92.6% of segments), followed by “Paved” (72.7%), “Raised” (33.7%), “Grass” (6.7%), and “Other” (2.5%).

- Crossing Median Extension Count: Most segments (59.9%) contained zero exits where a crossing median extension was present, with 26.6% containing one such exit, 11.0% containing two such exits, and 2.5% containing three such exits.

- Entrance Location Type Count and Entrance Location Type Presence: One entrance location type count and one entrance location type presence variable were created for each of the four entrance location values shown in Table 3.7 (Opposing, Adjacent, Other, and No Entrance Ramp). The most common entrance location was “Opposing” (present in 99.6% of segments), followed by “Other” (61.0%), “Adjacent” (35.1%), and “No Entrance Ramp” (23.8%).

- WW Citations 2018-2022 and WW Citation Presence: Since these variables both measured the frequency of WWD citations in a segment, only one of these variables was considered in a model at once. Slightly less than half of the segments (47.5%) contained zero WWD citations, with 31.2% containing one WWD citation, 7.4% containing two WWD citations, 4.6% containing three WWD citations, 6.7% containing four WWD citations, 1.1% containing five WWD citations, 1.1% containing six WWD citations, and 0.4% containing seven WWD citations.

- WW Crashes 2018-2022: This was the dependent variable. The mean was 0.982 and the standard deviation was 1.174, with 44.0% of segments containing zero WWCs, 29.4% containing one WWC, 17.4% containing two WWCs, 5.7% containing three WWCs, 1.8% containing four WWCs, 0.7% containing five WWCs, and 1.1% containing six WWCs.

Some of the microscopic data variables shown in Table 3.7 were not considered as segment variables. Exit ramp lighting and entrance ramp lighting were not considered for modeling since the presence of lighting would only affect nighttime WWD events and the model was developed using both nighttime and daytime WWD events. However, if a model were developed specifically for only nighttime WWD events in the future, these variables would be important to include. Most of the entrance ramp variables (except for entrance location) were also not considered as segment variables due to the number of entrance ramps not being the same for all segments. This would result in all exits without entrance ramps having the same values for all entrance-ramp related variables, which could bias the modeling results. Therefore, it was decided to have the entrance location type be the only entrance ramp-related variable considered in the modeling process.

WWD Hotspot Modeling Methodology and Results

After collecting the roadway segment data, the UCF research team developed the WWD hotspots model for Idaho limited access roadways. This section discusses the methodology and results of this modeling

process. These results can help ITD identify hotspot segments with high WWCR and were the basis for the WWCR reduction lone wolf optimization algorithm discussed later in this chapter.

WWD hotspot modeling methodology

The developed WWD hotspots model predicts WWCs over a five-year period on multi-exit limited access roadway segments in Idaho. As previously mentioned, segments containing three exits, four exits, five exits, and six exits were all modeled, with 6-exit segments resulting in the most accurate models. Therefore, the methodology and results for 6-exit segment modeling are primarily discussed in this section along with some comparisons of the final 6-exit segment model with models developed using other size segments. All models were developed using the software program SAS version 9.4 (SAS Institute Inc. 2020).

Since the dependent variables for the WWD hotspots model (number of WWCs during a five-year period) was a count variable, the two most appropriate modeling distributions was Poisson and negative binomial. The main difference between these two distributions is that the Poisson distribution assumes that the mean and variance are the same (represented by λ) while the negative binomial distribution can handle cases where the mean and variance differ. For 6-exit segments, the WWC count had a mean of 0.982 and a variance of 1.379, suggesting that a negative binomial model might be more appropriate than a Poisson model. However, both Poisson and negative binomial models were considered. Equation 5-1 shows the general form of the Poisson model and Equation 5-2 shows the general form of the negative binomial model. Both of these models have a logarithmic link function between the dependent variable and independent variables, resulting in the left sides of the equations containing a natural logarithm.

$$\ln(\lambda_y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n$$

Equation 5-1

$$\ln(\mu_y) = \sum_i (\beta_i x_i + \varepsilon_i)$$

Equation 5-2

Where:

ln = natural logarithm
λ_y = mean (and variance) of the segment WWC count over a five-year period for Poisson distribution
β_0 = intercept
β_i = coefficient of independent variable x_i (i = 1 to n)
x_i = statistically significant independent variable included in the model (i = 1 to n)
n = number of statistically significant independent variables included in the model

μ_y = mean of the segment WWC count over a five-year period for negative binomial distribution
ε_i = Gamma distributed error term (*i* = 1 to n)

Due to the correlation between roadway segments, GEEs were used for modeling instead of traditional Poisson or negative binomial regression models. These GEEs used the Poisson and negative binomial model forms shown in Equations 5-1 and 5-2, but also included a correlation structure for segments on the same roadway. There are many possible correlation structures, but the autoregressive structure (Equation 5-3) was chosen as the most appropriate for the utilized segmentation method. With this correlation structure, consecutive segments which share five exits (such as those shown in Figures 5.1 and 5.2) have a correlation of ρ (since they are one segment apart and t = 1). Segments which are two segments apart (t = 2) share four exits and have a correlation of ρ^2, with this pattern continuing for all segments on the same roadway. It was assumed that segments on different roadways did not have any correlation. The expected correlation for neighboring 6-exit segments is 5/6 = 0.833 since neighboring 6-exit segments share five of the same exits. Therefore, comparing the calculated correlation to this expected correlation of 0.833 was one performance measure used to compare models and identify the most accurate model.

$$Correlation\left(Y_{i,k}, Y_{i,k+t}\right) = \rho^t$$

Equation 5-3

Where:

$Y_{i,k}$ = segment *k* on roadway *i*
k = 1, 2, …, $s_i - 1$
s_i = number of segments on roadway *i*
t = 1, 2, …, $s_i - k$
ρ = correlation coefficient ($0 \leq \rho \leq 1$)

The GENMOD procedure in SAS was used to develop GEE Poisson and negative binomial models with autoregressive correlation between segments on the same roadway. A significance level of α = 0.1 was used, meaning that independent variables with a p-value greater than 0.1 were not included in the models. The only exceptions were the total WWD citations and WWD citation presence variables, which were included in the models if they had a p-value of 0.15 or lower. This was due to the importance of non-crash WWD events in representing the potential for WWCs. Independent variables were added to the model in groups and all insignificant variables were removed. As more variables were added to the model, any previous significant variables which became insignificant were also removed. Any binary variables where one value made up 95% or more of the data were removed, such as the FD presence variable for 6-exit segments (value of 1 for 99.3% of the data). These were removed since they do not provide much information as they are almost entirely one value. For related variables (such as count and

presence variables for the same characteristic), only one set of the related variables was added to the model before being removed and replaced with the other set of related variables, as previously discussed. These models were then compared using the quasi-likelihood information criterion (QIC). This value is provided by SAS and indicates the general fit of a GEE model. QIC values can only be used to compare models using the same data set, with lower QIC values indicating a better fitting model. The model with the lowest QIC value between these two was kept and used for the rest of the modeling. As an example, the interchange type count variables were added to the 6-exit segment negative binomial model first and the insignificant types were removed. Then, all the interchange type count variables were removed and the interchange type presence variables were added instead, with the insignificant ones removed. Comparing the model with the significant interchange type count variables to the model with the significant interchange type presence variables showed that the interchange type presence model had a lower QIC value, so the interchange type presence variables were used for future iterations of the 6-exit segment negative binomial model.

Once Poisson and negative binomial models were developed for the different-sized segments (3 exits, 4 exits, 5 exits, and 6 exits), additional performance measures were used to identify which segment size and modeling distribution were the most effective. Each model's significant variables were reviewed to make sure they made sense. Then, the predicted and actual WWC counts were compared in multiple ways. The mean absolute error (MAE) and root mean squared error (RMSE) were calculated using Equations 5-4 and 5-5, respectively, to understand the typical error for each data point. Lower values of these measures indicate a better model. It is expected that these errors will decrease as the sample size increases, so these values were not used to directly compare models for different data sets (unless a data set with a larger sample size had larger errors). In addition to these errors (which are standard performance measures for statistical models), innovative performance measures specific to the WWD hotspots models were also utilized. First, the percentage difference between the sum of the predicted WWC counts and the sum of the actual WWC counts (% $\text{Difference}_{WWC,all}$)was calculated using Equation 5-6 to see how good the model was at predicting the total number of WWCs on the modeled segments. Models with differences closer to zero were preferred as they predicted a similar overall WWC frequency to reality across all segments. Next, Equation 5-7 was used to determine the percentage of the total predicted WWCs that were predicted for segments with zero actual WWCs (Percentage_{zero}). Models with lower Percentage_{zero} values were preferred since they predicted more WWCs in segments which actually had WWCs, which was important to properly estimate each segment's WWCR. Finally, Equation 5-8 was used to determine the percentage difference between actual WWCs and predicted WWCs for segments with three or more actual WWCs (% $\text{Difference}_{WWC,high}$). Like Equation 5-6, models with differences closer to zero were preferred as they were better at predicting WWC frequency on these high-risk segments.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|N_{obs,i} - N_{pred,i}\right|$$

Equation 5-4

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(N_{obs,i} - N_{pred,i})^2}$$

Equation 5-5

$$\%\ Difference_{WWC,all} = \frac{\sum_K Predicted\ WWCs - \sum_K Actual\ WWCs}{\sum_K Actual\ WWCs} \times 100\%$$

Equation 5-6

$$Percentage_{zero} = \frac{\sum_{K,zero} Predicted\ WWCs}{\sum_K Predicted\ WWCs} \times 100\%$$

Equation 5-7

$$\%\ Difference_{WWC,high} = \frac{\sum_{K,high} Predicted\ WWCs - \sum_{K,high} Actual\ WWCs}{\sum_{K,high} Actual\ WWCs} \times 100\%$$

Equation 5-8

Where:

n = number of modeled segments
$N_{obs,i}$ = the *i*-th observed value (*i* = 1 to n)
$N_{pred,i}$ = the *i*-th predicted value (*i* = 1 to n)
K = set of all modeled segments
K,zero = set of all modeled segments with zero actual WWCs
K,high = set of all modeled segments with three or more actual WWCs

WWD hotspot modeling results

After developing multiple GEE models in SAS, the final model was selected based on the discussed performance measures. This final model was a negative binomial model and used 6-exit segments. Table 5.2 shows the significant variables in this model with their coefficients and p-values, while Equation 5-9 shows the model equation. Details on each of these variables are discussed after Equation 5-9, including their estimated impact on WWC frequency and possible reasons for their inclusion in the model and the signs of their coefficients. The calculated correlation for neighboring segments using this model was 0.765, which is not too far away from the expected correlation of 0.833. Compared to the models developed using 5-exit segments, 4-exit segments, and 3-exit segments, the final 6-exit segment model had slightly higher MAE and RMSE values (likely due to the 6-exit segment data having the smallest

sample size), but had lower % Difference$_{WWC,all}$, Percentage$_{zero}$, and % Difference$_{WWC,high}$ values. There were 277 actual WWCs in the modeled 6-exit segments and the final model predicted 267.1 WWCs (% Difference$_{WWC,all}$ of -3.6%), whereas the models for other size segments had % Difference$_{WWC,all}$ values ranging from -5.5% to -9.1%. The final 6-exit segment model had a Percentage$_{zero}$ value of 29.8% compared to Percentage$_{zero}$ values ranging from 36.0% to 55.5% for models developed using other size segments. For the segments with three or more actual WWCs, the final model predicted 47.2 WWCs compared to the actual count of 96 WWCs, resulting in a % Difference$_{WWC,high}$ of -50.9%. This value was closer to zero than the % Difference$_{WWC,high}$ values for models developed using other size segments, which ranged from -63.6% to -80.8%.

Table 5.2 Negative Binomial WWD Hotspots Model for 6-Exit Segments

Variable	Description	Coefficient	p-value
Intercept	Model intercept	-1.1565	< 0.0001
WW Citation Presence	Binary variable with a value of 1 if at least one WWD citation occurred in the segment from 2018-2022 and 0 if not	0.2231	0.1054
Average Crossing AADT	The average AADT on the crossing streets from 2018-2022, in thousands of vehicles per day	0.0790	< 0.0001
SD Presence	Binary variable with a value of 1 if at least one split diamond interchange was present in the segment and 0 if not	0.2276	0.0044
OD Presence	Binary variable with a value of 1 if at least one other diamond interchange was present in the segment and 0 if not	-0.5230	0.0004
Area Type	Binary variable with a value of 1 if the segment is primarily rural and 0 if the segment is primarily urban	0.3029	< 0.0001
Exit Merge Count	The number of exits in the segment which have an exit ramp that merges directly onto the crossing street	-0.2836	0.0070
Exit Right Angle Count	The number of exits in the segment which have an exit ramp that meets the crossing street at a right angle	0.1147	0.0370
Grass Crossing Median Presence	Binary variable with a value of 1 if at least one exit in the segment contains a grass median on the crossing street and 0 if not	-0.2655	0.0003
Other Entrance Ramp Presence	Binary variable with a value of 1 if at least one exit in the segment contains an entrance ramp not located adjacent to or directly across from the exit ramp and 0 if not	-0.1493	0.0679

$$\ln(Predicted\ WWCs)$$

$$= -1.1565 + 0.2231(WW\ Citation\ Presence)$$

$$+ 0.0790(Average\ Crossing\ AADT) + 0.2276(SD\ Presence)$$

$$- 0.5230(OD\ Presence) + 0.3029(Area\ Type)$$

$$- 0.2836(Exit\ Merge\ Count) + 0.1147(Exit\ Right\ Angle\ Count)$$

$$- 0.2655(Grass\ Crossing\ Median\ Presence)$$

$$- 0.1493(Other\ Entrance\ Ramp\ Presence)$$

Equation 5-9

Where:

ln = natural logarithm
Predicted WWCs = predicted number of WWCs in a segment for a five-year period
WW Citation Presence = 1 if at least one WWD citation occurred in the segment from 2018-2022 and 0 if no WWD citations occurred in the segment from 2018-2022
Average Crossing AADT = average AADT on the crossing roads (in thousands of vehicle per day) for all exits in the segment from 2018-2022
SD Presence = 1 if at least one split diamond interchange is present in the segment and 0 if no split diamond interchanges are present in the segment
OD Presence = 1 if at least one other diamond interchange is present in the segment and 0 if no other diamond interchanges are present in the segment
Area Type = 1 if the segment is primarily rural and 0 if the segment is primarily urban
Exit Merge Count = number of exits in the segment with an exit ramp that directly merges onto the crossing street (possible values of 0, 1, or 2)
Exit Right Angle Count = number of exits in the segment with an exit ramp that meets the crossing street at a right angle (possible values of 0, 1, 2, 3, 4, 5, or 6)
Grass Crossing Median Presence = 1 if the segment contains at least one exit where the crossing street has a grass median for potential left-turning WWD vehicles and 0 if segment contains no exits where the crossing street has a grass median for potential left-turning WWD vehicles
Other Entrance Ramp Presence = 1 if the segment contains at least one exit where the entrance ramp is not located adjacent to or directly across from the exit ramp and 0 if the segment contains no exits where the entrance ramp is not located adjacent to or directly across from the exit ramp

Table 5.2 and Equation 5-9 show that the final model contained various types of significant variables with different impacts on WWC frequency. The sign (positive or negative) and magnitude of each variable's coefficient provides insight into how changing each variable would impact the number of predicted WWCs. These coefficients can be used to estimate the percentage change in a segment's predicted WWC count for a unit change in a variable's value while holding all other variables constant. Five of the nine variables in the model (WW citation presence, average crossing AADT, SD presence, area type, and exit right angle count) had positive coefficients, indicating that increasing the values of these variables would increase the predicted number of WWCs. Segments with at least one WWD citation were expected to have approximately exp(0.2231) – exp(0) = 1.2499 – 1 = 0.2499 = 24.99% more WWCs than segments with zero WWD citations. This makes sense since the presence of WWD citations in segments suggests that WWD is more common in these segments than in segments without WWD citations. Increasing the crossing AADT by 1,000 vehicles per day would increase the number of predicted WWCs by exp(0.0790) – exp (0) = 1.0822 – 1 = 0.0822 = 8.22%, which makes sense since higher crossing AADT means there are more drivers who could potentially go WW. Segments with at least one SD interchange were predicted to have exp(0.2276) – exp(0) = 1.2556 – 1 = 0.2556 = 25.56% more WWCs than segments without SD interchanges. This could be due to drivers expecting the entrance ramp at an SD interchange to be across from the exit ramp and then incorrectly driving up the exit ramp since the entrance ramp is not where they expected it to be. Primarily rural segments were expected to have exp(0.3029) – exp(0) = 1.3538 – 1 = 0.3538 = 35.38% more WWCs than primarily urban segments. Some possible reasons for this finding are that rural segments often have longer distances between exits and higher speeds than urban segments, which can make it harder for WW drivers to correct their behavior and for right-way drivers to avoid WW drivers without crashing. Increasing the number of exits which meet the crossing road at a right angle by 1 was predicted to increase the number of WWCs by exp(0.1147) – exp(0) = 1.1215 – 1 = 0.1215 = 12.15%. This makes sense since exit ramps which meet the crossing street at a right angle can be easier for drivers to go WW on than exit ramps which meet the crossing street at a sharp angle. Exit ramps with right angles can be entered WW relatively easily by both left-turning and right-turning WWD vehicles (assuming there are no measures to make these movements more difficult), while exit ramps with sharp angles can make it difficult for either left-turning or right-turning WWD vehicles to enter the ramp WW (depending on the location and angle of the ramp).

The remaining four variables (OD presence, exit merge count, grass crossing median presence, and other entrance ramp presence) had negative coefficients, so increasing the values of these variables (holding all other variables constant) would decrease the predicted number of WWCs. Segments with at least one OD interchange were predicted to have exp(0) – exp(-0.5230) = 1 – 0.5927 = 0.4073 = 40.73% less WWCs than segments without OD interchanges. Most OD interchanges in Idaho had all the exit and entrance ramps meet at the same intersection with plenty of signage and markings to indicate the correct way of travel, which is the likely reason for these interchanges resulting in less WWCs. Increasing the number of exits which directly merge onto the crossing road by 1 was predicted to decrease the number of WWCs by exp(0) – exp(-0.2836) = 1 – 0.7531 = 0.2469 = 24.69%. This makes sense since it is more difficult for a driver to go WW on these direct merge exit ramps compared to exit ramps that meet

the crossing road at an intersection. Segments with at least one exit which contained a grass median on the crossing street were expected to have exp(0) – exp(-0.2655) = 1 – 0.7668 = 0.2332 = 23.32% less WWCs than segments without these grass medians. This could be due to grass medians being wider and more visible than raised medians, thereby providing more of a deterrent to potential WW drivers. Lastly, segments with at least one exit where the entrance ramp was located away from the exit ramp (and not adjacent to or directly across from the exit ramp) were expected to have exp(0) – exp(-0.1493) = 1 – 0.8613 = 0.1387 = 13.87% less WWCs than segments without any such exits. Since these entrance ramps were not located near the exit ramps, drivers had less of a reason to turn off the crossing street at the exit ramp terminal intersection (as there is no entrance ramp they would be trying to enter) and therefore could be less likely to turn WW on the exit ramp.

Using this model, predicted five-year WWC values were calculated for each segment. These predictions were then added to the actual WWC values from 2018 through 2022 to obtain WWCR values. The WWCR values consider both WWC history and the potential for WWCs due to WWD citations, crossing street volume, and the significant exit ramp and interchange design characteristics included in the model to provide a comprehensive understanding of WWC potential. Table 5.3 shows the actual WWCs from 2018 through 2022, the predicted five-year WWC values based on the model, and the WWCR values for each of the 282 modeled 6-exit Idaho limited access roadway segments. WWD hotspots were identified from these segments using three criteria. First, the 10% of segments (28 segments) with the highest WWCR values were selected as WWD hotspots since they are the most risky locations based on both WWC history and WWC potential. Second, any additional segments with more than two actual WWCs from 2018 through 2022 were selected as WWD hotspots (3 additional segments) since it was important to consider all segments with high counts of actual WWCs as WWD hotspots. Third, any additional segments predicted to have more than two WWCs from the model were selected as WWD hotspots (5 additional segments), as these are segments which could experience high WWC counts in the future if proactive treatments are not implemented. The 36 hotspot segments are highlighted gray in Table 5.3 and also identified as hotspots in the first column. These 36 hotspot segments were located on seven different roadways, with I-84 EB containing 11 hotspots, I-84 WB containing 7 hotspots, I-90 EB and I-90 WB each containing 6 hotspots, I-15 SB containing 4 hotspots, and I-15 NB and US 20 EB each containing 1 hotspot. I-86 EB, I-86 WB, and US 20 WB were the only modeled roadways which did not contain any WWD hotspots.

Table 5.3 Actual WWCs, Predicted WWCs, and WWCR Values for All Modeled Idaho Roadway Segments

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
A3 (Hotspot)	I-90 EB	N Spokane St	N 4th St	6	2.521	8.521
A2 (Hotspot)	I-90 EB	Pleasant View Rd	US 95	6	2.334	8.334
A4 (Hotspot)	I-90 EB	State Road 41	N 15th St	5	2.687	7.687

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
A1 (Hotspot)	I-90 EB	W Pointe Pkwy	Northwest Blvd	6	1.614	7.614
B24 (Hotspot)	I-90 WB	US 95	N Spokane St	4	3.439	7.439
A5 (Hotspot)	I-90 EB	Huetter Rest Area	N 23rd St	5	2.378	7.378
B25 (Hotspot)	I-90 WB	Northwest Blvd	Pleasant View Rd	4	2.614	6.614
B23 (Hotspot)	I-90 WB	N 4th St	E Seltice Way	4	2.560	6.560
B22 (Hotspot)	I-90 WB	N 15th St	State Road 41	4	2.531	6.531
A6 (Hotspot)	I-90 EB	Northwest Blvd	E Mullan Trail Rd	4	2.103	6.103
B27 (Hotspot)	I-90 WB	State Road 41	Spokane Bridge Rd.	3	2.491	5.491
C17 (Hotspot)	I-84 EB	Eagle Rd	S Vista Ave	3	2.466	5.466
I25 (Hotspot)	I-15 NB	US 26	E 1500 N	3	1.941	4.941
B26 (Hotspot)	I-90 WB	Huetter Rest Area	W Pointe Pkwy	3	1.913	4.913
C18 (Hotspot)	I-84 EB	I-184, W Franklin Rd	S Broadway Ave	3	1.757	4.757
D40 (Hotspot)	I-84 WB	S Vista Ave	Eagle Rd	2	2.654	4.654
D41 (Hotspot)	I-84 WB	N Orchard St	S Meridian Rd	2	2.489	4.489
C42 (Hotspot)	I-84 EB	Hagerman Rd	S 1150 E	3	1.406	4.406
J9 (Hotspot)	I-15 SB	W 145 N	E 1250 N	3	1.390	4.390
J10 (Hotspot)	I-15 SB	US 20	Bingham County Rest Area	3	1.342	4.342
C16 (Hotspot)	I-84 EB	S Meridian Rd	N Orchard St	2	2.312	4.312
C41 (Hotspot)	I-84 EB	1200 E	US 93	3	1.264	4.264
D42 (Hotspot)	I-84 WB	W Overland Rd	S Ten Mile Rd	2	2.229	4.229
D52 (Hotspot)	I-84 WB	Franklin Rd	Oasis Rd	3	1.203	4.203
C40 (Hotspot)	I-84 EB	US 26	Golf Course Rd	3	1.112	4.112
C39 (Hotspot)	I-84 EB	I-84 Business	W Rd	3	0.982	3.982

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
C15 (Hotspot)	I-84 EB	S Ten Mile Rd	W Overland Rd	2	1.974	3.974
J11 (Hotspot)	I-15 SB	W Broadway St	Rose Rd	3	0.912	3.912
I24	I-15 NB	W 65th S	N Berrett Rd	2	1.883	3.883
D51	I-84 WB	W Karcher Rd	State Road 44	2	1.876	3.876
C6	I-84 EB	State Road 44	W Karcher Rd	2	1.875	3.875
C38 (Hotspot)	I-84 EB	Bliss Rest Area	S Idaho St	3	0.814	3.814
K17 (Hotspot)	US 20 EB	9th N	S Bridge St	3	0.724	3.724
I23	I-15 NB	E 1250 N	W 145 N	2	1.691	3.691
D43 (Hotspot)	I-84 WB	W Overland Rd	N Idaho Center Blvd	1	2.689	3.689
I22	I-15 NB	Bingham County Rest Area	US 20	2	1.688	3.688
J12 (Hotspot)	I-15 SB	US 26	US 26	3	0.673	3.673
D48	I-84 WB	N Idaho Center Blvd	N 10th Ave	2	1.614	3.614
C13 (Hotspot)	I-84 EB	N Franklin Blvd	I-184, W Franklin Rd	1	2.580	3.580
D15	I-84 WB	S 1150 E	Hagerman Rd	2	1.580	3.580
J8	I-15 SB	N Berrett Rd	W 65th S	2	1.552	3.552
J7	I-15 SB	E 1500 N	US 26	2	1.546	3.546
D14	I-84 WB	Valley Rd	S Idaho St	2	1.539	3.539
I26	I-15 NB	W Broadway St	Camas Creek Rd	2	1.531	3.531
D47	I-84 WB	S Ten Mile Rd	Franklin Rd	2	1.482	3.482
C20	I-84 EB	W Overland Rd	Memory Rd	2	1.400	3.400
D16	I-84 WB	US 93	1200 E	2	1.352	3.352
C19	I-84 EB	W Overland Rd	E Gowen Rd	2	1.326	3.326
D13	I-84 WB	Ridgeway Rd	W Rd	2	1.247	3.247
C7	I-84 EB	US 26	Northside Blvd	2	1.239	3.239

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
D44 (Hotspot)	I-84 WB	I-184, W Franklin Rd	N Franklin Blvd	1	2.218	3.218
C43	I-84 EB	S Idaho St	Valley Rd	2	1.211	3.211
C4	I-84 EB	Black Canyon Rd	N 10th Ave	2	1.202	3.202
D12	I-84 WB	State Road 25	Golf Course Rd	2	1.143	3.143
D45 (Hotspot)	I-84 WB	Eagle Rd	Northside Blvd	1	2.119	3.119
D49	I-84 WB	N Franklin Blvd	Centennial Way	2	1.111	3.111
I27	I-15 NB	US 20	State Road 22	2	1.063	3.063
A20	I-90 EB	Bunker Ave	Markwell Ave	2	1.057	3.057
C14 (Hotspot)	I-84 EB	N Idaho Center Blvd	W Overland Rd	1	2.055	3.055
A21	I-90 EB	Hill St	The Harry F. Magnuson Way	2	1.048	3.048
D50	I-84 WB	Northside Blvd	US 26	2	1.018	3.018
I15	I-15 NB	Pocatello Creek Rd	US 26	2	1.007	3.007
D17	I-84 WB	Golf Course Rd	US 26	2	0.988	2.988
A19	I-90 EB	Airport Rd	N 3rd St	2	0.975	2.975
A8	I-90 EB	N 4th St	Lakes Divide Rd	2	0.953	2.953
C9	I-84 EB	N 10th Ave	N Idaho Center Blvd	1	1.923	2.923
D55	I-84 WB	US 26	US 95	2	0.882	2.882
K14	US 20 EB	W Main St	E 200 N	2	0.858	2.858
I14	I-15 NB	Center St	US 91	2	0.857	2.857
C3	I-84 EB	US 30	Centennial Way	2	0.843	2.843
A9	I-90 EB	N 15th St	State Road 3	2	0.836	2.836

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
A11	I-90 EB	E Mullan Trail Rd	S Latour Creek Rd	2	0.816	2.816
C11	I-84 EB	W Karcher Rd	S Meridian Rd	1	1.799	2.799
A16	I-90 EB	S Latour Creek Rd	Hill St	2	0.768	2.768
A13	I-90 EB	Lakes Divide Rd	E Frk Pine Creek Rd	2	0.764	2.764
K13	US 20 EB	University Blvd	N 7th E	2	0.761	2.761
A12	I-90 EB	State Road 97	Coeur D' Alene River Rd	2	0.740	2.740
C10	I-84 EB	Franklin Rd	S Ten Mile Rd	1	1.718	2.718
C2	I-84 EB	US 95	US 26	2	0.715	2.715
K15	US 20 EB	N Salem Highway	E 300 N	2	0.690	2.690
D56	I-84 WB	State Road 44	Oregon Trail Rest Area	2	0.687	2.687
B21	I-90 WB	N 23rd St	Huetter Rest Area	1	1.686	2.686
D39	I-84 WB	S Broadway Ave	I-184, W Franklin Rd	1	1.660	2.660
C37	I-84 EB	Gopher Knoll Rd	Hagerman Rd	2	0.656	2.656
K16	US 20 EB	W Center St	Cottonwood Dr	2	0.610	2.610
C8	I-84 EB	Centennial Way	N Franklin Blvd	1	1.514	2.514
B20	I-90 WB	E Mullan Trail Rd	Northwest Blvd	1	1.498	2.498
C5	I-84 EB	Oasis Rd	Franklin Rd	1	1.447	2.447
K10	US 20 EB	Farnsworth Way	N Salem Highway	1	1.368	2.368
I10	I-15 NB	US 30	Pocatello Creek Rd	1	1.364	2.364

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
D38	I-84 WB	E Gowen Rd	W Overland Rd	1	1.326	2.326
K11	US 20 EB	Main St	W Center St	1	1.319	2.319
J22	I-15 SB	Pocatello Creek Rd	US 30	1	1.171	2.171
C12	I-84 EB	Northside Blvd	Eagle Rd	0	2.170	2.170
I21	I-15 NB	Rose Rd	W Broadway St	1	1.165	2.165
A7	I-90 EB	US 95	State Road 97	1	1.135	2.135
C21	I-84 EB	N Orchard St	Blacks Creek Rest Area	1	1.124	2.124
I20	I-15 NB	US 26	US 26	1	1.117	2.117
I19	I-15 NB	US 91	W 65th S	1	1.042	2.042
C44	I-84 EB	W Rd	Ridgeway Rd	1	1.005	2.005
D37	I-84 WB	Memory Rd	W Overland Rd	1	0.966	1.966
C45	I-84 EB	Golf Course Rd	State Road 25	1	0.941	1.941
J13	I-15 SB	W 65th S	US 91	1	0.922	1.922
J14	I-15 SB	E 1250 N	E Ross Fork Rd	1	0.904	1.904
C46	I-84 EB	US 93	I-84 Business	1	0.892	1.892
A18	I-90 EB	E Frk Pine Creek Rd	Big Creek Rd	1	0.890	1.890
D53	I-84 WB	N 10th Ave	Black Canyon Rd	1	0.887	1.887
D26	I-84 WB	Commercial St	Sun Valley Hwy	1	0.885	1.885
J23	I-15 SB	Center St	E Jensen Rd	1	0.877	1.877
D54	I-84 WB	Centennial Way	US 30	1	0.875	1.875
K12	US 20 EB	W 5000 S	9th N	1	0.874	1.874
C22	I-84 EB	S Vista Ave	E Blacks Creek Rd	1	0.871	1.871

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
C47	I-84 EB	S 1150 E	I-84 Business	1	0.810	1.810
A17	I-90 EB	Coeur D' Alene River Rd	N Division St	1	0.803	1.803
J24	I-15 SB	S 5th Ave	Henderson Rd	1	0.796	1.796
D25	I-84 WB	Gopher Knoll Rd	Old Oregon Trail Rd	1	0.773	1.773
I5	I-15 NB	N Old Hwy 191	US 30	1	0.772	1.772
I29	I-15 NB	N Berrett Rd	Opal Way	1	0.748	1.748
I18	I-15 NB	E Ross Fork Rd	E 1250 N	1	0.746	1.746
I17	I-15 NB	Northgate Pkwy	Bingham County Rest Area	1	0.741	1.741
I30	I-15 NB	E 1500 N	W Camas Creek Rd	1	0.731	1.731
I12	I-15 NB	S 5th Ave	Northgate Pkwy	1	0.731	1.731
A10	I-90 EB	N 23rd St	Mission Rd	1	0.724	1.724
D27	I-84 WB	Old U.S. 30	Old U.S. 30	1	0.686	1.686
J25	I-15 SB	S 5th Ave	US 91	1	0.678	1.678
C48	I-84 EB	Valley Rd	State Road 77	1	0.669	1.669
I8	I-15 NB	Henderson Rd	S 5th Ave	1	0.668	1.668
D9	I-84 WB	State Road 77	Valley Rd	1	0.666	1.666
C51	I-84 EB	I-84 Business	Cassia County Rest Area	1	0.665	1.665
I11	I-15 NB	I-15 BL	I-86	1	0.651	1.651
A15	I-90 EB	Mission Rd	Bunker Ave	1	0.645	1.645
I4	I-15 NB	State Road 36	E Jensen Rd	1	0.645	1.645
A14	I-90 EB	State Road 3	Airport Rd	1	0.644	1.644
I13	I-15 NB	S 5th Ave	E Ross Fork Rd	1	0.642	1.642
D11	I-84 WB	I-84 Business	US 93	1	0.629	1.629
D18	I-84 WB	W Rd	I-84 Business	1	0.625	1.625

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
I28	I-15 NB	W 145 N	Sheep Sta Rd E	1	0.615	1.615
I7	I-15 NB	US 91	S 5th Ave	1	0.614	1.614
D10	I-84 WB	I-84 Business	S 1150 E	1	0.602	1.602
A22	I-90 EB	N Division St	Burke Rd	1	0.595	1.595
J26	I-15 SB	I-15 BL	E Treasure Ln	1	0.593	1.593
D1	I-84 WB	Juniper Rest Area	Cassia County Rest Area	1	0.590	1.590
C50	I-84 EB	State Road 25	E Yale Rd	1	0.587	1.587
C52	I-84 EB	I-84 Business	E 800 S	1	0.587	1.587
D19	I-84 WB	S Idaho St	Bliss Rest Area	1	0.583	1.583
I16	I-15 NB	I-86	Rose Rd	1	0.558	1.558
C1	I-84 EB	Payette County Rest Area	State Road 44	1	0.540	1.540
D8	I-84 WB	I-86	Ridgeway Rd	1	0.534	1.534
D23	I-84 WB	I-84 Business	Cold Springs Rd	1	0.531	1.531
I6	I-15 NB	E Treasure Ln	I-15 BL	1	0.531	1.531
D24	I-84 WB	Bliss Rest Area	Hammett Hill Rd	1	0.530	1.530
C55	I-84 EB	E Yale Rd	38000 W	1	0.529	1.529
A23	I-90 EB	Big Creek Rd	Golconda Rd	1	0.506	1.506
J27	I-15 SB	US 30	Bannock County Rest Area	1	0.505	1.505
D22	I-84 WB	US 26	Old U.S. 30	1	0.489	1.489
I3	I-15 NB	50 St S	Henderson Rd	1	0.430	1.430
A24	I-90 EB	N 3rd St	Ruddy Gulch Rd	1	0.429	1.429
J6	I-15 SB	Camas Creek Rd	W Broadway St	0	1.428	1.428
D46	I-84 WB	S Meridian Rd	W Karcher Rd	0	1.384	1.384

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
C53	I-84 EB	State Road 77	Sublett Rd	1	0.380	1.380
C54	I-84 EB	I-86	Sweetzer Rd	1	0.358	1.358
B19	I-90 WB	State Road 97	US 95	0	1.098	1.098
B6	I-90 WB	The Harry F. Magnuson Way	Bunker Ave	0	0.978	0.978
B18	I-90 WB	Lakes Divide Rd	N 4th St	0	0.974	0.974
L5	US 20 WB	N 7th E	W 5000 S	0	0.974	0.974
L8	US 20 WB	W Main St	E County Line Rd	0	0.968	0.968
L7	US 20 WB	N Salem Highway	Farnsworth Way	0	0.967	0.967
J17	I-15 SB	US 26	Pocatello Creek Rd	0	0.966	0.966
J5	I-15 SB	State Road 22	US 20	0	0.966	0.966
K2	US 20 EB	Fremont Ave	105th N	0	0.953	0.953
D35	I-84 WB	E Blacks Creek Rd	S Vista Ave	0	0.931	0.931
K3	US 20 EB	Presto St	E County Line Rd	0	0.923	0.923
L9	US 20 WB	University Blvd	105th N	0	0.919	0.919
J15	I-15 SB	Bingham County Rest Area	Northgate Pkwy	0	0.915	0.915
D36	I-84 WB	Blacks Creek Rest Area	N Orchard St	0	0.912	0.912
L6	US 20 WB	9th N	Main St	0	0.890	0.890
B7	I-90 WB	Markwell Ave	Airport Rd	0	0.887	0.887
H2	I-86 WB	US 30	Lakeview Rd	0	0.862	0.862
J18	I-15 SB	US 91	Center St	0	0.856	0.856
L4	US 20 WB	E 200 N	University Blvd	0	0.847	0.847

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
L10	US 20 WB	W 5000 S	25th E	0	0.846	0.846
B17	I-90 WB	State Road 3	N 15th St	0	0.834	0.834
K8	US 20 EB	E County Line Rd	University Blvd	0	0.825	0.825
K1	US 20 EB	Lindsay Blvd	25th E	0	0.821	0.821
B16	I-90 WB	Mission Rd	N 23rd St	0	0.818	0.818
L3	US 20 WB	E 300 N	W Main St	0	0.787	0.787
B15	I-90 WB	S Latour Creek Rd	E Mullan Trail Rd	0	0.774	0.774
L11	US 20 WB	Main St	N 15th E	0	0.770	0.770
K9	US 20 EB	S State St	W Main St	0	0.754	0.754
I9	I-15 NB	E Jensen Rd	Center St	0	0.753	0.753
H3	I-86 WB	Terminal Way	Rockland Highway	0	0.744	0.744
L13	US 20 WB	E County Line Rd	Fremont Ave	0	0.742	0.742
G7	I-86 EB	Lakeview Rd	US 30	0	0.739	0.739
L12	US 20 WB	Farnsworth Way	US 20 Bus	0	0.733	0.733
L14	US 20 WB	105th N	Lindsay Blvd	0	0.724	0.724
C31	I-84 EB	Sun Valley Hwy	Commercial St	0	0.709	0.709
K7	US 20 EB	105th N	W 5000 S	0	0.701	0.701
B14	I-90 WB	Coeur D' Alene River Rd	State Road 97	0	0.701	0.701
K4	US 20 EB	US 20 Bus	S State St	0	0.699	0.699
G3	I-86 EB	Lanes Gulch Rd	Lakeview Rd	0	0.696	0.696
G1	I-86 EB	N Yale Rd	Rockland Highway	0	0.692	0.692
B8	I-90 WB	N 3rd St	E Frk Pine Creek Rd	0	0.689	0.689

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
J16	I-15 SB	Rose Rd	I-86	0	0.689	0.689
K6	US 20 EB	25th E	Main St	0	0.669	0.669
D33	I-84 WB	Simco Rd	E Gowen Rd	0	0.662	0.662
H5	I-86 WB	Gas Plant Rd	Power County Rest Area	0	0.660	0.660
H6	I-86 WB	Lakeview Rd	Register Rd	0	0.659	0.659
H4	I-86 WB	Arbon Valley Highway	Rock Creek Rd	0	0.653	0.653
K5	US 20 EB	N 15th E	Farnsworth Way	0	0.651	0.651
L1	US 20 WB	S Bridge St	9th N	0	0.647	0.647
D34	I-84 WB	S Orchard Access Rd	S Broadway Ave	0	0.647	0.647
G6	I-86 EB	Rockland Highway	Terminal Way	0	0.644	0.644
C24	I-84 EB	E Gowen Rd	Simco Rd	0	0.640	0.640
C32	I-84 EB	Old Oregon Trail Rd	Gopher Knoll Rd	0	0.638	0.638
B13	I-90 WB	E Frk Pine Creek Rd	Lakes Divide Rd	0	0.634	0.634
I31	I-15 NB	Camas Creek Rd	Old Hwy 91	0	0.630	0.630
L2	US 20 WB	Cottonwood Dr	N Salem Highway	0	0.627	0.627
J21	I-15 SB	I-86	I-15 BL	0	0.626	0.626
J20	I-15 SB	Northgate Pkwy	S 5th Ave	0	0.624	0.624
H1	I-86 WB	Yellowstone Ave / US 91	Lakeview Rd	0	0.624	0.624
C23	I-84 EB	S Broadway Ave	S Orchard Access Rd	0	0.623	0.623
B9	I-90 WB	Big Creek Rd	Coeur D' Alene River Rd	0	0.623	0.623

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
G4	I-86 EB	Register Rd	Gas Plant Rd	0	0.621	0.621
D28	I-84 WB	Cold Springs Rd	Simco Rd	0	0.610	0.610
J4	I-15 SB	Sheep Sta Rd E	W 145 N	0	0.606	0.606
D2	I-84 WB	38000 W	E Yale Rd	0	0.595	0.595
J3	I-15 SB	Opal Way	N Berrett Rd	0	0.593	0.593
C30	I-84 EB	Old U.S. 30	Old U.S. 30	0	0.592	0.592
C49	I-84 EB	Ridgeway Rd	I-86	0	0.590	0.590
C57	I-84 EB	E 800 S	State Road 30	0	0.588	0.588
D6	I-84 WB	Cassia County Rest Area	I-84 Business	0	0.579	0.579
G2	I-86 EB	Coldwater Hill Rest Area	Lakeview Rd	0	0.573	0.573
J19	I-15 SB	E Ross Fork Rd	S 5th Ave	0	0.572	0.572
G5	I-86 EB	Rock Creek Rd	Arbon Valley Highway	0	0.565	0.565
B5	I-90 WB	Burke Rd	N Division St	0	0.565	0.565
D5	I-84 WB	E 800 S	I-84 Business	0	0.560	0.560
G8	I-86 EB	Lakeview Rd	Yellowstone Ave / US 91	0	0.559	0.559
D30	I-84 WB	Old Oregon Trail Rd	E Blacks Creek Rd	0	0.556	0.556
C36	I-84 EB	Commercial St	1200 E	0	0.556	0.556
D29	I-84 WB	Hammett Hill Rd	S Orchard Access Rd	0	0.552	0.552
B10	I-90 WB	N Division St	S Latour Creek Rd	0	0.548	0.548
J29	I-15 SB	Henderson Rd	State Road 36	0	0.541	0.541
J28	I-15 SB	E Jensen Rd	N Old Hwy 191	0	0.540	0.540
C33	I-84 EB	Hammett Hill Rd	Bliss Rest Area	0	0.540	0.540
D7	I-84 WB	E Yale Rd	State Road 25	0	0.532	0.532

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
C29	I-84 EB	Simco Rd	N Bannock St	0	0.526	0.526
C56	I-84 EB	Cassia County Rest Area	Juniper Rest Area	0	0.524	0.524
J2	I-15 SB	W Camas Creek Rd	E 1500 N	0	0.524	0.524
H7	I-86 WB	Lakeview Rd	Lanes Gulch Rd	0	0.520	0.520
C26	I-84 EB	Blacks Creek Rest Area	Sun Valley Hwy	0	0.501	0.501
J1	I-15 SB	Old Hwy 91	Camas Creek Rd	0	0.493	0.493
C27	I-84 EB	E Blacks Creek Rd	Old Oregon Trail Rd	0	0.490	0.490
C25	I-84 EB	Memory Rd	Old U.S. 30	0	0.488	0.488
C28	I-84 EB	S Orchard Access Rd	Hammett Hill Rd	0	0.486	0.486
C34	I-84 EB	N Bannock St	I-84 Business	0	0.485	0.485
B11	I-90 WB	Bunker Ave	Mission Rd	0	0.476	0.476
B12	I-90 WB	Airport Rd	State Road 3	0	0.461	0.461
D20	I-84 WB	Hagerman Rd	Gopher Knoll Rd	0	0.458	0.458
C35	I-84 EB	Old U.S. 30	US 26	0	0.446	0.446
D21	I-84 WB	1200 E	Commercial St	0	0.436	0.436
A25	I-90 EB	Markwell Ave	Mill Rd	0	0.415	0.415
I32	I-15 NB	State Road 22	S Valley Rd	0	0.405	0.405
D3	I-84 WB	Sweetzer Rd	I-86	0	0.402	0.402
D31	I-84 WB	Sun Valley Hwy	Blacks Creek Rest Area	0	0.399	0.399
D4	I-84 WB	Sublett Rd	State Road 77	0	0.382	0.382
H8	I-86 WB	Rockland Highway	N Yale Rd	0	0.381	0.381
D32	I-84 WB	Old U.S. 30	Memory Rd	0	0.374	0.374
H9	I-86 WB	Rock Creek Rd	I-84	0	0.350	0.350

Segment ID	Roadway	Starting Exit	Ending Exit	Actual WWCs 2018-2022	Predicted WWCs	WWCR
J30	I-15 SB	US 91	50 St S	0	0.337	0.337
I2	I-15 NB	Oneida County Rest Area	US 91	0	0.331	0.331
B4	I-90 WB	Golconda Rd	Big Creek Rd	0	0.322	0.322
J32	I-15 SB	Bannock County Rest Area	25800 N	0	0.301	0.301
J31	I-15 SB	E Treasure Ln	Woodruff Ln	0	0.298	0.298
I1	I-15 NB	Woodruff Ln	E Treasure Ln	0	0.288	0.288
B3	I-90 WB	Ruddy Gulch Rd	N 3rd St	0	0.282	0.282
B2	I-90 WB	Mill Rd	Markwell Ave	0	0.277	0.277
A26	I-90 EB	The Harry F. Magnuson Way	I-90 BL	0	0.274	0.274
L15	US 20 WB	25th E	I-15	0	0.247	0.247
G9	I-86 EB	Gas Plant Rd	I-15	0	0.243	0.243
B1	I-90 WB	I-90 BL	The Harry F. Magnuson Way	0	0.243	0.243
A27	I-90 EB	Burke Rd	I-90 BL	0	0.239	0.239
A28	I-90 EB	Golconda Rd	Northern Pacific Trail	0	0.232	0.232

Table 5.4 shows the exits in each of the 36 identified WWD hotspot segments. Many exits were in multiple hotspot segments due to the overlapping between the segments. Exits highlighted in gray in Table 5.4 are Idaho hotspot exits which were not present in any hotspot segment earlier in the table. These exits are also identified by "(New)" after the exit name. Note that the exit on I-90 WB at Spokane Bridge Rd. was not in any previous hotspot segment, but was not identified as a new exit since this exit is located in Washington and not in Idaho. Overall, the 36 hotspot segments contained 80 unique Idaho exits with 85 exit ramps. These exits consisted of 21 exits on I-84 EB, 17 exits on I-84 WB, 11 exits on I-90 EB, 10 exits on I-90 WB, 9 exits on I-15 SB, 6 exits on I-15 NB, and 6 exits on US 20 EB.

Table 5.4 Idaho WWD Hotspot Segments and Exits

Segment	Roadway	Exit 1	Exit 2	Exit 3	Exit 4	Exit 5	Exit 6
A1	I-90 EB	W Pointe Pkwy (New)	Pleasant View Rd (New)	N Spokane St (New)	State Road 41 (New)	Huetter Rest Area (New)	Northwest Blvd (New)
A2	I-90 EB	Pleasant View Rd	N Spokane St	State Road 41	Huetter Rest Area	Northwest Blvd	US 95 (New)
A3	I-90 EB	N Spokane St	State Road 41	Huetter Rest Area	Northwest Blvd	US 95	N 4th St (New)
A4	I-90 EB	State Road 41	Huetter Rest Area	Northwest Blvd	US 95	N 4th St	N 15th St (New)
A5	I-90 EB	Huetter Rest Area	Northwest Blvd	US 95	N 4th St	N 15th St	N 23rd St (New)
A6	I-90 EB	Northwest Blvd	US 95	N 4th St	N 15th St	N 23rd St	E Mullan Trail Rd (New)
B22	I-90 WB	N 15th St (New)	N 4th St (New)	US 95 (New)	Northwest Blvd (New)	Huetter Rest Area (New)	State Road 41 (New)
B23	I-90 WB	N 4th St	US 95	Northwest Blvd	Huetter Rest Area	State Road 41	E Seltice Way (New)
B24	I-90 WB	US 95	Northwest Blvd	Huetter Rest Area	State Road 41	E Seltice Way	N Spokane St (New)
B25	I-90 WB	Northwest Blvd	Huetter Rest Area	State Road 41	E Seltice Way	N Spokane St	Pleasant View Rd (New)
B26	I-90 WB	Huetter Rest Area	State Road 41	E Seltice Way	N Spokane St	Pleasant View Rd	W Pointe Pkwy (New)
B27	I-90 WB	State Road 41	E Seltice Way	N Spokane St	Pleasant View Rd	W Pointe Pkwy	Spokane Bridge Rd
C13	I-84 EB	N Franklin Blvd (New)	N Idaho Center Blvd (New)	S Ten Mile Rd (New)	S Meridian Rd (New)	Eagle Rd (New)	I-184, W Franklin Rd (New)
C14	I-84 EB	N Idaho Center Blvd	S Ten Mile Rd	S Meridian Rd	Eagle Rd	I-184, W Franklin Rd	W Overland Rd (New)
C15	I-84 EB	S Ten Mile Rd	S Meridian Rd	Eagle Rd	I-184, W Franklin Rd	W Overland Rd	W Overland Rd (New)
C16	I-84 EB	S Meridian Rd	Eagle Rd	I-184, W Franklin Rd	W Overland Rd	W Overland Rd	N Orchard St (New)
C17	I-84 EB	Eagle Rd	I-184, W Franklin Rd	W Overland Rd	W Overland Rd	N Orchard St	S Vista Ave (New)
C18	I-84 EB	I-184, W Franklin Rd	W Overland Rd	W Overland Rd	N Orchard St	S Vista Ave	S Broadway Ave (New)

Segment	Roadway	Exit 1	Exit 2	Exit 3	Exit 4	Exit 5	Exit 6
C38	I-84 EB	Bliss Rest Area (New)	I-84 Business (New)	US 26 (New)	1200 E (New)	Hagerman Rd (New)	S Idaho St (New)
C39	I-84 EB	I-84 Business	US 26	1200 E	Hagerman Rd	S Idaho St	W Rd (New)
C40	I-84 EB	US 26	1200 E	Hagerman Rd	S Idaho St	W Rd	Golf Course Rd (New)
C41	I-84 EB	1200 E	Hagerman Rd	S Idaho St	W Rd	Golf Course Rd	US 93 (New)
C42	I-84 EB	Hagerman Rd	S Idaho St	W Rd	Golf Course Rd	US 93	S 1150 E (New)
D40	I-84 WB	S Vista Ave (New)	N Orchard St (New)	W Overland Rd (New)	W Overland Rd (New)	I-184, W Franklin Rd (New)	Eagle Rd (New)
D41	I-84 WB	N Orchard St	W Overland Rd	W Overland Rd	I-184, W Franklin Rd	Eagle Rd	S Meridian Rd (New)
D42	I-84 WB	W Overland Rd	W Overland Rd	I-184, W Franklin Rd	Eagle Rd	S Meridian Rd	S Ten Mile Rd (New)
D43	I-84 WB	W Overland Rd	I-184, W Franklin Rd	Eagle Rd	S Meridian Rd	S Ten Mile Rd	N Idaho Center Blvd (New)
D44	I-84 WB	I-184, W Franklin Rd	Eagle Rd	S Meridian Rd	S Ten Mile Rd	N Idaho Center Blvd	N Franklin Blvd (New)
D45	I-84 WB	Eagle Rd	S Meridian Rd	S Ten Mile Rd	N Idaho Center Blvd	N Franklin Blvd	Northside Blvd (New)
D52	I-84 WB	Franklin Rd (New)	N 10th Ave (New)	Centennial Way (New)	US 26 (New)	State Road 44 (New)	Oasis Rd (New)
I25	I-15 NB	US 26 (New)	W Broadway St (New)	US 20 (New)	W 145 N (New)	N Berrett Rd (New)	E 1500 N (New)
J9	I-15 SB	W 145 N (New)	US 20 (New)	W Broadway St (New)	US 26 (New)	W 65th S (New)	E 1250 N (New)
J10	I-15 SB	US 20	W Broadway St	US 26	W 65th S	E 1250 N	Bingham County Rest Area (New)
J11	I-15 SB	W Broadway St	US 26	W 65th S	E 1250 N	Bingham County Rest Area	Rose Rd (New)
J12	I-15 SB	US 26	W 65th S	E 1250 N	Bingham County Rest Area	Rose Rd	US 26 (New)
K17	US 20 EB	9th N (New)	N 7th E (New)	E 200 N (New)	E 300 N (New)	Cottonwood Dr (New)	S Bridge St (New)

Development and Application of WWCR Reduction Lone Wolf Optimization Algorithm

ITD can use the developed WWD hotspots model to identify limited access segments with high potential for WWCs. However, this model alone does not provide sufficient information to understand which exits within the identified hotspot segments have the highest potential for WWCR reduction. Additionally, there could be standalone exits with high WWCR reduction potential outside of the hotspot segments. It is important to identify these standalone exits (or lone wolf exits) to effectively combat WWD. The UCF research team developed a WWCR reduction lone wolf optimization algorithm for Idaho limited access roadways to identify hotspot exits and lone wolf exits with high WWCR reduction potential. By following the results of the lone wolf optimization algorithm, ITD can best utilize their resources and optimally combat WWD.

This section discusses the development and application of the WWCR reduction lone wolf optimization algorithm to ITD limited access roadways. First, the components of the lone wolf optimization algorithm are discussed, along with how various parameters were calculated. The results of the lone wolf optimization algorithm are discussed next, including identification of the optimal locations for advanced WWD countermeasure deployment and comparisons between the optimal exits and the hotspot exits. Lastly, life-cycle benefit-cost evaluations are discussed for two different types of advanced WWD countermeasures to show the potential benefits of these technologies if they were deployed at Idaho limited access exits.

Components and parameters of the WWCR reduction lone wolf optimization algorithm

The purpose of the WWCR reduction lone wolf optimization algorithm was to estimate the WWCR reduction potential for each individual exit based on the WWCR values for all segments that contained the exit, the likelihood of these segments' WWD events originating from the exit, and the number of segments that contained the exit to determine which exits would likely provide the most WWCR reduction when equipped with improved WWD countermeasures. Every optimization problem contains an objective function, decision variables, and constraints. For this particular problem, the objective function was to maximize the total WWCR reduction and the decision variable was a binary variable for each exit (represented by X_j) indicating if that exit was selected by the optimization algorithm (value of 1) or not (value of 0). The constraints provided a limit on the possible X_j values based on resources, real-world considerations, or other similar factors. One important constraint was a limit on the number of exits selected by the algorithm. Without this constraint, all possible exits would be selected since that would provide the maximum possible WWCR reduction. Using the defined objective function and constraints, the algorithm identifies the best X_j values to maximize the objective function value while meeting all defined constraints.

Equation 5-10 shows the objective function utilized by the Idaho WWCR reduction lone wolf optimization algorithm, Equation 5-11 shows the constraint used to limit the number of exits selected by the algorithm, and Equation 5-12 shows the equation used to calculate the WWCR reduction for each segment.

$$maximize\ f = \sum_{k} R_k\ , k \in K$$

Equation 5-10

$$\sum_{j} r_j X_j = H, j \in J$$

Equation 5-11

$$R_k = (WWCR_k)\left[\sum_{j}\left(E_{j,k}\right)(P)\left(X_j\right)\right], k \in K, \forall j \subset k$$

Equation 5-12

Where:

f = the total WWCR reduction on all roadway segments due to the exits selected by the optimization algorithm
R_k = the WWCR reduction on segment *k* due to the exits selected by the optimization algorithm
K = the set of studied roadway segments
r_j = the number of exit ramps at exit *j*
X_j = the binary decision variable for exit *j* (value of 1 if the exit is selected by the algorithm and a value of 0 if the exit is not selected by the algorithm)
H = the number of exit ramps to be selected by the algorithm
J = the set of studied roadway exits
$WWCR_k$ = the WWCR value for segment *k* based on the WWD hotspots model
$E_{j,k}$ = the weighted proportion of WWD events likely originating from exit *j* in segment *k*
P = the estimated percent reduction in WWCR due to deployment of WWD countermeasures

These equations contain the following important parameters which are required for the algorithm to work properly: r_j, *H*, $WWCR_k$, $E_{j,k}$, and *P*. The values of r_j (number of exit ramps at each exit) were already collected during the data collection process and the $WWCR_k$ values were obtained for each segment from the WWD hotspots model. The value of *P* was initially set to 1, allowing the algorithm to calculate the maximum possible WWCR reduction for each exit. Exits with high WWCR reduction values have the

most potential for WWD reduction and should therefore be priority locations for WWD countermeasure treatments. Different values of *P* corresponding to the effectiveness of different WWD countermeasures were used later when conducting benefit-cost evaluations to compare between countermeasures and estimate life-cycle benefits. To identify the selection order of all ITD exits based on their potential WWCR reduction, the optimization algorithm was run with a starting value of $H = 1$. This *H* value was then increased by 1 on each subsequent iteration of the algorithm until all possible exit ramps were selected by the algorithm. With this iterative process, it was possible to determine the order in which the exits were selected by the algorithm.

The final parameter is $E_{j,k}$. This parameter represents the distribution of WWD events within each segment and is the key component to allow the algorithm to identify WWCR reduction values for each exit. To determine this parameter, WWD entry values were determined for each exit. These WWD entry values included WWD events (WWCs and WWD citations) which were known to have originated from the exit and WWD events with unknown origins which potentially could have come from the exit. For every known origin WWD event, a WWD entry value of 1 was assigned to the exit where the WW vehicle entered the highway. For the unknown origin WWD events, the travel distribution of WWD vehicles was examined to determine how each event was assigned to the nearest potential WWD entry points.

Figure 5.3 shows the distance from the nearest exit (in miles) for all 97 exit ramp and unknown origin WWCs from 2010-2022 and 65 exit ramp and unknown origin WWD citations from 2018-2023 (total of 162 non-overlapping WWD events). Note that 2023 WWCs were not considered as the 2023 crash data were not complete when determining this distribution. Some important insights from this figure are that approximately 38% of WWD events occurred directly where an exit ramp meets the mainline (distance of 0 miles), 63% occurred less than 1 mile from the nearest exit, 95% occurred 5.9 miles or less from the nearest exit, and the maximum distance from the nearest exit was 13.8 miles.

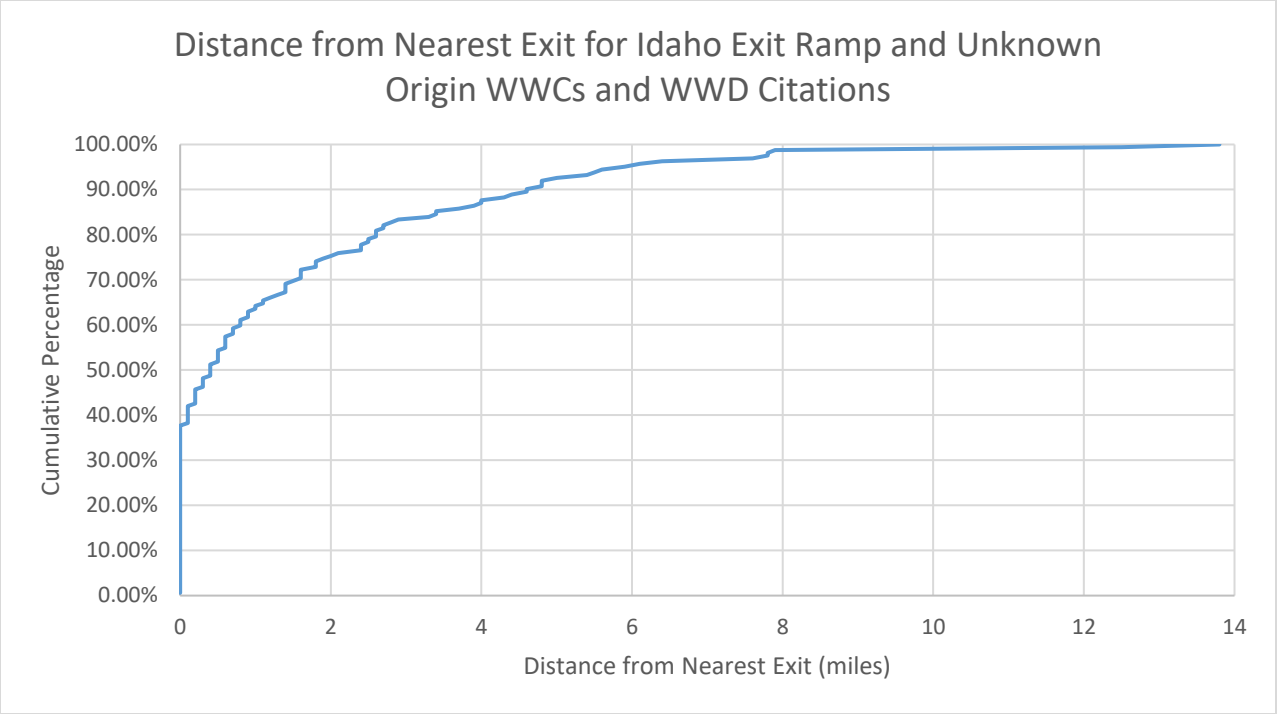

Figure 5.3 Distribution of distance to the nearest exit for Idaho exit ramp and unknown origin WWCs (2010-2022) and WWD citations (2018-2023)

Using this distribution, all WWD events with unknown origins were distributed to the nearest exits and associated WWD entry values were determined. Since 6-exit segments were used in modeling, each event was distributed to a maximum of six exits. First, the distances to the six nearest exits were calculated for each event. Then, the cumulative likelihood of the WWD vehicle originating from each exit was determined based on the exit's distance from the WWD event location and the distribution shown in Figure 5.3. Finally, each exit's WWD entry value for that event was calculated by taking the difference between that exit's cumulative likelihood value and the cumulative likelihood value of the next exit nearest to the WWD event location. Table 5.5 shows an example of this method for a WWD citation which occurred on June 17th, 2022, on I-90 EB near Exit 11 at Northwest Blvd. Based on the distribution shown in Figure 5.3, there was a 38% chance that this WWD vehicle came from exit A7 (distance of 0 miles from the WWD event location), a 59% chance it came from exit A8 or closer (distance of 0.7 miles from the WWD event location), a 66% chance it came from exit A9 or closer (distance of 1.2 miles), a 76% chance it came from exit A10 or closer (distance of 2.3 miles), an 85% chance it came from exit A11 or closer (distance of 3.5 miles), and a 94% chance it came from exit A12 or closer (distance of 5.6 miles). Taking the difference between each exit's cumulative likelihood value and the cumulative likelihood value of the previous exit resulted in WWD entry values for this event of 0.38 for exit A7, 0.21 for exit A8, 0.07 for exit A9, 0.10 for exit A10, 0.09 for exit A11, and 0.09 for exit A12.

Table 5.5 Example WWD Entry Value Calculations for WWD Citation on 6/17/2022

Relative Location to WWD Event	Exit ID	Distance from WWD Event (miles)	Cumulative Likelihood	Event WWD Entry Value
Nearest Exit	A7	0	0.38	0.38
2nd Nearest Exit	A8	0.7	0.59	0.59 – 0.38 = 0.21
3rd Nearest Exit	A9	1.2	0.66	0.66 – 0.59 = 0.07
4th Nearest Exit	A10	2.3	0.76	0.76 – 0.66 = 0.10
5th Nearest Exit	A11	3.5	0.85	0.85 – 0.76 = 0.09
6th Nearest Exit	A12	5.6	0.94	0.94 – 0.85 = 0.09

This procedure was repeated for all unknown origin WWD events, with the unknown origin WWD entry values then added to the known origin WWD entry values for each exit. Any exits more than 5.9 miles from the WWD event location were assigned a cumulative likelihood value of 0.95 since very few events in Figure 5.3 had a distance to the nearest exit greater than 5.9 miles, making it hard to accurately distribute events at these distances. This is analogous to how unknown WWD events in Florida were only distributed to the nearest three exits since 95% of WW drivers traveled three exits or less (Sandt et al. 2021, 256). Therefore, the maximum sum of the WWD entry values across all exits for a specific unknown origin WWD event was 0.95 compared to the WWD entry value of 1 for known origin WWD events. This put slightly more weight on WWD events with known origin points, which makes sense since these exits are known to be the origin of at least one WWD event and should therefore be considered higher priority by the optimization algorithm.

Once the WWD entry values were determined for each exit, any WWD entry values of zero were changed to 0.01. This change was made to ensure that a positive WWCR reduction value could be calculated for each exit. If an exit had a WWD entry value of zero, the algorithm would calculate that exit as having zero WWCR and therefore no possible WWCR reduction. This does not make sense in the real world as all exits have WWCR, even if it is very low. Using a small WWD entry value like 0.01 at these exits rather than zero allowed the algorithm to identify the potential WWCR reduction at these exits while still indicating that these exits have low WWD potential.

Next, segment WWD entry values were determined for each modeled segment by adding the exit WWD entry values for all exits in the segment. WWD entry proportions were then calculated for each exit within each segment by dividing each exit's WWD entry value by the segment's WWD entry value. The optimization algorithm multiplies these proportions by the segment's WWCR value to estimate the WWCR value for each exit in the segment. A specific exit can be in multiple segments and have different WWCR values for each of these segments, so the optimization algorithm adds all the exit WWCR values from each segment containing the exit to obtain a total WWCR value for the exit. Multiplying this exit WWCR value by *P* results in the exit's potential WWCR reduction. The algorithm then selects the exits which provide the highest total WWCR reduction while meeting the defined constraints. Since the

optimization algorithm uses the exit WWCR values for all segments containing the exit to determine the exit's potential WWCR reduction, exits in more segments are generally more likely to be selected (as they have more segments which could contribute to their WWCR values and are therefore more likely to have higher WWCR values). To address this, the WWD entry proportions were weighted before being used by the optimization algorithm. Each exit was in *n* segments, where *n* ranges from 1 to 6. Therefore, each proportion was multiplied by a weighting factor of 6/*n*. This means that the proportions for exits in six segments had a weighting factor of 6/6 = 1, proportions for exits in five segments had a weighting factor of 6/5 = 1.2, proportions for exits in four segments had a weighting factor of 6/4 = 1.5, proportions for exits in three segments had a weighting factor of 6/3 = 2, proportions for exits in two segments had a weighting factor of 6/2 = 3, and proportions for exits which were only located in one segment had a weighting factor of 6/1 = 6. These weighted proportions are the $E_{j,k}$ values used in Equation 5-12.

Table 5.6 shows an example of how $E_{j,k}$ values were calculated for segment A1 (the first segment on I-90 EB). This table shows the WWD entry values, proportions, number of segments containing the exit, weights, and weighted proportions ($E_{j,k}$ values) for each exit in the segment. The segment WWD entry value was the sum of all six exit WWD entry values, or 0.01 + 0.01 + 1.70 + 0.18 + 0.77 + 3.57 = 6.24. $E_{j,k}$ values were calculated in this same manner for all exits within all other segments.

Table 5.6 Example Calculation of $E_{j,k}$ Values for Segment A1 on I-90 EB

Exit	WWD Entry Value	Proportion of Segment WWD Entry Value	Number of Segments Containing the Exit	Weight	Weighted Proportion ($E_{j,k}$)
A1	0.01	0.01/6.24 = 0.0016	1	6	0.0016 x 6 = 0.0096
A2	0.01	0.01/6.24 = 0.0016	2	3	0.0016 x 3 = 0.0048
A3	1.70	1.70/6.24 = 0.2724	3	2	0.2724 x 2 = 0.5449
A5	0.18	0.18/6.24 = 0.0288	4	1.5	0.0288 x 1.5 = 0.0433
A6	0.77	0.77/6.24 = 0.1234	5	1.2	0.1234 x 1.2 = 0.1481
A7	3.57	3.57/6.24 = 0.5721	6	1	0.5721 x 1 = 0.5721

Application of WWCR reduction lone wolf optimization algorithm to Idaho limited access roadways

With all the necessary parameters determined, the optimization algorithm was developed using General Algebraic Modeling System (GAMS) software version 25.1.3 (GAMS Development Corp. 2018). The GAMS code for identifying the selection order of the ITD exits was provided to ITD as a separate file along with this report. After excluding exits not in Idaho, the studied roadway segments contained 326 limited access WWD exits with 336 exit ramps (10 exits had 2 exit ramps each). To determine the selection order of these exits based on potential WWCR reduction, 336 runs of the optimization

algorithm were made, with each run having a different value of *H* from 1 to 336. Note that the number of ramps was used rather than the number of exits since countermeasure deployment costs are on a per-ramp basis. For exits with two ramps, it was assumed that either both ramps or no ramps at the exit would be selected, since it is impossible to know which ramp at an exit had higher WWCR reduction potential based on the available data. The reported exit WWCR reduction values from the optimization algorithm were for all segments containing the exit over the studied five-year period. To better understand these values, they were divided by six to obtain an average WWCR reduction value from the six segments (real or weighted) containing the exit and then divided by five to obtain annual WWCR reduction values. These values represent how many potential WWCs originate from each exit per year.

Table 5.7 shows the optimization selection order for all 326 exits based on their annual potential WWCR reduction values, with the 80 hotspot exits highlighted in gray and indicated as hotspots in the first column. The total annual potential WWCR for all exits was 19.7209. When an exit with two ramps was selected, an already selected exit with one ramp was removed from the existing selection since the value of *H* was only increased by 1 for each successive iteration. This removed exit was then added back in the next iteration. Therefore, an exit with two ramps was only selected when the additional WWCR reduction it provided (i.e., the difference between its WWCR reduction and the WWCR reduction of the removed single-ramp exit) was greater than the WWCR reduction provided by adding the next best single-ramp exit to the selection. This is why the WWCR reduction values for two-ramp exits (as indicated in the last column) were higher than the surrounding values for single-ramp exits.

The first two exits selected by the optimization algorithm (I-90 EB at Northwest Blvd. and I-90 WB at State Road 41) were both in the identified hotspots and had very high WWCR reduction values compared to other exits, indicating that they should be considered first for future WWD countermeasure deployments. Conversely, some exits in the hotspots had very low WWCR reduction potential, such as I-15 SB at Rose Rd. This exit was the last hotspot exit selected by the algorithm and was selected 307th out of 326 exits, indicating that deploying WWD countermeasures at all hotspot exits would not be an effective use of resources. The third exit selected by the optimization algorithm (I-84 WB at Golf Course Rd.) was the first lone wolf exit, showing that exits outside of the identified hotspots can have high WWCR reduction potential. This exit was also the only exit with multiple exit ramp origin WWCs and WWD citations (as discussed in Chapter 4), emphasizing the importance of deploying treatments at this exit. For the 50 exits with the highest potential WWCR reduction, 11 were located on I-84 WB, 11 were located on I-84 EB, 8 were located on I-90 EB, 8 were located on I-15 NB, 5 were located on I-15 SB, 3 were located on I-90 WB, 3 were located on US 20 EB, and 1 was located on I-86 EB. These findings agree with the findings from the hotspots model that I-84 and I-90 contain many of the exits with high WWCR.

Table 5.7 WWCR Reduction Lone Wolf Optimization Algorithm Selection Order of ITD Exits

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
1 (Hotspot exit)	A7	I-90 EB	Northwest Blvd	0.9238
2 (Hotspot exit)	B5	I-90 WB	State Road 41	0.9052
3	D46	I-84 WB	Golf Course Rd	0.5221
4 (Hotspot exit)	D17	I-84 WB	Eagle Rd	0.5182
5 (Hotspot exit)	C43	I-84 EB	Hagerman Rd	0.4836
6 (Hotspot exit)	A3	I-90 EB	N Spokane St	0.4315
7 (Hotspot exit)	J27	I-15 SB	US 26	0.4021
8 (Hotspot exit)	C21	I-84 EB	N Orchard St	0.3963
9	I17	I-15 NB	Pocatello Creek Rd	0.3719
10	J11	I-15 SB	US 30	0.3363
11	K16	US 20 EB	N Salem Highway	0.2918
12	I9	I-15 NB	Henderson Rd	0.2833
13 (Hotspot exit)	D20	I-84 WB	W Overland Rd	0.2821
14	A22	I-90 EB	Hill St	0.2777
15	A17	I-90 EB	S Latour Creek Rd	0.2771
16	C4	I-84 EB	Black Canyon Rd	0.2690
17	C7	I-84 EB	US 26	0.2495
18	I21	I-15 NB	US 91	0.2485
19 (Hotspot exit)	I28	I-15 NB	W Broadway St	0.2446
20 (Hotspot exit)	C13	I-84 EB	N Franklin Blvd	0.2437
21 (Hotspot exit)	D12	I-84 WB	Northside Blvd	0.2326
22	A25	I-90 EB	N 3rd St	0.2283
23 (Hotspot exit)	D5	I-84 WB	Oasis Rd	0.2211
24	D11	I-84 WB	W Karcher Rd	0.2143
25 (Hotspot exit)	C22	I-84 EB	S Vista Ave	0.2085
26 (Hotspot exit)	I30	I-15 NB	W 145 N	0.2064
27 (Hotspot exit)	A6	I-90 EB	Huetter Rest Area	0.2018
28	C11	I-84 EB	W Karcher Rd	0.1995
29	C49	I-84 EB	Valley Rd	0.1986
30 (Hotspot exit)	B7	I-90 WB	Northwest Blvd	0.1942
31 (Hotspot exit)	J28	I-15 SB	W Broadway St	0.1925

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
32	A14	I-90 EB	Lakes Divide Rd	0.1858
33	D36	I-84 WB	Old U.S. 30	0.1794
34	D44	I-84 WB	S Idaho St	0.1743
35	D50	I-84 WB	Ridgeway Rd	0.1726
36 (Hotspot exit)	K20	US 20 EB	E 200 N	0.1667
37	I26	I-15 NB	W 65th S	0.1656
38	J21	I-15 SB	US 91	0.1647
39 (Hotspot exit)	C17	I-84 EB	Eagle Rd	0.1614
40 (Hotspot exit)	B6	I-90 WB	Huetter Rest Area	0.1595
41 (Hotspot exit)	D10	I-84 WB	Franklin Rd	0.1566
42 (Hotspot exit)	A10	I-90 EB	N 15th St	0.1531
43 (Hotspot exit)	I29	I-15 NB	US 20	0.1529
44 (Hotspot exit)	K23	US 20 EB	S Bridge St	0.1426
45	D32	I-84 WB	Old Oregon Trail Rd	0.1408
46 (Hotspot exit)	C44	I-84 EB	S Idaho St	0.1387
47 (Hotspot exit)	I32	I-15 NB	E 1500 N	0.1350
48 (Hotspot exit)	J29	I-15 SB	US 20	0.1341
49	C56	I-84 EB	E Yale Rd	0.1333
50	G2	I-86 EB	N Yale Rd	0.1315
51	I36	I-15 NB	Opal Way	0.1297
52	C55	I-84 EB	I-86	0.1291
53	D2	I-84 WB	US 95	0.1286
54 (Hotspot exit)	D6	I-84 WB	State Road 44	0.1267
55 (Hotspot exit)	C18	I-84 EB	I-184, W Franklin Rd	0.2545 (2 ramps)
56 (Hotspot exit)	J25	I-15 SB	E 1250 N	0.1215
57 (Hotspot exit)	K19	US 20 EB	N 7th E	0.1206
58 (Hotspot exit)	D8	I-84 WB	Centennial Way	0.1191
59 (Hotspot exit)	I27	I-15 NB	US 26	0.1188
60 (Hotspot exit)	B3	I-90 WB	N Spokane St	0.1060
61 (Hotspot exit)	B2	I-90 WB	Pleasant View Rd	0.1057
62 (Hotspot exit)	C20	I-84 EB	W Overland Rd	0.1027
63	D62	I-84 WB	Juniper Rest Area	0.1012

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
64	C30	I-84 EB	Old U.S. 30	0.0979
65 (Hotspot exit)	K22	US 20 EB	Cottonwood Dr	0.1980 (2 ramps)
66	D54	I-84 WB	State Road 77	0.0967
67	K10	US 20 EB	S State St	0.0907
68	C8	I-84 EB	Centennial Way	0.0841
69 (Hotspot exit)	A11	I-90 EB	N 23rd St	0.0821
70 (Hotspot exit)	C42	I-84 EB	1200 E	0.0789
71 (Hotspot exit)	C46	I-84 EB	Golf Course Rd	0.0761
72	H9	I-86 WB	Lakeview Rd	0.0739
73	L19	US 20 WB	N 7th E	0.0730
74	H11	I-86 WB	Gas Plant Rd	0.0723
75	D57	I-84 WB	Cassia County Rest Area	0.0682
76 (Hotspot exit)	A8	I-90 EB	US 95	0.0659
77 (Hotspot exit)	A12	I-90 EB	E Mullan Trail Rd	0.0633
78 (Hotspot exit)	C45	I-84 EB	W Rd	0.0623
79 (Hotspot exit)	D19	I-84 WB	W Overland Rd	0.0623
80	A15	I-90 EB	State Road 3	0.0581
81	C9	I-84 EB	N 10th Ave	0.0577
82 (Hotspot exit)	C47	I-84 EB	US 93	0.1147 (2 ramps)
83	D34	I-84 WB	Cold Springs Rd	0.0542
84	C60	I-84 EB	Sweetzer Rd	0.0532
85 (Hotspot exit)	J26	I-15 SB	W 65th S	0.0511
86	L16	US 20 WB	N Salem Highway	0.0497
87	K17	US 20 EB	W Center St	0.0496
88	L15	US 20 WB	W Main St	0.0483
89 (Hotspot exit)	A5	I-90 EB	State Road 41	0.0470
90	L18	US 20 WB	9th N	0.0455
91	C10	I-84 EB	Franklin Rd	0.0444
92	C50	I-84 EB	Ridgeway Rd	0.0433
93	A26	I-90 EB	Markwell Ave	0.0428
94	A24	I-90 EB	Big Creek Rd	0.0421
95	I10	I-15 NB	E Jensen Rd	0.0411

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
96	D61	I-84 WB	38000 W	0.0397
97	C12	I-84 EB	Northside Blvd	0.0382
98	K11	US 20 EB	Farnsworth Way	0.0380
99	C58	I-84 EB	E 800 S	0.0346
100 (Hotspot exit)	K21	US 20 EB	E 300 N	0.0339
101	K12	US 20 EB	Main St	0.0339
102	H1	I-86 WB	I-84	0.0668 (2 ramps)
103	K4	US 20 EB	Presto St	0.0300
104	K3	US 20 EB	Fremont Ave	0.0296
105	D45	I-84 WB	W Rd	0.0295
106 (Hotspot exit)	D9	I-84 WB	N 10th Ave	0.0293
107	B13	I-90 WB	State Road 97	0.0289
108	C24	I-84 EB	E Gowen Rd	0.0280
109	K2	US 20 EB	Lindsay Blvd	0.0274
110	B12	I-90 WB	E Mullan Trail Rd	0.0269
111	B14	I-90 WB	Lakes Divide Rd	0.0263
112	L8	US 20 WB	105th N	0.0263
113	A13	I-90 EB	State Road 97	0.0257
114 (Hotspot exit)	J24	I-15 SB	Bingham County Rest Area	0.0252
115	C57	I-84 EB	Cassia County Rest Area	0.0245
116	L9	US 20 WB	E County Line Rd	0.0243
117	B23	I-90 WB	N Division St	0.0238
118	B11	I-90 WB	N 23rd St	0.0237
119	B15	I-90 WB	State Road 3	0.0235
120	B21	I-90 WB	Bunker Ave	0.0233
121	K5	US 20 EB	US 20 Bus	0.0231
122 (Hotspot exit)	D18	I-84 WB	I-184, W Franklin Rd	0.0464 (2 ramps)
123	A27	I-90 EB	The Harry F. Magnuson Way	0.0229
124	B24	I-90 WB	Big Creek Rd	0.0226
125	L7	US 20 WB	25th E	0.0226
126 (Hotspot exit)	C14	I-84 EB	N Idaho Center Blvd	0.0225
127	I33	I-15 NB	Camas Creek Rd	0.0219

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
128	D26	I-84 WB	Blacks Creek Rest Area	0.0218
129 (Hotspot exit)	A9	I-90 EB	N 4th St	0.0215
130	B16	I-90 WB	Mission Rd	0.0215
131	L6	US 20 WB	N 15th E	0.0214
132	G9	I-86 EB	Lakeview Rd	0.0213
133	G10	I-86 EB	Lakeview Rd	0.0212
134	L11	US 20 WB	Farnsworth Way	0.0211
135 (Hotspot exit)	C19	I-84 EB	W Overland Rd	0.0209
136	D25	I-84 WB	Memory Rd	0.0209
137	B25	I-90 WB	N 3rd St	0.0207
138	D55	I-84 WB	I-86	0.0205
139	B20	I-90 WB	Airport Rd	0.0205
140	L5	US 20 WB	US 20 Bus	0.0204
141 (Hotspot exit)	B4	I-90 WB	E Seltice Way	0.0202
142	D24	I-84 WB	E Gowen Rd	0.0201
143	B17	I-90 WB	S Latour Creek Rd	0.0200
144 (Hotspot exit)	B10	I-90 WB	N 15th St	0.0197
145	B18	I-90 WB	Coeur D' Alene River Rd	0.0191
146	B19	I-90 WB	E Frk Pine Creek Rd	0.0191
147	L3	US 20 WB	Fremont Ave	0.0190
148	K6	US 20 EB	N 15th E	0.0188
149	G11	I-86 EB	Gas Plant Rd	0.0187
150	J35	I-15 SB	Sheep Sta Rd E	0.0185
151	B26	I-90 WB	Markwell Ave	0.0184
152	G12	I-86 EB	Arbon Valley Highway	0.0183
153	G13	I-86 EB	Terminal Way	0.0182
154	J36	I-15 SB	Opal Way	0.0179
155	H8	I-86 WB	Rockland Highway	0.0178
156	D23	I-84 WB	S Broadway Ave	0.0177
157	L12	US 20 WB	Main St	0.0176
158	G8	I-86 EB	Rockland Highway	0.0175
159 (Hotspot exit)	D16	I-84 WB	S Meridian Rd	0.0174

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
160	G14	I-86 EB	US 30	0.0171
161 (Hotspot exit)	K18	US 20 EB	9th N	0.0170
162	J37	I-15 SB	W Camas Creek Rd	0.0169
163	D27	I-84 WB	E Blacks Creek Rd	0.0169
164	G7	I-86 EB	Rock Creek Rd	0.0166
165	D4	I-84 WB	Black Canyon Rd	0.0166
166	J38	I-15 SB	Old Hwy 91	0.0164
167	L2	US 20 WB	Lindsay Blvd	0.0162
168	G5	I-86 EB	Register Rd	0.0161
169	C37	I-84 EB	Commercial St	0.0161
170	K7	US 20 EB	25th E	0.0159
171	C36	I-84 EB	Old U.S. 30	0.0159
172 (Hotspot exit)	B9	I-90 WB	N 4th St	0.0156
173	J34	I-15 SB	State Road 22	0.0152
174 (Hotspot exit)	D22	I-84 WB	S Vista Ave	0.0149
175 (Hotspot exit)	B1	I-90 WB	W Pointe Pkwy	0.0148
176	B27	I-90 WB	The Harry F. Magnuson Way	0.0148
177	G4	I-86 EB	Lanes Gulch Rd	0.0146
178	L13	US 20 WB	W 5000 S	0.0136
179	C35	I-84 EB	N Bannock St	0.0135
180	J5	I-15 SB	N Old Hwy 191	0.0134
181	G15	I-86 EB	Yellowstone Ave / US 91	0.0134
182	J33	I-15 SB	Camas Creek Rd	0.0128
183	C38	I-84 EB	Gopher Knoll Rd	0.0125
184	J4	I-15 SB	State Road 36	0.0123
185 (Hotspot exit)	C23	I-84 EB	S Broadway Ave	0.0121
186	J15	I-15 SB	S 5th Ave	0.0121
187	D28	I-84 WB	S Orchard Access Rd	0.0119
188	J6	I-15 SB	Bannock County Rest Area	0.0117
189	K8	US 20 EB	105th N	0.0116
190	J17	I-15 SB	Pocatello Creek Rd	0.0114
191	B28	I-90 WB	Burke Rd	0.0113

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
192	H10	I-86 WB	Lakeview Rd	0.0111
193	C33	I-84 EB	Hammett Hill Rd	0.0110
194	J18	I-15 SB	I-86	0.0109
195 (Hotspot exit)	B8	I-90 WB	US 95	0.0108
196	J7	I-15 SB	E Treasure Ln	0.0106
197 (Hotspot exit)	D21	I-84 WB	N Orchard St	0.0105
198	A23	I-90 EB	N Division St	0.0105
199	J3	I-15 SB	50 St S	0.0104
200	I2	I-15 NB	Oneida County Rest Area	0.0103
201	J32	I-15 SB	E 1500 N	0.0103
202	G3	I-86 EB	Coldwater Hill Rest Area	0.0103
203 (Hotspot exit)	D7	I-84 WB	US 26	0.0102
204	J1	I-15 SB	Woodruff Ln	0.0100
205	I1	I-15 NB	Woodruff Ln	0.0096
206	J8	I-15 SB	US 91	0.0095
207	J14	I-15 SB	S 5th Ave	0.0095
208	B29	I-90 WB	Golconda Rd	0.0093
209 (Hotspot exit)	C39	I-84 EB	Bliss Rest Area	0.0093
210	L14	US 20 WB	University Blvd	0.0092
211	B30	I-90 WB	Ruddy Gulch Rd	0.0089
212	B31	I-90 WB	Mill Rd	0.0087
213	D29	I-84 WB	Simco Rd	0.0085
214	I22	I-15 NB	US 26	0.0083
215	J9	I-15 SB	Henderson Rd	0.0082
216	C32	I-84 EB	Old Oregon Trail Rd	0.0082
217	B33	I-90 WB	I-90 BL	0.0081
218	I3	I-15 NB	50 St S	0.0079
219	D53	I-84 WB	I-84 Business	0.0079
220	A33	I-90 EB	I-90 BL	0.0078
221	J19	I-15 SB	Northgate Pkwy	0.0077
222	J31	I-15 SB	N Berrett Rd	0.0076
223	D39	I-84 WB	Bliss Rest Area	0.0071

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
224	D40	I-84 WB	I-84 Business	0.0070
225	D38	I-84 WB	Gopher Knoll Rd	0.0070
226	I4	I-15 NB	State Road 36	0.0068
227	A32	I-90 EB	I-90 BL	0.0068
228	D41	I-84 WB	US 26	0.0067
229	K9	US 20 EB	E County Line Rd	0.0066
230	J13	I-15 SB	I-15 BL	0.0065
231	D42	I-84 WB	1200 E	0.0062
232	I5	I-15 NB	N Old Hwy 191	0.0061
233	A31	I-90 EB	Mill Rd	0.0059
234	J16	I-15 SB	Center St	0.0117 (2 ramps)
235	J10	I-15 SB	E Jensen Rd	0.0058
236	I7	I-15 NB	E Treasure Ln	0.0056
237 (Hotspot exit)	C15	I-84 EB	S Ten Mile Rd	0.0054
238	A30	I-90 EB	Ruddy Gulch Rd	0.0053
239	D30	I-84 WB	Old U.S. 30	0.0051
240	A29	I-90 EB	Golconda Rd	0.0049
241 (Hotspot exit)	C48	I-84 EB	S 1150 E	0.0048
242	C31	I-84 EB	Sun Valley Hwy	0.0048
243	D37	I-84 WB	Commercial St	0.0047
244	I8	I-15 NB	US 91	0.0046
245	J20	I-15 SB	E Ross Fork Rd	0.0045
246 (Hotspot exit)	J30	I-15 SB	W 145 N	0.0045
247	C26	I-84 EB	Blacks Creek Rest Area	0.0044
248	I11	I-15 NB	US 30	0.0044
249	C27	I-84 EB	E Blacks Creek Rd	0.0044
250 (Hotspot exit)	C41	I-84 EB	US 26	0.0042
251	I12	I-15 NB	I-15 BL	0.0041
252	L1	US 20 WB	I-15	0.0082 (2 ramps)
253	A28	I-90 EB	Burke Rd	0.0041
254	G16	I-86 EB	I-15	0.0081 (2 ramps)
255	C28	I-84 EB	S Orchard Access Rd	0.0040

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
256	D43	I-84 WB	Hagerman Rd	0.0040
257	I14	I-15 NB	S 5th Ave	0.0038
258	I15	I-15 NB	S 5th Ave	0.0036
259	A21	I-90 EB	Bunker Ave	0.0035
260	A20	I-90 EB	Airport Rd	0.0034
261	D31	I-84 WB	Sun Valley Hwy	0.0033
262	I16	I-15 NB	Center St	0.0033
263 (Hotspot exit)	C40	I-84 EB	I-84 Business	0.0066 (2 ramps)
264	A19	I-90 EB	E Frk Pine Creek Rd	0.0033
265	A18	I-90 EB	Coeur D' Alene River Rd	0.0031
266 (Hotspot exit)	D15	I-84 WB	S Ten Mile Rd	0.0029
267	C1	I-84 EB	Payette County Rest Area	0.0029
268	C2	I-84 EB	US 95	0.0029
269	C6	I-84 EB	State Road 44	0.0028
270	C5	I-84 EB	Oasis Rd	0.0027
271	C3	I-84 EB	US 30	0.0027
272	C29	I-84 EB	Simco Rd	0.0027
273	I23	I-15 NB	Rose Rd	0.0026
274 (Hotspot exit)	C16	I-84 EB	S Meridian Rd	0.0026
275	I20	I-15 NB	E Ross Fork Rd	0.0026
276	A16	I-90 EB	Mission Rd	0.0026
277	H2	I-86 WB	N Yale Rd	0.0026
278 (Hotspot exit)	A2	I-90 EB	Pleasant View Rd	0.0025
279	I37	I-15 NB	W Camas Creek Rd	0.0025
280 (Hotspot exit)	A1	I-90 EB	W Pointe Pkwy	0.0025
281 (Hotspot exit)	D14	I-84 WB	N Idaho Center Blvd	0.0024
282	I24	I-15 NB	Bingham County Rest Area	0.0024
283	I19	I-15 NB	Northgate Pkwy	0.0023
284	C25	I-84 EB	Memory Rd	0.0045 (2 ramps)
285	K15	US 20 EB	W Main St	0.0022
286	K14	US 20 EB	University Blvd	0.0021
287	C51	I-84 EB	State Road 25	0.0021

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
288	H4	I-86 WB	Lanes Gulch Rd	0.0021
289	I25	I-15 NB	E 1250 N	0.0020
290	K13	US 20 EB	W 5000 S	0.0020
291	I18	I-15 NB	I-86	0.0020
292	L23	US 20 WB	S Bridge St	0.0019
293	H5	I-86 WB	Register Rd	0.0019
294	D49	I-84 WB	Valley Rd	0.0018
295	C52	I-84 EB	I-84 Business	0.0018
296	D48	I-84 WB	S 1150 E	0.0018
297 (Hotspot exit)	D13	I-84 WB	N Franklin Blvd	0.0018
298	D33	I-84 WB	Hammett Hill Rd	0.0018
299	D51	I-84 WB	State Road 25	0.0017
300	L20	US 20 WB	E 200 N	0.0017
301 (Hotspot exit)	J22	I-15 SB	US 26	0.0017
302	L22	US 20 WB	Cottonwood Dr	0.0017
303	L21	US 20 WB	E 300 N	0.0016
304	H6	I-86 WB	Power County Rest Area	0.0016
305	D52	I-84 WB	I-84 Business	0.0016
306 (Hotspot exit)	I31	I-15 NB	N Berrett Rd	0.0016
307 (Hotspot exit)	J23	I-15 SB	Rose Rd	0.0016
308	D47	I-84 WB	US 93	0.0015
309	C53	I-84 EB	I-84 Business	0.0015
310	I34	I-15 NB	State Road 22	0.0015
311	H7	I-86 WB	Rock Creek Rd	0.0015
312	I35	I-15 NB	Sheep Sta Rd E	0.0014
313	H15	I-86 WB	Yellowstone Ave / US 91	0.0013
314	D3	I-84 WB	US 30	0.0012
315	H14	I-86 WB	US 30	0.0011
316	D60	I-84 WB	Sweetzer Rd	0.0010
317	H13	I-86 WB	Terminal Way	0.0010
318	I38	I-15 NB	Old Hwy 91	0.0010
319	C54	I-84 EB	State Road 77	0.0010

Selection Order	Exit ID	Roadway	Location	Annual Potential WWCR Reduction
320	H12	I-86 WB	Arbon Valley Highway	0.0009
321	D59	I-84 WB	Sublett Rd	0.0008
322	D58	I-84 WB	E 800 S	0.0007
323	C61	I-84 EB	38000 W	0.0006
324	C62	I-84 EB	Juniper Rest Area	0.0006
325	C59	I-84 EB	Sublett Rd	0.0005
326	D56	I-84 WB	E Yale Rd	0.0005

Comparing the exits selected by the lone wolf optimization algorithm to the hotspot exits shows the benefits that this algorithm provides. The hotspot segments contained 80 exits (85 exit ramps) with a total annual potential WWCR reduction of 10.2831 (52.14% of the overall total of 19.7209). Selecting the optimal 85 exit ramps (same number of exit ramps as in the identified hotspot segments) resulted in 82 exits with a total annual potential WWCR reduction of 16.4448 (83.39% of the overall total of 19.7209). Therefore, following the lone wolf optimization algorithm results improved the potential WWCR reduction by (16.4448 – 10.2831)/10.2831 = 0.5992 = 59.92% compared to only selecting the hotspot exits. The 85 exit ramps selected by the lone wolf optimization algorithm included 48 hotspot exit ramps at 45 hotspot exits and 37 lone wolf exit ramps at 37 lone wolf exits. By identifying these 37 lone wolf exit ramps, the lone wolf optimization algorithm helps ITD improve their resource utilization by 37/85 = 0.4353 = 43.53% by allowing ITD to focus WWD treatment efforts at these lone wolf exits instead of hotspot exits with low WWCR reduction potential. The 37 lone wolf exits consisted of 10 exits on I-84 WB, 9 exits on I-84 EB, 5 exits on I-15 NB, 5 exits on I-90 EB, 2 exits on I-15 SB, 2 exits on US 20 EB, 2 exits on I-86 WB, 1 exit on I-86 EB, and 1 exit on US 20 WB. These lone wolf exits were selected over 9 hotspot exits (10 ramps) on I-84 WB, 9 hotspot exits (10 ramps) on I-84 EB, 5 hotspot exits on I-15 SB, 5 hotspot exits on I-90 WB, 4 hotspot exits on I-90 EB, 2 hotspot exits on US 20 EB, and 1 hotspot exit on I-15 NB. I-86 EB, I-86 WB, and US 20 WB did not have any identified WWD hotspots, but did have exits selected by the lone wolf optimization algorithm, showing how this algorithm can help identify high-WWCR locations on roadways without high-risk segments.

The optimization results were also used to identify the optimal number of exits to equip with advanced or improved WWD countermeasures to achieve the most benefits. To identify this optimal number, the percent gain was determined for each exit. The percent gain is the difference between the percentage of total benefits provided by the exit and percentage of the total number of exit ramps present at the exit. For this application, the benefits were represented by the annual potential WWCR reduction, while the percentage of ramps represented the costs (since countermeasures costs are on a per-ramp basis). These percent gains were added together as more exits were selected to obtain a cumulative percent gain curve, as shown in Figure 5.4. The maximum point on this curve represents the largest difference between the cumulative percentage of benefits and percentage of ramps for the selected exits and is

therefore the optimal number of exits for WWD countermeasure deployment. This maximum of 58.11% occurred when 79 exits (81 exit ramps) were selected. These 81 exit ramps (24.11% of all exit ramps) had 82.22% of the total potential WWCR reduction. Exits selected after these 79 exits provided a lower percentage of benefits than their percentage of ramps, causing the cumulative percent gain to decrease. Therefore, it is recommended to start WWD countermeasure deployments at these 79 exits (which are the first 79 listed in Table 5.7) to optimally obtain WWCR reduction benefits. These optimal 79 exits consist of 19 exits on I-84 EB, 18 exits on I-84 WB, 11 exits on I-90 EB, 10 exits on I-15 NB, 6 exits on I-15 SB, 6 exits on US 20 EB, 5 exits on I-90 WB, 2 exits on I-86 WB, 1 exit on I-86 EB, and 1 exit on US 20 WB.

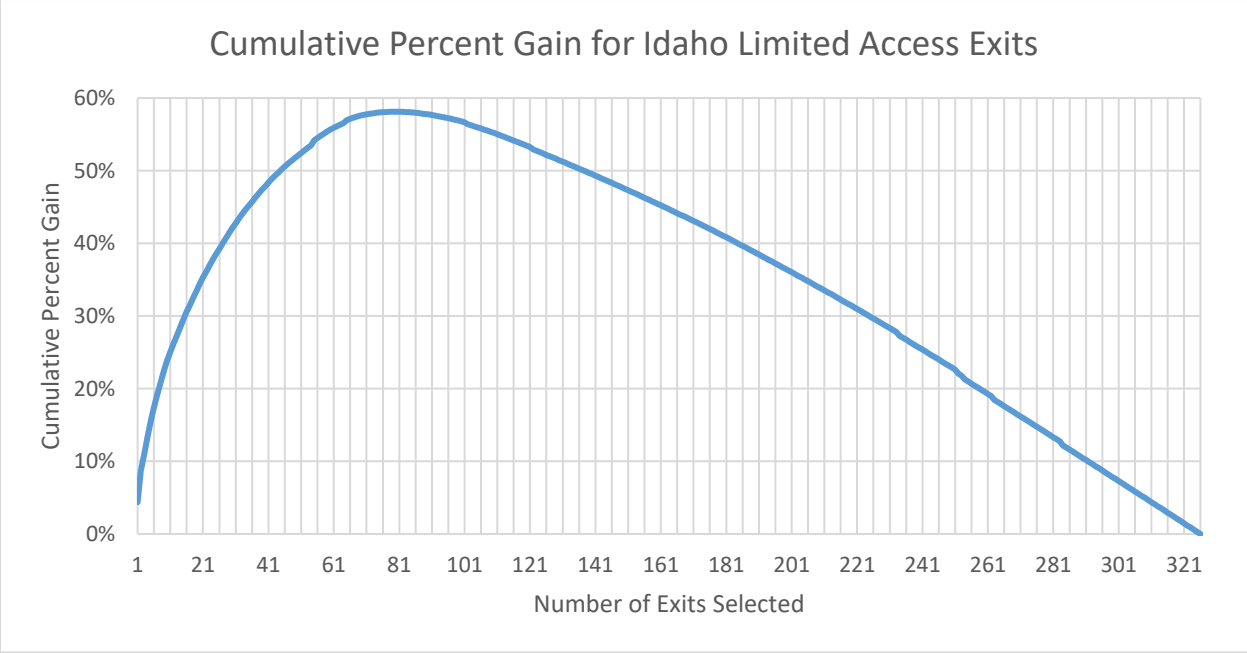

Figure 5.4 Cumulative percent gain for Idaho limited access exits

Life-cycle benefit cost evaluations for RFB and LED WWD countermeasures

The WWCR reduction lone wolf optimization algorithm was also used to estimate the life-cycle benefits and costs of deploying advanced WWD countermeasures at ITD limited access exits. Two different countermeasures were considered: a single set of LED WW signs (two signs) per ramp and a double set of RFB WW signs (four signs) per ramp. These are the same countermeasures which were previously evaluated for the FTE toll road network (Sandt and Al-Deek 2021). Evaluating the benefits and costs of deploying these WWD countermeasure technologies at Idaho exits can help ITD make cost-effective implementation decisions to best reduce WWD in the future. Since the effectiveness and costs of these countermeasures were based on Florida data (as there have been no implementations of these technologies in Idaho), the actual benefits and costs in Idaho could differ from the estimates discussed in this section. Therefore, it is not recommended to make financial decisions regarding the deployment of RFB or LED WWD countermeasures solely on the results of these benefit-cost evaluations.

Additionally, changes could be made to the setup of these countermeasures (such as the use of additional signs and cameras) which could improve their effectiveness.

To estimate the potential WWC reduction benefits of these countermeasures, it was first necessary to estimate the average cost of a WWC. Table 5.8 shows the number of injuries and injury cost per severity level for all 97 exit ramp and unknown origin WWCs from 2010-2022. The costs per injury for each injury level were comprehensive injury costs obtained from the National Safety Council (2025). Injury costs were considered rather than crash costs since Sandt and Al-Deek (2021) showed that WWCs have higher injury costs compared to other types of crashes due to their high fatality rate. The average comprehensive injury cost per crash for these 97 WWCs was $4,715,490. This is slightly higher than the average injury cost per crash of $4,689,714 for Florida WWCs reported in Sandt and Al-Deek (2021), due to the higher costs per injury severity level compared to the values used in the previous study. Overall, the fatality rate was 1.36 fatalities per fatal WWC, which is lower than the 1.51 fatalities per fatal WWC reported in Florida (Sandt and Al-Deek 2021). This suggests that Idaho WWCs are not as severe as Florida WWCs.

Table 5.8 WWC Injury Costs

Injury Category	Number of People	Cost per Injury	Total Idaho WWC Injury Cost	Number of WWCs	Injury Rate per WWC
Fatality (K)	30	$13,111,000	$393,330,000	22	0.309
Serious Injury (A)	43	$1,066,000	$45,838,000	18	0.443
Minor Injury (B)	38	$232,000	$8,816,000	13	0.392
Possible Injury (C)	56	$126,000	$7,056,000	21	0.577
No or Unknown Injury (O)	135	$17,500	$2,362,500	23	1.392
Total	**302**	**$4,715,490**	**$457,402,500**	**97**	**3.113**

Using this average injury cost of $4,715,490 per WWC, injury savings due to the deployment of RFB or LED countermeasures were estimated for each exit. The RFB and LED countermeasures were assumed to reduce WWCs by 70.8% and 21.3%, respectively, as these were the effectiveness values used in Sandt and Al-Deek (2021). Therefore, P = 0.708 was used in the optimization algorithm to estimate WWCR reductions due to RFBs and P = 0.213 was used to estimate WWCR reductions due to LEDs. Multiplying these WWCR reductions by the average injury cost resulted in estimated annual injury savings for each exit. For example, I-90 EB at Northwest Blvd. (the first exit selected by the optimization algorithm) had an annual WWCR reduction of 0.6538 for RFBs and 0.1969 for LEDs, resulting in annual injury savings of 0.6538 x $4,715,490 = $3,082,939 for RFBs and 0.1969 x $4,715,490 = $928,397 for LEDs. These annual savings were converted to a present value (in 2025 dollars) for a 10-year life cycle using Equation 5-13. A discount rate of 4% was used for these conversions as this was the rate used by Sandt and Al-Deek (2021) based on recommendations from FDOT and no recommendations on appropriate discount rates to use for benefit-cost analyses in Idaho were found.

$$PV = AV \times \left[\frac{1-(1+i)^{-n}}{i}\right]$$

Equation 5-13

Where:

PV = present value of life-cycle WWC injury savings, 2025 dollars
AV = annual WWC injury savings, dollars
i = discount rate, percentage
n = length of life cycle, in years

The costs of the RFB and LED countermeasures were taken from Sandt and Al-Deek (2021) and converted to 2025 dollars to be consistent with the calculated life-cycle injury savings. These conversions resulted in life-cycle costs (including capital deployment costs and annual operations and maintenance costs) of $82,295 per ramp for RFBs and $49,265 per ramp for LEDs. Each exit's injury savings benefits were then divided by the costs to obtain life-cycle benefit-cost ratios for each exit. Benefit-cost ratios greater than 1 indicated that the benefits of the countermeasure deployments were expected to outweigh the costs over the 10-year life cycle.

Table 5.9 shows the results of the benefit-cost evaluations for three different scenarios: countermeasure deployments at all 326 exits (336 exit ramps), countermeasure deployments only at cost-effective exits with life-cycle benefit-cost ratios greater than 1, and countermeasure deployments only at the 79 optimal exits (81 exit ramps) identified previously. These evaluations show that the RFB countermeasures were expected to have higher benefit-cost ratios than the LED countermeasures for all scenarios. Deploying RFBs at the 274 exit ramps with a life-cycle benefit-cost ratio greater than 1 was estimated to provide 99.4% of the maximum possible benefits (if RFBs were deployed at all 336 ramps) for 81.5% of the maximum cost (if RFBs were deployed at all 336 ramps). Similarly, deploying LEDs at the 237 exit ramps with a life-cycle benefit-cost ratio greater than 1 was estimated to provide 98.6% of the maximum possible benefits for 70.5% of the maximum cost. Only deploying RFBs at the 81 optimal exit ramps was estimated to provide life-cycle injury savings of almost $440 million (82.2% of the maximum possible benefits) for life cycle-costs of approximately $6.7 million (24.1% of the maximum cost), resulting in a life-cycle benefit-cost ratio of 65.85. Based on these results, it is recommended to deploy a double set of RFB WWD countermeasures rather than a single set of LED WWD countermeasures at as many of the 79 optimal exits selected by the lone wolf optimization algorithm as possible given ITD's available resources. It is expected that deploying a double set of LED WWD countermeasures would provide more benefits than a single set, but there have not been any statistical evaluations to compare double sets of RFB WWD countermeasures with double sets of LED WWD countermeasures. However, the survey results discussed in Kayes et al. (2018) showed that RFBs were generally preferred over LEDs due to both the extra set of signs and better flashing. Therefore, it is recommended to deploy RFB WWD countermeasures if possible.

Table 5.9 Life-Cycle Benefit-Cost Evaluations of RFB and LED WWD Countermeasures

Parameter	All RFB Exits	All LED Exits	Cost-Effective RFB Exits	Cost-Effective LED Exits	Optimal RFB Exits	Optimal LED Exits
Number of Exit Ramps	336	336	274	237	81	81
Life-Cycle WWCR Reduction	139.56	42.03	138.76	41.44	114.75	34.55
Life-Cycle Benefits (2025$)	$533,787,371	$160,744,950	$530,717,974	$158,504,521	$438,870,626	$132,161,682
Life-Cycle Costs (2025$)	$27,651,043	$16,552,885	$22,548,767	$11,675,696	$6,665,876	$3,990,428
Life-Cycle Benefit-Cost Ratio	19.30	9.71	23.54	13.58	65.85	33.12

Modeling and Optimization Summary, Conclusions, and Recommendations

The WWD hotspots model and WWCR reduction lone wolf optimization algorithm developed in this document provided meaningful insights into WWD which ITD can use to reduce WWD effectively and proactively on Idaho limited access roadways. By considering non-crash WWD citation data, traffic volumes, area type, and a multitude of exit design characteristics, the WWD hotspots model showed what factors most impacted WWC frequency and what roadways had numerous high-risk hotspots based on actual and predicted WWC counts. The WWCR reduction lone wolf optimization algorithm improved on this WWD hotspots model by identifying specific exits with high WWCR reduction potential based on the model results and the likelihood of specific exits being origin points for WWD events. This algorithm can help ITD identify the optimal quantity and locations of exits for priority treatment to ensure that resources are utilized most effectively.

Since WWCs are rare and it is often unknown where exactly the WW driver entered the mainline, the WWD hotspots model used roadway segments rather than individual exits as data points. Using segments helped to account for this uncertainty in the WWD origin point (since each segment contained multiple potential origin points) while also reducing the number of data points with zero WWCs and allowing for easier comparison between neighboring data points. An overlapping segmentation method was used to have each segment differ from its direct neighbors by only one exit, with GEEs used when developing the WWD hotspots model to handle the correlation between segments caused by this overlapping method. Segments of various sizes (3-exit segments, 4-exit segments, 5-exit segments, and

6-exit segments) were created using this method to test which size resulted in the best model. The various roadway and WWD event data discussed in Chapters 3 and 4 were used to develop segment variables for modeling, including segment WWC and WWD citation counts from 2018 through 2022, average traffic volumes, primary area type, and numerous design-related variables.

Using these segment data, multiple WWD hotspot models were developed using GEEs with Poisson and negative binomial distributions for the different segment sizes. Various performance measures were used to compare models during and after the modeling process, including QIC, MAE, RMSE, total predicted WWCs, predicted WWCs in segments with zero actual WWCs, and predicted WWCs in segments with three or more actual WWCs. Based on these performance measures, a negative binomial model using 6-exit segments was selected as the final model. This model contained nine significant variables. Segments with at least one WWD citation, higher crossing street traffic volumes, at least one SD interchange, more exit ramps which met the crossing street at a right angle, and which were primarily rural were predicted to have more WWCs. Conversely, segments with at least one OD interchange, more exit ramps which merged directly onto the crossing street, at least one exit where the crossing street had a grass median, and at least one exit where the entrance ramp was located away from the exit ramp were predicted to have fewer WWCs. ITD can use these findings to better treat WWD at existing or future limited access exit ramps.

The model results were used to calculate WWCR values by adding the actual WWCs to the predicted WWCs for each segment. Based on these WWCR values, 36 WWD hotspot segments were identified. These included the 28 segments (10% of all segments) with the highest WWCR, 3 additional segments with more than two actual WWCs during the study period (2018-2022), and 5 additional segments predicted to have more than two WWCs during a five-year period. These hotspots contained 80 unique Idaho exits (85 exit ramps) with I-84 EB and I-84 WB containing almost half of these exits.

To better understand WWCR at individual exits, the WWCR reduction lone wolf optimization algorithm was developed and applied to Idaho limited access exit ramps. This algorithm was used to determine the annual WWCR reduction potential for each exit and obtain a selection order for all 336 studied Idaho exit ramps. WWD events with unknown origin points were distributed to the nearest possible exits based on the distances between the event and these exits to obtain WWD entry values for each exit. These WWD entry values were used to estimate the proportion of WWD events that likely originated from each exit within each segment. Based on these proportions (which were weighted to accommodate exits located in fewer than six segments) and the WWCR values from the WWD hotspots model, annual potential WWCR reduction values were determined for each exit. These values showed that I-90 EB at Northwest Blvd. and I-90 WB at State Road 41 were the highest risk exits (almost double the risk of the next exit) and are therefore priority candidates for WWD treatment. The optimization algorithm identified many lone wolf exits with high WWCR reduction potential which would be more effective locations for WWD treatment than some of the exits in the identified WWD hotspots. In the first 85 exit ramps selected by the optimization, 48 were in the identified hotspots and 37 were at lone wolf exits, indicating that ITD could improve their resource utilization by 43.5% if they followed the lone wolf optimization algorithm's recommendations. The exits selected by the algorithm also had 60% more

potential WWCR reduction compared to the hotspot exits and included some exits on roadways which did not have any identified WWD hotspots (I-86 EB, I-86 WB, and US 20 WB). Additionally, the lone wolf optimization algorithm results showed that deploying WWD treatments at 81 exit ramps would be the most optimal use of resources, as these ramps would provide the maximum difference (or percentage gain) of 58.11% between the percentage of total WWCR reduction benefits (82.22%) and percentage of total ramps equipped (24.11%).

The lone wolf optimization algorithm was also used to estimate the potential life-cycle benefits of select WWD countermeasure technologies. Advanced RFB and LED WWD countermeasures which have been implemented successfully in Florida were evaluated to determine their potential benefits and costs for Idaho limited access roadways. Review of Idaho WWC data showed that the average WWC had a comprehensive injury cost of $4,715,490. Benefits (crash savings) and costs were estimated for each countermeasure over a ten-year life cycle using RFB and LED effectiveness measures of 70.8% and 21.3%, respectively, and life-cycle costs of $82,295 per ramp (double set of RFBs) and $49,265 per ramp (single set of LEDs). These evaluations showed that RFBs were more cost-effective than LEDs, as deploying RFB countermeasures at the optimal 81 exit ramps would result in a life-cycle benefit-cost ratio of 65.85 compared to 33.12 for LEDs. However, since these evaluations used effectiveness and cost values from deployments in Florida, the actual performance and costs of these countermeasures could differ when actually deployed at Idaho exit ramps.

The modeling and optimization results discussed in this chapter provide ITD with valuable knowledge which they can use to proactively reduce WWD on limited access exit ramps in the future. Based on these results, it is recommended to begin plans for deployment of advanced WWD countermeasures (such as the double set of RFB countermeasures like the ones used in Florida or effective WWD countermeasures used in neighboring states to Idaho) at the identified high-risk locations as soon as possible. I-90 EB at Northwest Blvd. and I-90 WB at State Road 41 are the two locations where these countermeasures are most needed, but it is recommended to consider countermeasure deployment at as many of the optimal 81 exit ramps as possible based on ITD's available resources. ITD can use the selection order list provided in this document to determine phased deployments of countermeasures until they are implemented at these 81 exit ramps or more. It is also recommended to update the UCF developed WWD hotspots model and lone wolf optimization algorithm in the future (every two years or so) once advanced WWD countermeasures have been deployed and studied in Idaho. This way, the results will better reflect the performance of these countermeasures on Idaho limited access roadways. Improved data collection efforts (such as the collection of additional non-crash WWD event data throughout the state) could also help make the WWD hotspots model more accurate and representative of real-world WWCR. By following these recommendations, ITD can best reduce WWD and improve traffic operations and safety on their limited access roadways.

6. Summary and Conclusions

In this project, Professor Al-Deek and his UCF research team thoroughly analyzed and investigated WWD on Idaho limited access facilities to identify common trends and characteristics of WWD events, significant factors that influence WWC frequency, high-risk locations for priority countermeasure deployment, and recommendations for improved WWD data collection in the future. The comprehensive literature review showed the importance of studying both WWC and non-crash WWD event data to fully understand the extent of WWD. In particular, the innovative WWCR modeling and optimization approach developed by Professor Al-Deek and his UCF research team was very successful in helping Florida agencies understand and combat WWD. Therefore, this approach was adapted and applied to Idaho limited access facilities in this project. WWD countermeasure deployments throughout the US were also reviewed so ITD can make informed decisions regarding the use of these countermeasures at Idaho exit ramps.

Extensive data collection and analysis efforts were made by the UCF research team to thoroughly understand WWD in Idaho. Various roadway data (interchange designs, AADT values, exit locations, microscopic exit and entrance ramp design characteristics, and existing WW signage and pavement marking countermeasures) were collected for 341 exits on six Idaho limited access roadways (with each roadway direction considered separately). Some important insights from these roadway data were that many exit ramps did not have external lighting (which could make it hard for drivers to see they are going WW at nighttime), many crossing streets did not have medians to make it harder for drivers to turn left onto the exit ramp, and there was limited WWD-related signage on crossing streets.

WWC and non-crash WWD data (ISP citations and WWD dispatch reports) were also collected and analyzed. Multiple queries had to be made in the Idaho crash database to obtain potential WWCs due to inconsistencies in reporting. Yearly WWC counts and rates per million people and million licensed drivers have increased since 2019, possibly due to Idaho's large population growth in recent years. Compared to Florida, Idaho's WWCs rates are much higher, illustrating the need for WWD treatments. I-84 and I-90 experienced the most WWCs, with I-184, I-90, and US 20 having the highest WWC rates per mile. Over 25% of WWCs involved a fatality, with 10% of the people involved in these crashes experiencing fatal injuries. Unknown origin WWCs were common on I-84 and I-15 (suggesting that WWD detection devices would be useful on these roadways) while mainline and construction crossover WWCs were common on I-84 and US 20 (suggesting that mainline treatments are needed on these roadways). Most exit ramp and unknown origin WWCs occurred at night while most mainline and construction crossover WWCs occurred in the afternoon and evening hours (with icy roads being a common cause). WWD citations were issued for three different Idaho statutes and did not contain latitude or longitude coordinates. These citation counts have not increased like WWC counts in recent years, so increased law enforcement presence could be one way to reduce WWCs, especially on I-90 and during nighttime hours. Limited WWD ISP dispatch reports were available, so meaningful conclusions could not be made. However, these reports are important and should be collected for all Idaho limited access roadways.

Using the collected roadway and WWD event data, a WWD hotspots model was developed. This model predicted the number of WWCs on 6-exit roadway segments over five years. The final model showed that segments with WWD citations, SD interchanges, higher crossing street AADT, more exit ramps with right angles at the crossing street, and located in rural areas were predicted to have more WWCs. Segments with OD interchanges, grass medians on the crossing street, exits with entrance ramps not located adjacent to or across from the exit ramp, and more exit ramps merging directly onto the crossing street were predicted to have less WWCs. These findings can help ITD make design improvements to reduce WWD at existing or future exits. From this model, 36 WWD hotspot segments containing 85 exit ramps were identified, with most of these hotspots on I-84.

The WWCR reduction lone wolf optimization algorithm was then used to identify specific exits with high WWCR. WWCs and WWD citations with unknown origins were distributed to the nearest exits based on the distances between these exits and the WWD event locations. Annual WWCR values were then calculated for each Idaho limited access exit. Compared to deploying WWD countermeasures at the 85 hotspot exit ramps, countermeasure deployments at the 85 exit ramps selected by the optimization algorithm would provide 60% more potential WWCR reduction and allow ITD to improve their resource utilization by 43.5%. This improved resource utilization was due to the algorithm selecting 37 lone wolf exit ramps not in the identified hotspots. The algorithm also showed that deploying countermeasures at 81 exit ramps would be the most optimal approach. To estimate the potential benefits of ITS WWD countermeasure deployments, RFB and LED countermeasures previously deployed in Florida were evaluated for Idaho exit ramps. The average cost of a WWC in Idaho was slightly more than $4.7 million, resulting in benefit-cost ratios of 65.85 for double sets of RFBs and 33.12 for single sets of LEDs at the 81 optimal exit ramps.

Overall, this project showed that WWD is a growing problem in Idaho and could become a major issue if left unchecked. Based on the findings from this project, Professor Al-Deek and his UCF research team have recommendations for ITD, as listed below. By following these recommendations, ITD can efficiently and effectively combat WWD on their limited access roadways in the future to improve traffic operations, save lives, and make travel safer and more convenient for Idaho motorists.

- Prioritize deployment of WWD countermeasures using the lone wolf optimization algorithm results at the first 79 exits (containing 81 exit ramps) listed in Table 5.7, as these were the optimal exits identified by the WWCR reduction lone wolf optimization algorithm based on percent gain. I-90 EB Exit 11 at Northwest Blvd., I-90 WB Exit 7 at State Road 41, and I-84 WB Exit 168 at Golf Course Rd. are of highest priority as the two I-90 exits had very high WWCR values and the I-84 exit was the origin point for many WWD events. If advanced ITS WWD countermeasure systems are deployed, it is recommended to use at least two sets of signs (four total signs) per exit ramp rather than only one set of signs (two total signs). This recommendation is based on the results of the conducted benefit-cost evaluations where using a double set of RFBs per ramp was expected to be more effective than using a single set of LEDs per ramp. It is also recommended to deploy RFB countermeasures as they were preferred over LED countermeasures by more than 70% of surveyed law enforcement officers, transportation

officials, and drivers in Florida due to the extra set of signs and improved flashing (Kayes et al., 2018). The actual results of countermeasure deployments in Idaho might differ since Florida data and costs were used for these evaluations. Therefore, it is recommended to conduct an evaluation study of advanced ITS WWD countermeasure deployments in Idaho. It is also recommended to consider WWD detection devices on I-84 and I-15 exit ramps due to the high number of unknown origin WWCs on these roadways.

- Reach out to nearby states who have implemented WWD detection and countermeasure systems (Oregon, Nevada, Utah, and Arizona) to find out more details about these deployments and their effectiveness as needed. These findings can help ITD select WWD countermeasures for deployment at ITD exit ramps.

- Evaluate lighting at exit and entrance ramps to help drivers distinguish between them at nighttime. If lighting is found to be insufficient or missing, consider enhancing or adding lighting. It is recommended to start these evaluations at the more than 40% of exit ramp terminals which were not found to have exit ramp lighting in this project.

- Consider installing additional crossing street signage (such as “No Right Turn” or “No Left Turn” signs) near exit ramp terminals to reduce the potential for confused drivers turning WW onto the exit ramp. These signs were not present for 84% of exit ramps. Also recommend checking the orientation and nighttime visibility of signs and pavement markings. These checks are important to ensure that the signs can be seen by potential WW drivers, especially at nighttime when most WWD occurs.

- Consider treatments on crossing streets to reduce the potential of vehicles making left turns onto the exit ramp. These treatments could include medians, median extensions, striping, delineators, or other similar measures. Approximately 60% of crossing streets did not have any median at the exit ramp terminal.

- Increase law enforcement presence at areas with high WWCR to potentially reduce WWCs. WWD citation counts have not increased the same as WWC counts, suggesting a need for more law enforcement to apprehend WW drivers before they cause a crash. I-90 and nighttime hours should be the priority focus areas for these increases.

- Work on standardizing the reporting of WWCs and issuing of WWD citations. Approximately 45% of the collected WWCs were not identified as having a contributing circumstance of “Wrong Side or Wrong Way”. Training ISP officers to report all types of WWCs (including mainline crossovers) consistently will make it easier to collect and analyze WWC data in the future. Similarly, WWD citations were issued for three different Idaho statutes (mainly 49-636), so it is recommended to train ISP officers to issue WWD citations for the most appropriate statute.

- Collect additional information on non-crash WWD events. The WWD citation data provided in this project did not contain latitude and longitude coordinates, which made it hard to accurately locate some of these citations. Collecting these coordinates in the future will make it

easier to locate these events. The ISP WWD dispatch reports provided in this project were only for a small stretch of I-90 in District 1. It is recommended to increase the collection of these reports to all ITD districts and limited access roadways, as these reports can be a valuable source of non-crash WWD data.

- Update the UCF invented WWD hotspots model and WWCR reduction lone wolf optimization algorithm every two or three years with the most recent ITD WWD event data. These updates will ensure that the results are current based on any data collection improvements (such as the collection of additional non-crash data) and changes to WWD activity.

- Conduct additional research efforts on mainline and construction crossover WWCs to better understand their characteristics and potential treatments (such as median barriers and alternative construction practices). These events were discussed briefly in this report, but were not studied in detail since the main focus of this project was on exit ramp WWD. Due to the frequency of mainline and construction crossover WWCs (especially on I-84 and US 20), it is recommended to investigate these events in more detail as part of a future research project.

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