VTRC
Virginia Transportation Research Council

We Bring Innovation to Transportation

A Systemic Evaluation of Wrong Way Driving Crashes and Countermeasures

https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/25-R10.pdf

HYUN W. CHO, Ph.D., P.E.
Research Scientist

ERIN M. ROBARTES, Ph.D.
Research Scientist

BENJAMIN H. COTTRELL, JR., P.E.
Principal Research Scientist

Final Report VTRC 25-R10

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginia.gov

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 25-R10	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: A Systemic Evaluation of Wrong Way Driving Crashes and Countermeasures on Virginia Roads		5. Report Date: January 2025 6. Performing Organization Code:
7. Author(s): Hyun W. Cho, Ph.D., P.E.; Erin Robartes, Ph.D.; Benjamin Cottrell Jr., P.E.		8. Performing Organization Report No.: VTRC 25-R10
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 121990
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes: This is an SPR-B report.		

16. Abstract:

Wrong-way driving (WWD) crashes are a small percentage of all crashes but tend to be more severe. The purpose of this project was to perform a systemic evaluation of WWD incident and crash risks and identify countermeasures for Virginia's roadways. This evaluation included assessing the magnitude of WWD crashes and WWD-related 911 calls in Virginia, investigating roadway features such as interchange type that could affect offramp entries to interstate highways and selected multilane divided highways. The study developed a list of WWD countermeasures and resources and provided guidance and a plan to prioritize deployment of these countermeasures.

WWD-related crash data and 911 calls were obtained and analyzed for interstate highways in Virginia, and WWD 911 data were analyzed for selected multilane divided highways. WWD crashes on interstates in Virginia are relatively few but are more severe than other crash types. The 911 data provided a snapshot of WWD incidents that fortunately did not result in a crash in most cases. A major limitation of WWD crash and 911 data is the lack of information of the entry point for the WWD.

Guidance and a proposed plan for using WWD countermeasures were developed, with a focus on low-cost countermeasures and a potential review of select locations or corridors and three interchange types. The planning level benefit-cost ratio range for these WWD treatments was estimated to be between 4 and 23.

17. Key Words: Wrong way driving crashes, Wrong way driving 911 calls, Countermeasures	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 61	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

A SYSTEMIC EVALUATION OF WRONG-WAY DRIVING CRASHES AND COUNTERMEASURES ON VIRGINIA'S ROADS

Hyun W. Cho, Ph.D., P.E.
Research Scientist

Erin Robartes, Ph.D.
Research Scientist

Benjamin H. Cottrell Jr., P.E.
Principal Research Scientist

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Dept. of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

January 2025
VTRC 25-R10

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

Copyright 2025 by the Commonwealth of Virginia.
All rights reserved.

ABSTRACT

Wrong-way driving (WWD) crashes are a small percentage of all crashes but tend to be more severe. The objective of this project was to perform a systemic evaluation of WWD incident and crash risks and identify countermeasures for Virginia's roadways. This evaluation included assessing the magnitude of WWD crashes and WWD-related 911 calls in Virginia, investigating roadway features such as interchange type that could affect offramp entries to interstate highways and selected multilane divided highways. The study developed a list of WWD countermeasures and resources and provided guidance and a plan to prioritize deployment of these countermeasures.

WWD-related crash data and 911 calls were obtained and analyzed for interstate highways in Virginia, and WWD 911 data were analyzed for selected multilane divided highways. WWD crashes on interstates in Virginia are relatively small in number but are more severe than other crash types. The 911 data provided a snapshot of WWD incidents that fortunately did not result in a crash in most cases. A major limitation of WWD crash and 911 data is the lack of information of the entry point for the WWD.

Guidance and a proposed plan for using WWD countermeasures were developed, with a focus on low-cost countermeasures and a potential review of select locations or corridors and three interchange types. The planning level benefit-cost ratio range for these WWD treatments was estimated to be between 4 and 23.

FINAL REPORT

A SYSTEMIC EVALUATION OF WRONG-WAY DRIVING CRASHES AND COUNTERMEASURES ON VIRGINIA'S ROADS

Hyun W. Cho, Ph.D., P.E.
Research Scientist

Erin Robartes, Ph.D.
Research Scientist

Benjamin H. Cottrell Jr., P.E.
Principal Research Scientist

INTRODUCTION

Wrong-way driving (WWD) on divided highways occurs when a vehicle enters a divided roadway on the wrong side at an interchange or intersection and travels against the oncoming traffic. WWD incidents present an immediate and significant operational impact and carry a severe risk of a head-on collision that is likely to cause severe injuries and/or fatalities. In the United States, between 2010 and 2018, 2,921 fatal wrong-way crashes resulted in 3,885 deaths—an average of 430 deaths per year (Villavicencio et al., 2021).

In a preliminary review, the authors identified 22 fatalities due to head-on crashes from 2016 to 2021 on interstates in Virginia. However, the actual number of WWD crashes is higher, in part because not all WWD crashes result in head-on collisions and because this analysis was limited to interstates. While selecting fatal head-on crashes from crash databases is relatively simple, assessing and addressing WWD crashes is difficult using typical crash evaluation methods, not only because the current crash reports do not have a WWD crash code, but also because they are relatively rare events. Furthermore, previous research indicates that the number of WWD incidents is significantly greater than the number of WWD crashes because not all WWD incidents resulted in crashes. However, detecting WWD incidents is difficult without evidence from cameras or WWD warning systems. Consequently, WWD risks are difficult to measure and may be under-represented. Moreover, crash statistics would not capture WWD incidents that do not result in a crash.

Characteristics of WWD crashes (which are relatively rare compared with other crash types) give clues that the prevention and mitigation of WWD crashes may benefit from a systemic approach like the treatment of roadway departure crashes on rural roads. In a previous project (Cho et al., 2020), the research team developed a systemic safety improvement plan for two-lane rural roadway departure crashes using low-cost countermeasures. The systemic implementation of safety countermeasures will help to address the identified crashes on the entire road system, not just at specific high-crash spot locations.

The systemic safety approach is a two-pronged effort to reduce crashes and serious injuries on roadways. This approach offers a means to:

1. Identify crash types and the location-related factors that contribute to the highest number of fatal and serious injury crashes of each type from a system-wide data driven analysis.
2. Widely implement low-cost countermeasures over several locations with similar WWD characteristics and/or similar roadway features.

Systemic countermeasures typically take the form of signing, markings, tactile notifications, intersection channelization, traffic signal modifications, lighting, and/or warning devices to alert drivers. Mitigation measures for WWD events may include the use of intelligent transportation systems (ITS) to detect WWD, activate flashing lights on signs directed at the WW driver, then notify the Virginia Department of Transportation (VDOT), law enforcement, and other drivers of the WWD incident.

PURPOSE AND SCOPE

The purpose of this project was to perform a systemic evaluation of WWD incidents and crash risks and identify countermeasures for VDOT's roadways. This effort included assessing the magnitude of WWD crashes and WWD-related 911 calls in Virginia, investigating roadway features such as interchange type that could affect offramp entries to interstate highways and selected multilane divided highways. Also, the study developed a list of WWD countermeasures and resources and provided a plan to prioritize deployment of these countermeasures.

The project scope was restricted to interstate highway ramps and interchanges and selected multilane divided highways. WWD on one-way streets or undivided roads was not examined. Incidents where a driver crosses over to the wrong side of an undivided road or where a driver traverses the median to the wrong side of a divided highway are not WWD-related for the purposes of this research.

METHODS

Six tasks were performed to achieve the study purpose:

1. Review of the literature.
2. Collect and analyze WWD data.
3. Analyze statewide interstate interchanges and ramps for WWD.
4. Review of WWD on selected multilane divided highways.
5. Identify WWD countermeasures.
6. Develop guidance and a proposed plan to deploy treatments.

Review of the Literature

A literature review was conducted to identify analysis methods and countermeasures related to WWD. Relevant search engines, such as the Transportation Research International Documentation (TRID) and Transport database, were used. The VTRC library also assisted in the literature review search.

Collect and Analyze WWD Data

This task consisted of WWD incident and crash collection and analysis of all interstate highways and selected multilane divided highways. WWD incident and crash data were gathered from January 2016 to July 2022 and from January 2016 to November 2022, respectively. Selected multilane divided highways were chosen in conjunction with the district staff.

Based on the definition of WWD in the literature, crashes where the driver was described as crossing the median were not classified as WW crashes but as road departure crashes.

WWD Crash Data

The police crash report form (FR 300) for the Commonwealth of Virginia Department of Motor Vehicles, has an option for “Wrong Side of Road – Not Overtaking” under driver action type. However, not all “Wrong Side of Road – Not Overtaking” crashes are categorized as WWD crashes, and vice versa. As a result, WWD crashes could not be identified solely from FR 300 crash report categories. This task investigated how to extract WWD crashes from VDOT’s Roadway Network System (RNS) crash database. The detailed steps used to extract the WWD data are as follows:

1. From the RNS crash database, extract all crashes that occurred from January 2016 to July 31, 2022, on Limited Access Freeways (full access control; Access only at interchanges, interstate, etc.).
2. In the extracted dataset, select cases from the crash description column that include either (1) “wrong,” (2) both “east” and “west,” or (3) both “north” and “south.”
3. Remove duplicates and make a union dataset from the cases identified in step 2.
4. Manually review crash descriptions from the union dataset. Identify WWD crashes.

WWD 911 Call Data

The researchers requested 911 call data that had been flagged as relating to WWD from the Virginia State Police (VSP). VSP staff provided more than 6 years of WWD related 911 call data between January 2016 and July 2022 for a total of 7,586 calls. The 911 data includes an identifier variable, VSP division and area codes, location, start date and time, end date and time, and the time the incident was open. The VSP area codes correlate to a county or city in Virginia. The format of the 911 location data is not uniform, and many entries are lacking enough detail to infer an approximate location (see Table 1). Particularly on non-interstate roads, location data is difficult to parse without manual interpretation.

Table 1. Sample of 911 Call Data

Incident Number	Division	Area	Location	Entry Date and Time	Close Date and Time	Total Time Incident Open (Min)
DIV118058397	1	3	EB RT 60 NEAR BROTHERS PIZZA,063	2018-05-25 21:05:11	2018-05-25 21:09:14	4
DIV116095882	1	3	EB 64 TO EXIT 211 RT 106,063	2016-07-17 12:59:18	2016-07-17 13:09:53	10
DIV116096443	1	7	NB 95 AT 35MM,074	2016-07-18 15:14:50	2016-07-18 15:39:22	25
DIV116096612	1	4	WB 64 AT 152MM,037	2016-07-18 19:43:00	2016-07-18 20:01:47	18
DIV621109124	6	41	NB 220, 033	2021-11-06 22:00:56	2021-11-06 22:19:49	19
DIV116098790	1	6	NB 295 SO VEB 18MM,020	2016-07-23 10:03:22	2016-07-23 10:09:44	6
DIV116099150	1	6	EB 360 AT BUDDY'S RESTURANT,004	2016-07-24 05:26:22	2016-07-24 05:29:38	3
DIV116099698	1	2	OCCUPACIA RD/TIDEWATER TR, 028	2016-07-25 14:45:17	2016-07-25 15:42:32	57

The data were cleaned thoroughly to decode whether the location variable indicated a mile marker along an interstate, an intersection of two roads, an address, a location along one road, or some other description. Many calls contained insufficient information, such as a single road name with no mile marker, direction, or landmark. The data was geolocated, using ArcGIS to create a spatial representation of the 911 data and locate hotspots. ArcGIS address locator tools were used to determine an approximate latitude and longitude of a 911 call. Additionally, calls with a clear mile marker and freeway name were matched to maps of mile marker coordinates.

The NCHRP *Wrong-Way Driving Solutions Handbook* Screening Method One was followed to develop a hotspot map of 911 calls statewide, using ArcGIS kernel density estimates through heat map symbology tools.

VaTraffic Data

VaTraffic data are focused on incident management and include some WWD incident data. WWD incident data were obtained for the period from January 2015 to March 11, 2022. WWD incidents were identified through a search of free text notes of incident events for wrong way and wrong-way driver. A total of 578 records were identified. A manual review of these records identified 68 confirmed WWD incidents, including 11 fatalities. After comparing these findings with the crash and 911 data, the project team determined that VaTraffic data were a secondary or less robust source of WWD data. Therefore, no further analysis of the data was conducted.

Interchange Data

Interchange (IC) data were from a VDOT dataset in a Geographic Information System (GIS) format that included a shapefile and geodatabase. The team converted the GIS file of IC influence areas to a spreadsheet table; its columns included a unique ID, IC type, and location (latitude, longitude, route name, ramp name, minimum and maximum mile points).

Analyze Statewide Interstate Highway Interchanges and Ramps for WWD

The following describes the process of combining the crash data with interchange data to estimate WWD entry points. A similar process was followed, using the 911 call data and interchange data.

Combine WWD Crash Dataset and IC Dataset

The purpose of this task is to find IC locations and types that may be entry points for WWD by combining two prepared datasets: WWD crashes and IC influence areas. While the WWD crash dataset is point (node) data, the IC influence area dataset is line (link) data of freeway mainlines that are connected to the interchanges.

To match the two datasets, researchers completed the following steps to transform IC dataset into point data:

1. Assuming WWD vehicles enter the mainline from offramps, only “offramp” interchanges were selected in the IC dataset.
2. For each offramp influence area, the maximum mile point for eastbound (EB) and northbound (NB) ramps and the minimum mile point for westbound (WB) and southbound (SB) ramps were identified and stored. This step aimed to find the mile point of the offramp gore point.
3. Route name and direction variables were reviewed for consistency.
4. For WWD crashes that occurred on the mainline, is the project team assumed that the WWD vehicle entered downstream of the crash location. WWD crash mile points were matched to the nearest downstream offramp, using the mile points determined in step two. The Excel “Xlookup” function was used to identify the mile points.
5. WWD crashes, which occurred at an offramp or where the crash description specified the WW driver entry point, were matched directly to that IC offramp.

To match every WWD crash to the exact or nearest downstream IC offramp, researchers calculated a WWD score for each IC offramp, using the following process, adapted from Zhou et al. (2015).

6. Assign weights of WWD crashes to matched offramps. For known entry point crashes or crashes which occurred onramps, the matched ramp was given a score of 1.0. For unknown entry point crashes, the nearest possible entry point was given a weighted score of 0.75, and the second nearest possible entry point was given a weighted score of 0.25 (see Figure 1).
7. Scores assigned to each IC offramp were summed to determine the total WWD score for each offramp.

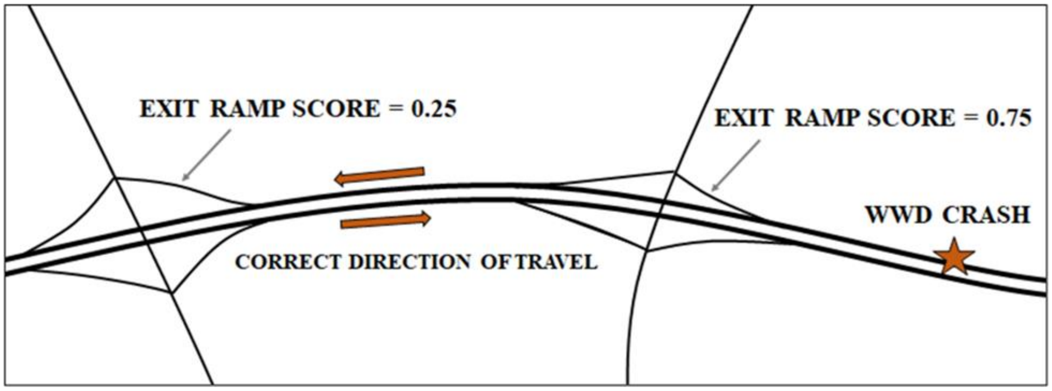


Figure 1. Visualization of Wrong-Way Driving Score Methodology for Interchange Offramps

After combining WWD crash and interchange data and assigning a WWD score for each offramp, the offramps were ranked based on the WWD score. The top 50 offramps were manually reviewed to identify patterns that may contribute to WWD. Finally, interchanges were reviewed by type and a ranked list of interchange types was developed based on the WWD scores.

Review of WWD on Select Multilane Divided Highways

District Traffic Engineers (DTEs) Survey

All VDOT DTEs were emailed a survey asking for (1) locations of concern for WWD for limited access roads and multilane divided road sections with a speed limit of 55 mph or greater, (2) any studies conducted on WWD, (3) any challenges, issues, or concerns with WWD and (4) other comments related to WWD.

911 Data Applied to Survey Results

Each of the locations identified by the districts were examined using 911 data. The 911 data was chosen rather than police reported crash data for this effort because WWD crashes in Virginia primarily occur on interstates, whereas the 911 data, though less accurate than crash data in terms of location, has much greater coverage outside of interstates. For each location identified, all 911 calls in the relevant county or city on the specified roads were retrieved from the 911 dataset by filtering the dataset by county or city code and searching for road names. Then, each 911 call was manually geolocated using the location description. From this data, any WWD hot spots in the region could be visually identified. A high-level review of the hotspots was conducted primarily using Google Maps.

Identify WWD Countermeasures

This task identified signing, marking, and channelizing countermeasures for WWD in general. Advanced safety features such as WWD detection and warning systems were also reviewed. This included a description of the countermeasures and cost estimates. The approach was to review countermeasures of signs and markings and other countermeasures and geometric features with a focus on channelization to deter WWD. Education strategies were briefly reviewed.

Develop Guidance and Proposed Plan to Deploy Treatments

Using the information gathered in the previous tasks, guidance and a proposed plan for reviewing WWD concerns and installing WWD countermeasures were developed. The guidance included WWD countermeasures and resources to use for implementing plans to address WWD. The proposed plan includes action that may be taken to address WWD.

RESULTS

Literature Review

Characteristics of WWD Crashes

The literature shows that many WWD crashes share similar characteristics. WWD crashes frequently occur at night. Zhou et al. (2015) found that 51.2% of 217 confirmed WWD crashes in Illinois occurred between midnight and 5 a.m., 80% during nighttime hours and frequently on weekends. Pour-Rouholamin et al. (2016) found that almost 80% of WWD crashes in Alabama happened during the evening and night, and two other studies found that most WWD crashes happened when it was dark (Lathrop et al., 2010; Simpson and Bruggeman, 2015)

The WW driver is often under the influence of drugs or alcohol. Data from several studies showed that almost one-half of all drivers were under the influence of alcohol (Pour-Rouholamin et al., 2016; Zhou et al., 2015), and Lathrop et al. (2010) found that 63% of WW drivers had a blood-alcohol content over the legal limit.

Research also shows that WW drivers are more frequently male than female, with studies finding 67%–77% of WW drivers were male (Lathrop et al., 2010; Pour-Rouholamin et al., 2016; Zhou et al., 2015). Older drivers are overrepresented in the WW driver pool in some studies (Pour-Rouholamin et al., 2016; Zhou et al., 2015) but not in others (Lathrop et al., 2010). Pour-Rouholamin et al. (2016) found that 26% of WW drivers were older than 65; the same age group was responsible for 7.9% of other crash types.

WWD crashes are a small portion of overall crashes; however, they are much more likely to result in fatal or severe injury crashes than other crash types (Simpson and Bruggeman, 2015; Zhou et al., 2015). Simpson and Bruggeman reviewed 245 crashes in Arizona from 2004 to 2014 and found that fatalities occurred in 25% of WWD crashes and in 1% of other crash types.

Wrong-Way Driving Solutions Handbook

NCHRP Research Report 1050, *Wrong-Way Driving Solutions Handbook* (Zhou et al., 2023), hereafter referred to as the *NCHRP WWD Handbook* or *the handbook*, was developed to provide solutions to reduce the risk of WWD crashes using data collection methods and network screening for WWD. The handbook also provides descriptions of countermeasures, including traditional traffic control devices, advanced technologies, geometric design elements, and education and enforcement strategies. The handbook is a comprehensive resource that includes many photos and illustrations of WWD countermeasures, state-of-the-art literature reviews, and presents best practices for addressing and reducing WWD incidents and crashes on freeways and divided highways. Some of the modeling literature that contributed to the development of the *NCHRP WWD Handbook* is described as follows.

WWD Event Risk Factors and Screening Methods

A body of literature exists on determining characteristics that impact the likelihood of a WWD event, determining risk factors for WWD, and identifying high risk interchanges or segments in a network. Work completed in Florida has contributed to the development of methods to optimize WWD countermeasure implementation. Rogers et al. (2015) developed Network Screening Method One in the *NCHRP WWD Handbook* (Zhou et al., 2023), which consists of developing heat maps of combined WWD 911 calls, citations, and crashes after removing overlapping events. This work also developed Poisson regression models of Florida interstate crashes using 911 calls and citations as independent variables (Rogers et al., 2015). Building upon this work, Rogers et al. (2016) developed more elaborate models of WWD crashes in Florida, incorporating information such as annual average daily traffic (AADT) and nearby interchange frequency (major directional interchanges and two- to three-leg directionals) in addition to citations and 911 calls to determine WWD crash risk on routes or segments. These models make up “Network Screening Method 3” in the *NCHRP WWD Handbook* (Zhou et al., 2023).

Further work used WWD event duration to determine WWD hotspots (Sandt et al., 2017) and developed an ITS countermeasure optimization approach on Florida Turnpike exit ramps (Sandt, and Al-Deek, 2020). Recent work has incorporated even more Florida freeway exit ramp WWD predictive variables such as interchange type, intersection angle, tollbooth presence, channelizing island, rural/urban designation, freeway-to-freeway designation, exit ramp lanes, exit ramp AADT, crossroad AADT, and main line AADT (Kayes et al., 2019). Most recently, Sandt et al. (2021) broadly applied a newly developed WWD crash risk segment model and countermeasure optimization to determine optimal locations for WWD ITS countermeasures on Florida limited access roads. This work also made an estimation of how far WW drivers typically travel in the wrong direction before stopping or crashing based on available WWD events (911 calls, citations, and crashes) with multiple data points. The authors estimated that about 58% of WWD drivers traveled less than one exit, and 95% traveled less than 3 exits.

Additional research resulted in methods to determine characteristics contributing to WWD crashes, WWD risk at exit ramps, and models for specific high-risk interchange types such as partial cloverleaf interchanges and common diamond interchanges. Zhou et al. (2015) found that WWD crashes frequently occurred on weekends between 12 a.m. and 5 a.m., were located in urban areas, involved passenger cars, and involved drivers under the influence of drugs and alcohol. Compressed diamond interchanges, single point diamond interchanges, partial cloverleaf interchanges, and freeway feeders had the highest WWD crash rates (Zhou et al., 2015). The methodology in this study is also available in the *NCHRP WWD Handbook* as

"Network Screening Method Two" (Zhou et al., 2023). Jalayer et al. (2017) found that driver age, driver condition, road surface condition, and lighting condition significantly contributed to WWD crashes. Later work with crash data produced "Network Screening Methods Five and Six" discussed in the *NCHRP WWD Handbook* (Zhou et al., 2023). These studies developed models to determine the risk of WWD at exit ramp terminals for partial cloverleaf interchanges (Network Screening Method Five [Zhou et al., 2023]), using data from Alabama and Georgia (Atiquzzaman and Zhou, 2022) and the risk of WWD at diamond interchange ramp terminals (Network Screening Method Six [Zhou et al., 2023]), using Alabama and Illinois freeway crash data (Atiquzzaman and Zhou, 2018). Partial cloverleaf interchanges have been shown to be susceptible to WWD, and diamond interchanges are very common, which is why these two interchange types were targeted in the *NCHRP WWD Handbook*.

Based on the readily available data in Virginia (crash data, 911 data, event data, and interchange data) Network Screening Methods One and Two were used in this analysis to rank interchanges and interchange types.

Collect and Analyze WWD Data

WWD Crash Data

This section summarizes descriptive statistics of collected WWD crash data. A total of 121,675 crashes were recorded on limited access highways or freeways in Virginia from January 2016 to July 2022 in the initial dataset. Among the crash description were these key words: 399 crashes include "wrong," 445 crashes have both "east" and "west," and 640 crashes show both "north" and "south" in their crash descriptions. Among those 1,484 cases, 57 were duplicates, and the remaining 1,427 cases were prepared for further investigation.

The research team thoroughly scrutinized crash descriptions of the selected cases. Results showed that most cases containing those specific key words were not WWD crashes. For most WWD crashes, the first sentence described a vehicle traveling in the wrong direction. On the other hand, non-WWD crash descriptions typically describe other driving actions such as spinning or crossing the median. Tables 2 and 3 show crash descriptions of confirmed WWD crashes and confirmed non-WWD crashes containing the key words.

Table 2. Examples of Wrong-Way Driving Crashes Based on Key Words

Key Word	Crash Description
Wrong	Vehicle #1 was traveling in the **wrong** direction. Vehicle #1 swerved right to avoid coming traffic striking the jersey wall. Vehicle #1 lost control crossing all lanes, striking the guardrail.
East and West	Vehicle #1 was traveling **east** in the **westbound** lane. Vehicle #1 struck vehicle #2 head on spinning vehicle #2, vehicle #2 then struck jersey wall.
North and South	Vehicle #1 traveling **southbound** in the **northbound** lanes struck vehicle #2 in the roadway.

Table 3. Examples of Non-Wrong-Way Driving Crashes Based on Key Words

Key Word	Crash Description
Wrong	Vehicle #1 failed to maintain proper control and spun out facing the **wrong** direction. Vehicle #1 struck vehicle #2 head on.
East and West	Vehicle #1 was traveling **eastbound** on interstate 64 when vehicle #1 lost control, running off the road to the left and crossing the median into the **westbound** interstate 64 lanes.
North and South	Vehicle #1 went off road left and struck the jersey wall. Vehicle #1 reentered into the left lane facing **northbound** in **southbound** lane with no headlights available.

From the investigation, 183 cases (12.8%) were marked as WWD crashes. Among those, 157 cases (85.8% of WWD crashes) were interstate crashes, while 16 cases (14.2%) occurred on non-interstate limited access freeway (LAF) facilities. In VDOT's roadway inventory, there are 11,720 miles of LAF roadways recorded. Among those, 18.0% (2,104 miles) are interstate roadways, while 82.0% (9,616 miles) are non-interstate LAF facilities. Considering the small number on non-interstate LAF WWD crashes, the research team focused on interstate WWD crashes only.

From further investigation of the VDOT roadway inventory, the researchers found that some interstate ramps are not classified as LAF, and crashes at those ramps were not included in the initial data collection. The team added those missing interstate ramp WWD crashes to the dataset. Also, it was found that some crash descriptions denote directions as acronyms (NB, SB, EB, WB), descriptions that step 2 of the selection process did not capture. The team also added those cases to the dataset. During this research effort, seven additional WWD crashes occurred on interstates between August 1, 2022, and November 30, 2022; these crashes were added to the dataset. The final dataset included 193 WWD crashes that occurred from January 1, 2016, through November 30, 2022.

For the 193 WWD crashes on interstates, 24 (12.4%) crashes occurred on an offramp, whereas the remaining 169 crashes were located on the mainline. Among those 169 cases, 8 crash descriptions included the WWD vehicle's entry point. Below are some examples:

- Vehicle 1 started driving the wrong way on the I-264W exit ramp near '**Victory Blvd**.'
- Vehicle #1 was travelling from '**Seminary Road**' onto I-395S the wrong way.
- Vehicle #1 was traveling north from '**MM245**' southbound offramp.

Figure 2 shows WWD crashes by collision type. Noteworthy is that while "Head On" is the dominant collision type, other collision types are present for interstate WWD crashes. The majority (51%) of WWD crashes were "Head On," and 14.0% were "Sideswipe-Opposite direction."

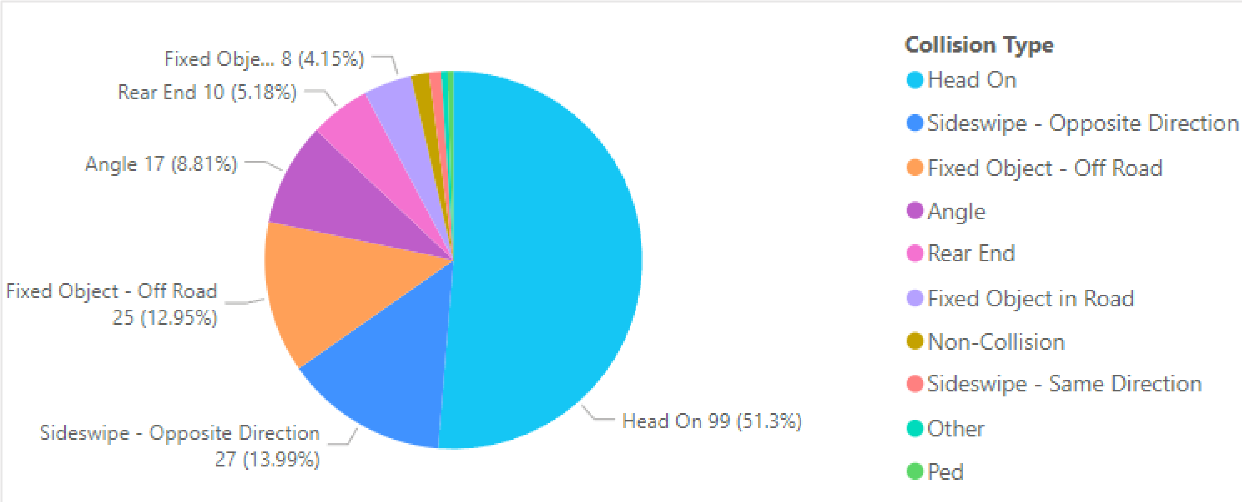


Figure 2. Summary of Interstates' Wrong-Way Driving Crashes by Collision Type

Table 4 provides injury severity statistics for interstate WWD crashes compared with all crashes on LAFs during the study design period. This table highlights the severity of WWD crashes; 16.1% of WWD crashes resulted in a fatality, and 23.3% resulted in a severe injury. For all crashes on LAFs during the study period, 0.6% were fatal crashes and 4% were severe injury crashes.

Table 4. Summary of Interstate WWD Crashes and All Crashes on LAF by Severity

Severity	Number of Interstate WWD Crashes	%	Number of Crashes on LAF	%
Fatal (K)	31	16.1	689	0.6
Serious Injury (A)	45	23.3	4,869	4.0
Minor/Possible Injury (B)	50	25.9	23,182	19.1
No Apparent Injury (C)	5	2.6	3,592	3.0
No Injury (O)	62	32.1	89,305	73.4
Total	193	100	121,637	100

LAF = limited access freeways; WWD = wrong-way driving.

To differentiate the possible WW driver from the victim, driver action types of identified drivers were further investigated. Results were that about 46% of drivers' action type was the "No Improper Action" type. This study assumed those drivers to be right way drivers. Further analysis excluded the presumed right way drivers to investigate the actions of the WW drivers. As seen in Figure 3, with the possible victim drivers excluded, the majority of WW drivers' action type was "Wrong Side of Road – Not Overtaking." However, as previously mentioned, not all WWD driver's action types were marked as "Wrong Side of Road"; some drivers' action types were "Avoiding Other Vehicle," and "Fail to Maintain Proper Control." There is a possibility that those types are right-way drivers' actions.

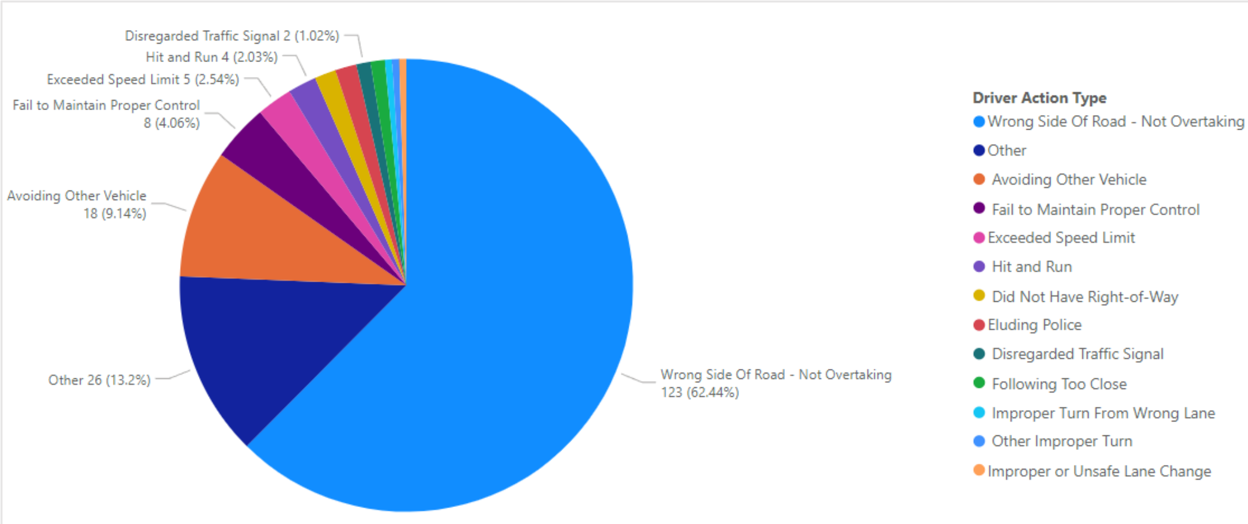
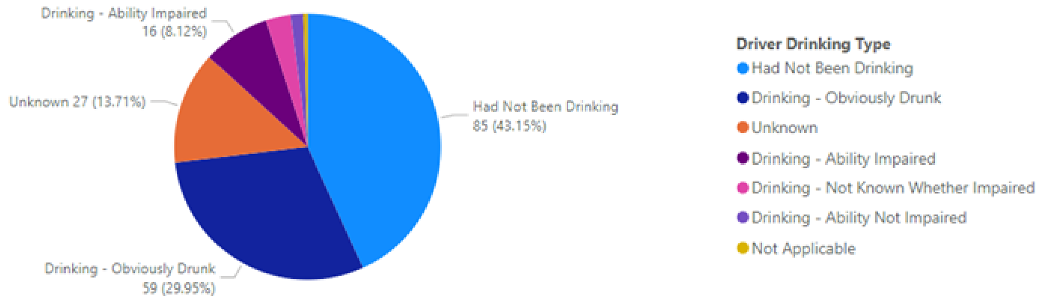


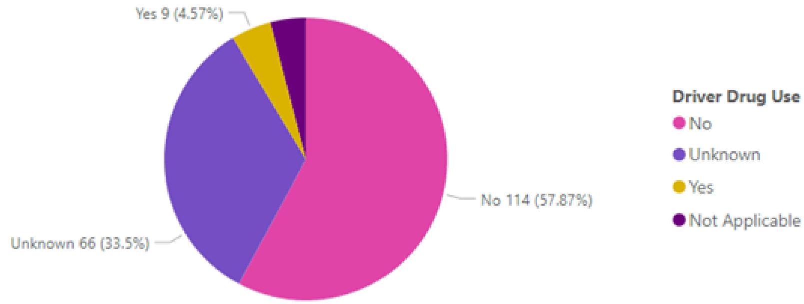
Figure 3. Summary of Interstates' Wrong-Way Driving Driver Action Type for Possible Wrong-Way Driving Crash Offender

Figure 4 shows (a) drinking type, (b) drug use, (c) condition type, and (d) age group for the presumed WW drivers. About 40% of drivers had been drinking, and about 5% had used drugs. About 5% of drivers were under the influence of alcohol for all crashes in Virginia, so the rate of drivers drinking is about eight times higher for WWD crashes than for other crash types. The percentage of WW senior age drivers was recorded as about 17.8%, which is higher than the historic average of 11.4% across all crash types.

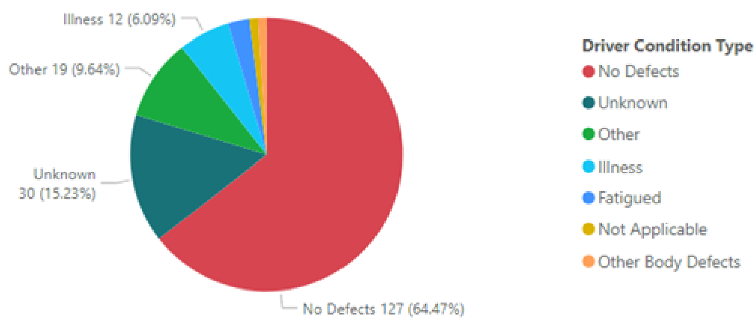
Figure 5 shows light condition types at the time of WWD crashes. Most crashes (73%) occurred at night with a lighting condition of "Darkness – Road Not Lighted" (37.8%) or "Darkness – Road Lighted" (35.2%). About two-thirds of WWD crashes occurred between 9 p.m. and 5 a.m. For all interstate crashes in Virginia, about 30% occurred at night with a lighting condition of darkness, whether lighted or not lighted.



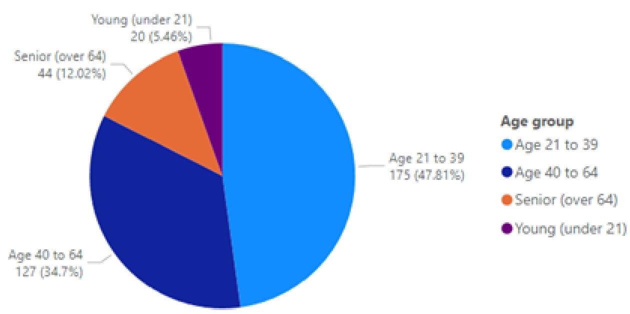
(a) Driver Drinking Type



(b) Driver Drug Use



(c) Driver Condition Type



(d) Age group

Figure 4. Summary of Possible Wrong-Way Driver Characteristics by (a) Drinking Type, (b) Drug Use, (c) Conditions, and (d) Age Group

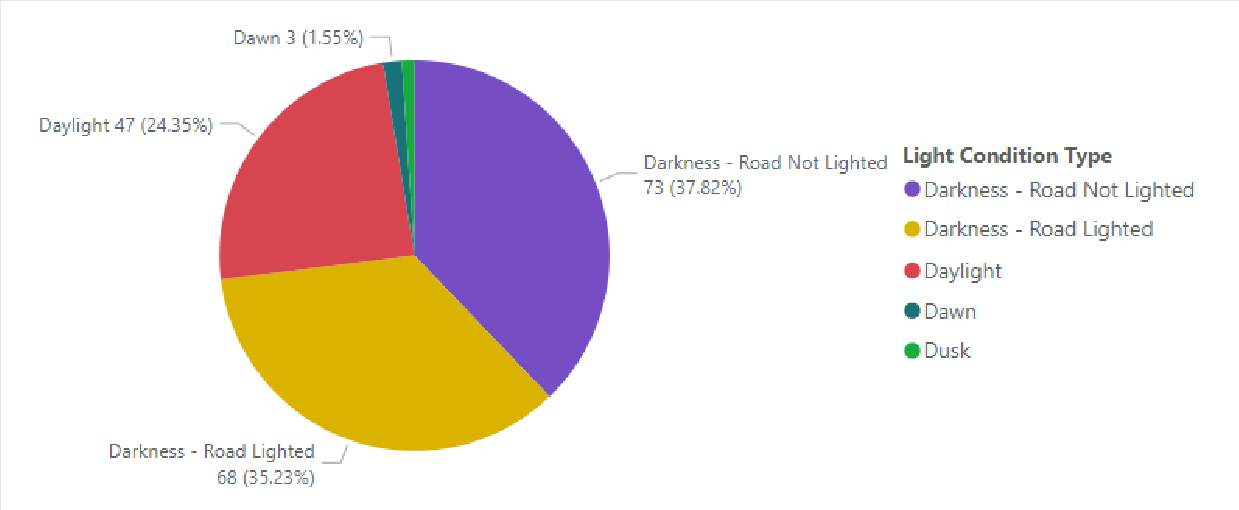


Figure 5. Summary of Interstates' Wrong-Way Driving Crashes by Light Condition

Based on the lighting condition results, it appears that lighting, or the lack thereof, plays a role in WWD crashes. Considering that the actual location of crashes may be far from the drivers' entry point onto the interstate, studying the light condition of access ramps would be more meaningful than just looking at lighting where a crash occurred. VDOT has a Highway Maintenance Management System (HMMS) that manages assets such as signals, signs, lighting, and cameras. The team explored the system to obtain the lighting condition of interstate ramps. As seen in Figure 6, the system has an inventory of lights and their locations. Figures 6 (a) and (b) show that urban areas have more lights (yellow circles) than rural areas (see Figures 6 (c) and (d)). Although HMMS is maintained by VDOT, it is not integrated with VDOT's in-house-developed linear referencing system. Therefore, combining lighting data with crash data is difficult. Also, although HMMS indicates whether VDOT lighting is present, the system has no magnitude information (wattage/lumens output), and it is limited to VDOT-owned luminaires, not locally or utility-maintained streetlights as is common on interstates. Consequently, HMMS information does not provide a complete view of the light condition. Therefore, the team decided not to use HMMS and not to include light condition of interstate offramps in this study.

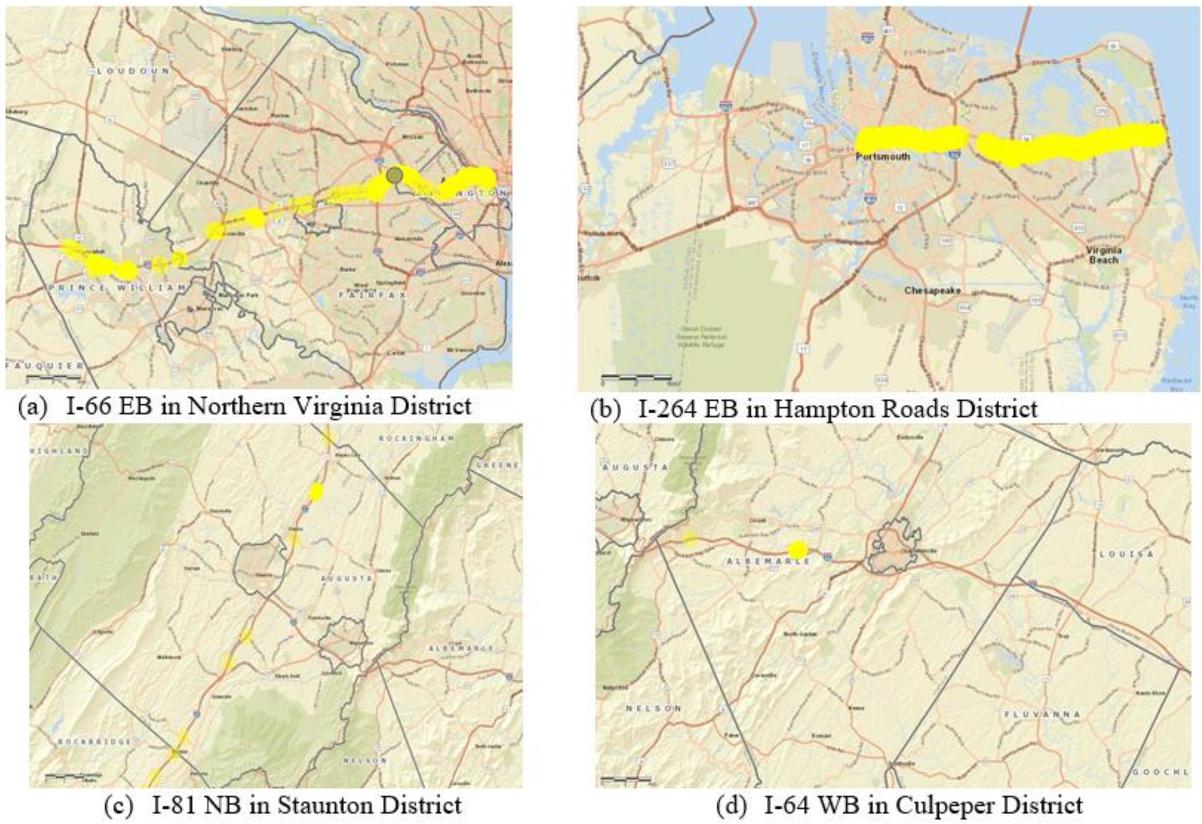


Figure 6. Screenshots of VDOT Highway Maintenance Management System’s Lighting Inventory Maps for (a) I-66 Eastbound in Northern Virginia District, (b) I-264 Eastbound in Hampton Roads District, (c) I-81 Northbound in Staunton District, and (d) I-64 Westbound in Culpeper District

Analyze Statewide Interstate Highway Interchanges and Ramps for WWD

WWD Crash Matching to Exit Ramp of Interchange

This section explains the estimated results of the magnitude of WWD risk for each IC offramp. Table 5 shows an inventory of VDOT interchange types. More than one-half of the ramps are diamond and cloverleaf interchanges. When the eight partial cloverleaf types are combined, they represent 16.3% of ramps. Figure 7 shows partial cloverleaf interchange types, where the horizontal red lines represent the crossroad, and the vertical blue lines represent the freeway.

Table 5. Inventory of VDOT Interstate Interchange Types

Interchange Type	Number of Ramps	Percentage of Ramps
Diamond	301	31.29
Cloverleaf	202	21.00
System	87	9.04
Partial Cloverleaf - B	54	5.61
Trumpet	50	5.20
Collector-Distributor	37	3.85
Partial Cloverleaf - A	37	3.85
Half Diamond	33	3.43
Rest Area	33	3.43
Express Lane Access	27	2.81
Partial Cloverleaf - B4	22	2.29
Partial Cloverleaf - AB4	15	1.56
Partial Cloverleaf - AB2	14	1.46
Weigh Station	10	1.04
Buttonhook	9	0.94
Partial Cloverleaf - A4	9	0.94
Diverging Diamond	4	0.42
HOV Access	4	0.42
Partial Cloverleaf - A2	4	0.42
Partial Cloverleaf - AB3	2	0.21

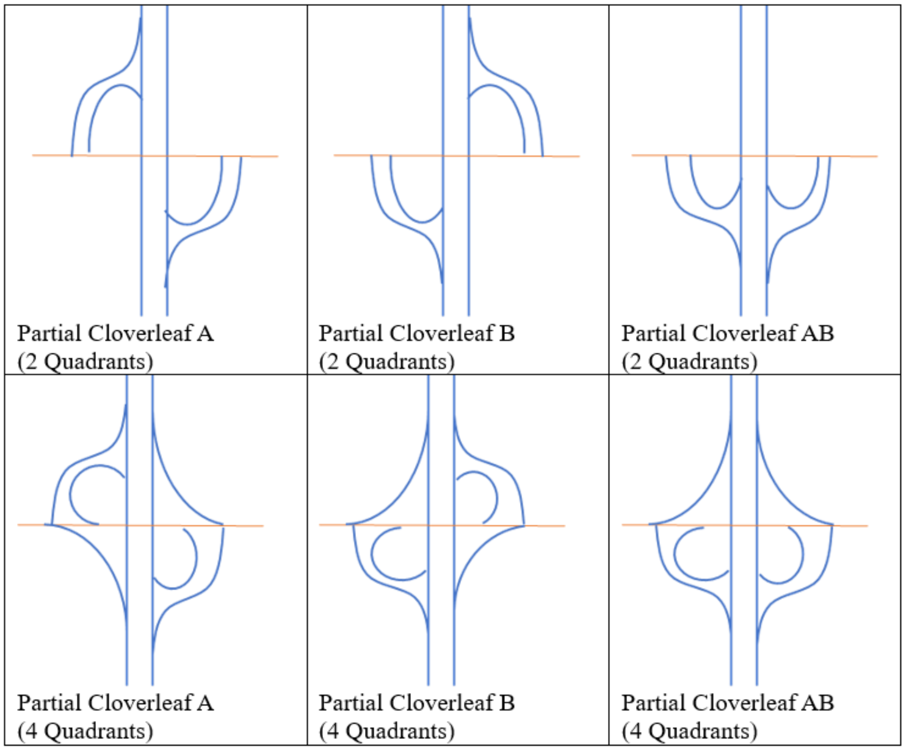


Figure 7. Partial Cloverleaf Interchange Types

From the total number of WWD crashes analyzed (196 crashes), 29 cases occurred on express lanes, reversible lanes, or near connections between interstates or other LAFs, where the nearest access points are not from local roads. Those cases could not be matched to the IC data; 167 cases were matched to IC data. As each crash has a score of 1 (entry point is precisely identified) or 0.75 (first nearest possible entry point) and 0.25 (second nearest possible entry point), the WWD scores for the IC dataset should total 167. Table 6 shows numbers and percentages of ramps in terms of WWD score threshold groups: 249 (25.9 %) interstate exit ramps may have experienced a WWD entry that resulted in a crash (WWD score > 0). Only 152 ramps have WWD scores greater than 0.5 (5.8% of all ramps), 50 ramps have scores greater than 1 (5.2%), and 16 ramps have scores greater than 1.5 (1.7%). Those numbers and percentages may be altered by changing weights and thresholds.

Table 6. Summary of Numbers and Percentages of Ramp by WWD Score Thresholds

	All ramps	**WWD Score Groups > 0**			
		> 0	**≥ 0.5**	**≥ 1**	**≥ 1.5**
Numbers (Percentages) of Ramps	962 (100%)	249 (25.9%)	152 (15.8%)	50 (5.2%)	16 (1.7%)

WWD = wrong-way driving.

Table 7 presents the total number of weighted and normalized WWD scores by interchange types. Two of the top three scores are partial cloverleaf interchanges. When all types of partial cloverleaf ramps are aggregated, normalized WWD score of partial cloverleaf ramps becomes 19.5.

Table 7. Total Number of Weighted and Normalized WWD Scores by Interchange Type (Based on Crash Analysis)

Interchange Type	**Total Number of Weighted WWD Scores**	**Normalized WWD Scores**
HOV Access	2.25	56.25
Partial Cloverleaf - AB3	0.75	37.50
Partial Cloverleaf - A	12	32.43
Trumpet	14.25	28.50
Collector-Distributor	9.25	25.00
Partial Cloverleaf - AB4	3.25	21.67
System	16.75	19.25
Diamond	55.75	18.52
Half Diamond	5.75	17.42
Partial Cloverleaf - B	8.75	16.20
Buttonhook	1.25	13.89
Partial Cloverleaf - A2	0.5	12.50
Cloverleaf	24	11.88
Partial Cloverleaf - A4	1	11.11
Partial Cloverleaf - AB2	1.5	10.71
Partial Cloverleaf - B4	2.25	10.23
Express Lane Access	2.25	8.33
Diverging Diamond	0.25	6.25
Rest Area	1.25	3.79

WWD = wrong-way driving.

Table 8 shows a list of all 16 exit ramps with a WWD score equal to or greater than 1.5, sorted by descending order of WWD score. The highest-ranking exit ramp is I-95S 173A, which had a score of 3. Some ramps have slightly higher scores than others (the top five ranked interchanges have scores greater than 2), and WWD entries are widely dispersed, rather than concentrated in hot spots. Of note is that the WWD score value changes when the first and second nearest entry weights are changed, but when tested, this did not affect the ramp rankings results.

Table 8. Summary of Ramp of WWD Score ≥ 1.5 on Interstates' Exit Ramps (Based WWD Crash Analysis Period from January 2016 to November 2022)

Rank	Route Common Name	Ramp Exit	Ramp Type	WWD Score[1]	District
1	I-95S	173A	Trumpet	3	NoVA
2	I-264E	19A	Partial Cloverleaf - B	2.25	Hampton Roads
2	I-495S Express	2A	HOV Access	2.25	NoVA
2	I-64E	279A	Partial Cloverleaf - AB4	2.25	Hampton Roads
5	I-664N	6A	System	2	Hampton Roads
6	I-95S	166B	Cloverleaf	1.75	NoVA
7	I-264E	16A	Cloverleaf	1.5	Hampton Roads
7	I-264E	19B	Partial Cloverleaf - B	1.5	Hampton Roads
7	I-64W	124A	Diamond[2]	1.5	Culpeper
7	I-64W	159A	Diamond	1.5	Richmond
7	I-66E	75A	System	1.5	NoVA
7	I-81N	296A	Diamond	1.5	Staunton
7	I-81N	323A	Diamond	1.5	Staunton
7	I-81S	101A	Diamond	1.5	Salem
7	I-81S	217A	Diamond	1.5	Staunton
7	I-95S	104A	Partial Cloverleaf - A	1.5	Fredericksburg

NoVA = Northern Virginia; WWD = wrong-way driving.
[1]The WWD score is based on a method that assumes the nearest interchange or second nearest interchange offramps are the locations where the WWD entered the wrong way. Because most crash reports do not include the entry point, there is uncertainty about the actual entry point without documented evidence. Therefore, the WWD score is only an estimate and should be viewed as such.
[3]Changed to Diverging Diamond Intersection in 2023.

Figure 8 shows Google Earth satellite and street view images of the top-ranked ramp in Table 8, I-95 westbound, exit number 173A in Northern Virginia district, a trumpet interchange type. This offramp's WWD score was three because of two ramp crashes (2 x 1), one first nearest the crash (0.75 x 1) and one second nearest crash (0.25 x 1). Figure 8 shows right way (blue, right) and WW (red, left) driving maneuvers. From the figure, a WW driver could inadvertently make a left turn onto the exit ramp.

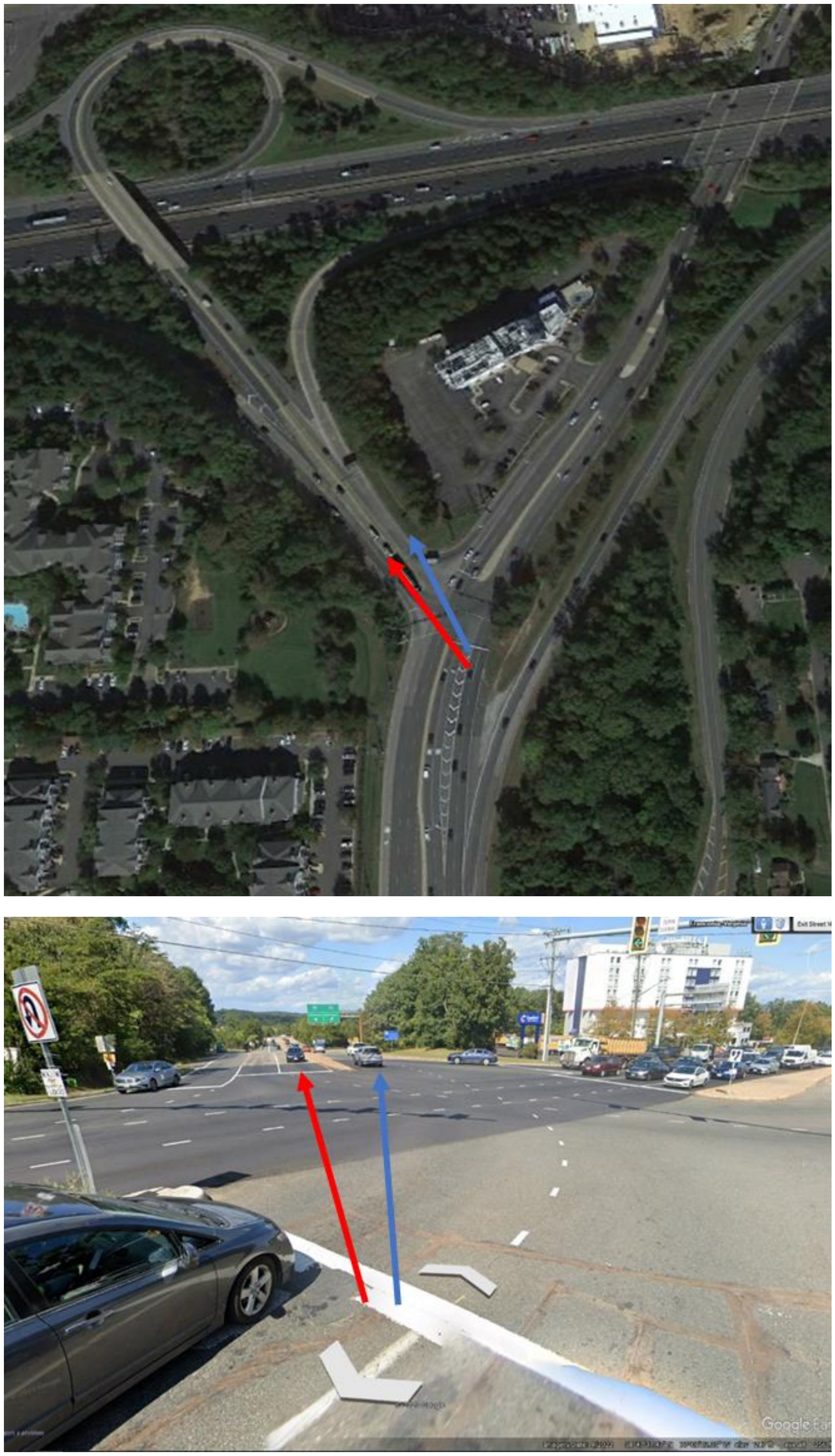


Figure 8. Satellite Image (top) and Google Streetview Image (bottom) of Wrong-Way Driving Rank #1 Ramp I-95S 173A (trumpet) (Google Street View). Blue (right) Arrow Indicates Right Way; Red (left) Arrow Indicates Wrong-Way Driving Maneuvers

Figure 9 shows the second ranked ramp in Table 8, I-264 eastbound, exit number 19A in Hampton Roads district, a partial cloverleaf -B interchange. This offramp's WWD score was 2.25 due to the three first nearest possible crashes (0.75 x 3). Figure 9 also shows possible right way (blue, right) and WW (red, left) driving maneuvers. The signal at this site does not have a left-turn phase, so why wrong-way drivers mistakenly enter the offramp is unclear. In this case, a WWD action is unlikely, and the high score may be a function of how a ramp's proximity to crashes impacts the score.

Figure 9. Wrong-Way Driving Rank #2 Ramp I-264 EB 19A (Google Aerial Image). Blue (right) Arrow Indicates Right Way; Red (left) Arrow Indicates Wrong-Way Driving Maneuvers

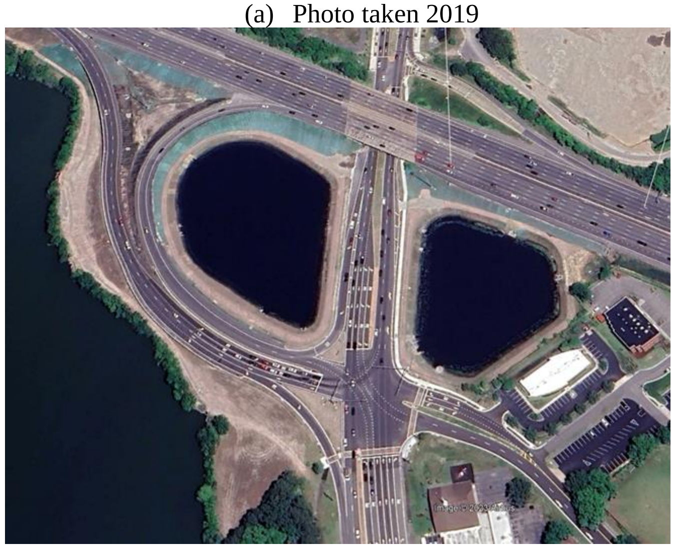
To further understand WWD near the I-264 EB Exit 19A offramp, the study team investigated the three related crashes. Figure 10 shows a Google aerial map of I-264 EB Exit 19A (right) and 18A (left), which is about 1.75 miles upstream. All three related crashes (yellow pins in the figure) occurred near I-264 EB Exit 18A offramp. Below are crash descriptions of those three crashes in order of left to right.

- Vehicle 1 changed lanes to avoid vehicle 2 which was traveling the wrong direction. Vehicle 2 then changed lanes striking vehicle 1.
- Vehicle one was traveling the wrong way westbound in the eastbound lanes of interstate 264E. Vehicle one struck vehicle two in the opposing direction.
- Vehicle #1 drove the wrong way, and vehicle #2 tried to avoid vehicle #1. Vehicle #1 struck vehicle #2.

Figure 10. I-264 Eastbound Interchanges 18A (left) and 19A (right) (Google Aerial Image)

The research team investigated the top 50 ranked sites, using Google aerial photos and Street View and matching WWD crashes to identify patterns of WWD entry or potential for safety improvement of wrong entry. The team determined that left-turn access for partial cloverleaf, trumpet, and diamond interchanges frequently could explain WW driver entries. For some sites, the path of the WW driver was not apparent. Like the I-264 EB Exit 19A offramp, there were some interchanges that showed no clear evidence of geometrics that could lead to WWD. Additionally, many crash locations were long distances from the WWD entry point. However, using Google Earth and Google Street View had some limitations because some high ranked offramps appear to have already been updated, but some Google Street View images were not updated or were unavailable. As an example, Figure 11 (b) shows rank #8, I-264 EB Exit 16A was changed (permanently closed) in 2023 compared with photo taken in 2019 (Figure 11 (a)).

(a) Photo taken 2019



(b) Photo taken 2023

Figure 11. Examples of Interchanges, Satellite Images of Wrong-Way Driving Rank #7 Ramp I-264E 16A Taken in (a) 2019 and (b) 2023 (Google Aerial Image)

Due to stated limitations and small numbers of WWD crashes, conflating WWD crash and IC type did not generate systemic patterns of WWD behavior by IC type. Conversely, each of those small numbers of WWD crashes on interstates can be reviewed by district traffic engineers for further investigation. Figure 12 summarizes interstate WWD crashes by VDOT district. As expected, the majority of WWD crashes occurred in the districts with high traffic urban areas (Hampton Roads, Northern Virginia, and Richmond Districts). However, of note is that Staunton district had the most fatal WWD crashes with ten. Appendix A contains a summary of all WWD crashes by district with route, mile marker, GPS coordinates, and severity.

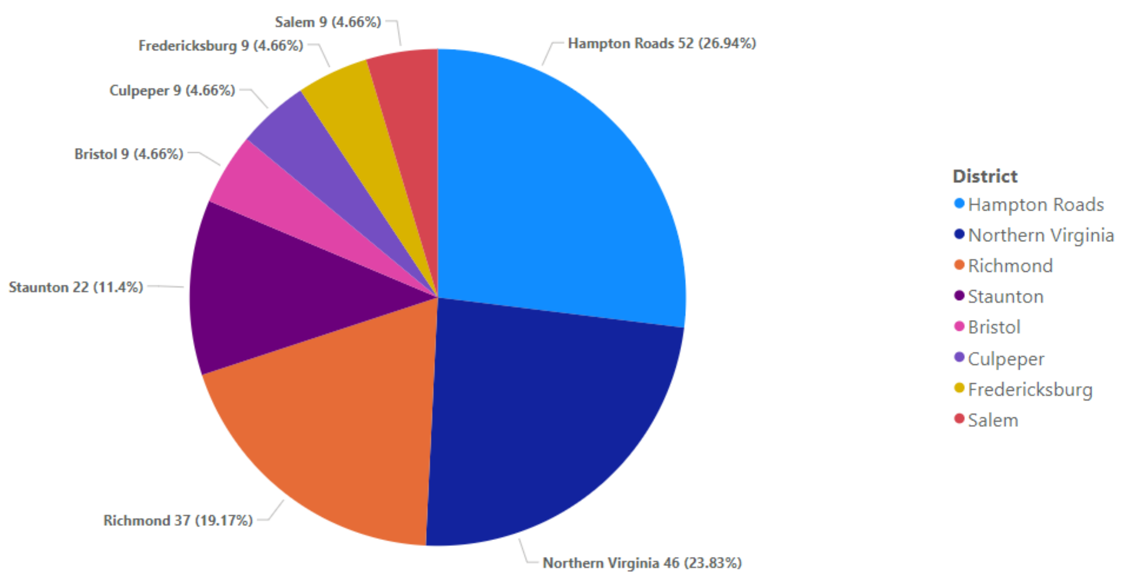


Figure 12. Summary of Interstates' Wrong-Way Driving Crashes by VDOT District

911 Data

Of the 7,586 911 calls, ultimately 4,144 (55%) were geolocated, and 72% of those were on interstates. Interstate 911 calls frequently contained mile marker information that was readily mapped. Figure 13 shows the locations of those calls statewide.

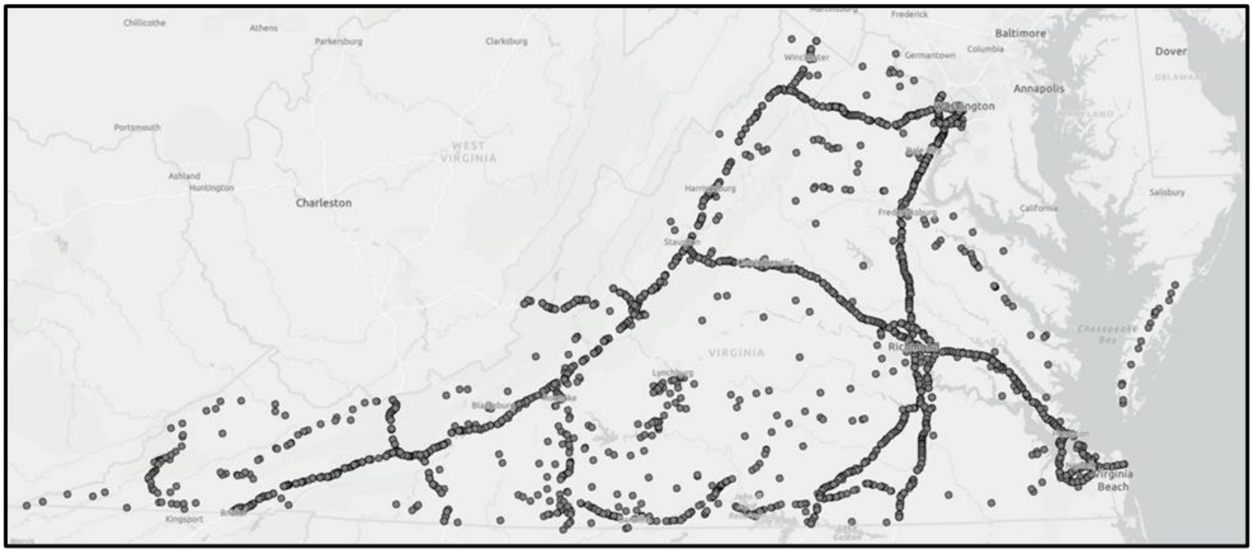


Figure 13. Wrong-Way Driving 911 Calls in Virginia from January 2016 through July 2022 (N = 4,144)

Hotspot Analysis

As was previously discussed, the 911 call location data is often insufficient to determine a location. On interstates, however, location data is consistently reported as an interstate name and mile marker, which readily can be mapped to Virginia's interstate data. In this way, a hotspot analysis could be performed, highlighting interchanges with many nearby WWD 911 calls. Following Screening Method One from the *NCHRP WWD Handbook*, a visual hotspot map was created using ArcGIS kernel density estimates through heat map symbology tools (see Figure 14). Locations in yellow represent spatial clusters of 911 calls. Duplicate calls for the same event (defined as calls within 20 minutes, 20 miles, and on the same direction on the same interstate) were removed from the dataset.

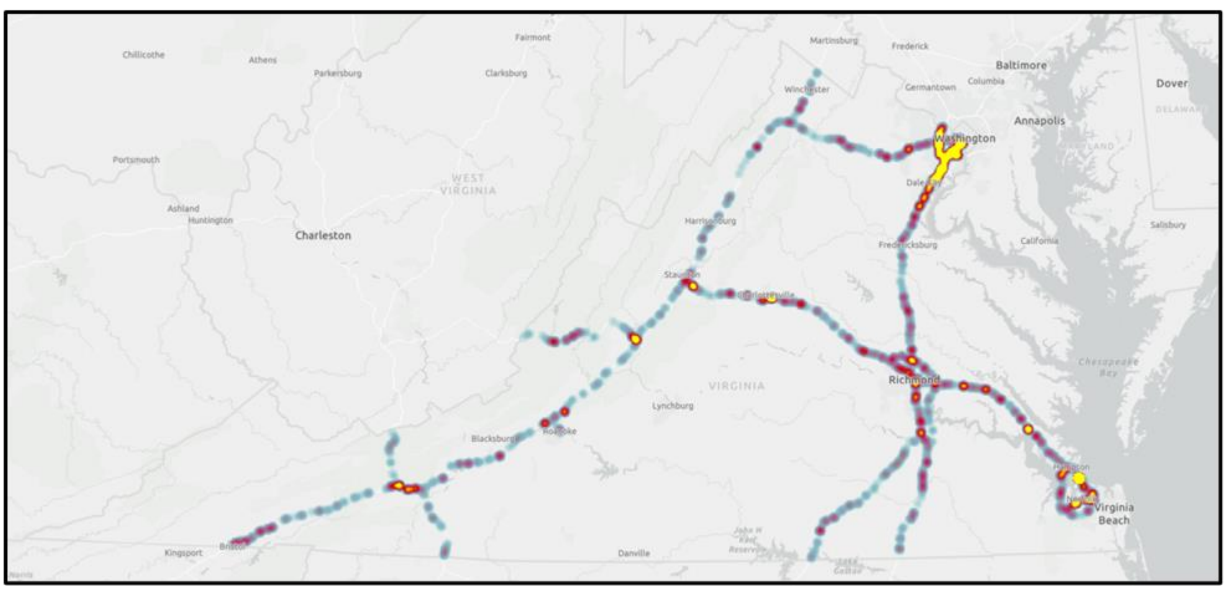


Figure 14. Wrong-Way Driving 911 Calls on Interstates in Virginia. Yellow > Red > Blue Indicates Density of Located Calls

The same screening method used for the crash data (adopted from Zhou et al. 2014b), assigning weights to possible WW entry points, was applied to the 911 call dataset. Due to the lack of detail in 911 location data, minor modifications were made to the methodology. For a given 911 call, if the mile marker mentioned in the location variable matched an exit ramp number, the ramp was given a score of 1; if no exit ramp matched the 911 call mile marker, the nearest downstream ramp was given a score of 0.75; and the second nearest ramp scored 0.25. Summing all scores of 1, 0.75 and 0.25, exit ramps on Virginia's interstates were given a total WWD score. Table 9 shows the top 20 ranked exit ramps statewide. Exit 124 on I-64 West (ranked fifth) also appears in the top ranked exit ramp table for the crash data in Table 8 (ranked seventh) as does Exit 166 on I-95S (ranked ninth), which is ranked sixth in the crash data exit ramp table. Compared with the same analysis performed with the crash data (Table 8), the WWD scores from the 911 data analysis are much higher because the WWD 911 call dataset contains many more cases than the WWD crash dataset.

Table 9. Summary of Top 20 Ranked Interchanges Statewide (Based on 911 WWD Analysis Period from January 2016 to July 2022)

Rank	Interstate	Exit	Interchange Type	WWD Score[1]	District
1	I-64W	272	Buttonhook	290	Hampton Roads
2	I-95N	166	Cloverleaf	34.25	NoVA
3	I-495S	43	Trumpet	32.5	NoVA
4	I-95N	163	Partial Cloverleaf - AB2	25.75	NoVA
5	I-64W	124	Diamond[2]	25	Culpeper
6	I-64E	91	Diamond	21	Staunton
7	I-95S	166	Cloverleaf	18.75	NoVA
8	I-81N	191	System	18.5	Staunton
9	I-95N	166	Cloverleaf	18	NoVA
10	I-64E	211	Diamond	17.75	Richmond
11	I-64W	243	Trumpet	17.25	Hampton Roads
12	I-95S	163	Partial Cloverleaf - AB2	16.5	NoVA
13	I-395N	8	System	16.5	NoVA
14	I-95N	169	Collector-Distributor	15.75	NoVA
15	I-395S	4	Collector-Distributor	15.75	NoVA
16	I-495S	47	Cloverleaf	15	NoVA
17	I-81S	73	Trumpet	15	Bristol
18	I-95S	166	Cloverleaf	14.25	NoVA
19	I-495N	47	Cloverleaf	14	NoVA
20	I-95N	161	System	14	NoVA

NoVA = Northern Virginia; WWD = wrong-way driving.
[1]The WWD score is based on a method that assumes the nearest interchange or second nearest interchange offramps are the locations where the WWD entered the wrong way. Because 911 calls do not include the entry point, there is uncertainty about the actual entry point without documented evidence. Therefore, the WWD score is only an estimate and should be viewed as such.
[2]Changed to Diverging Diamond Intersection in 2023.

The first exit ramp highlighted by 911 calls on Virginia's interstates is I-64 West Exit 272, a buttonhook interchange in Norfolk, the last westbound exit before the Hampton Roads

Bridge Tunnel (HRBT). This interchange is unique as drivers often have been observed to deliberately enter the wrong way. The number of 911 calls related to this exit ramp vastly outnumbers any other exit ramp in Virginia with approximately 300 calls during the 6½ years observed timeframe. Some drivers often attempt to use Ocean View Ave. to avoid I-64 West during the frequent multiple-mile traffic backups approaching the HRBT. To curb the impacts of these diversions on Ocean View Ave., VDOT uses gates to close the onramp onto I-64 West during certain times of day. However, some drivers attempted to get around those ramps by driving the wrong way on the offramp for a short distance and then making a hard right onto the interstate. As shown in Figure 15, temporary barriers have modified this interchange.

Figure 15. I-64 West Exit 272 Ramps (Google Street View, July 2023)

Other locations highlighted by the screening method are two adjacent interchanges on I-95 in Lorton, Virginia. These interchanges include a cloverleaf where the exit ramp meets a frontage road at a 90° angle and a partial cloverleaf (see Figure 16). I-95 Exit 166 is listed 4 times in Table 10.

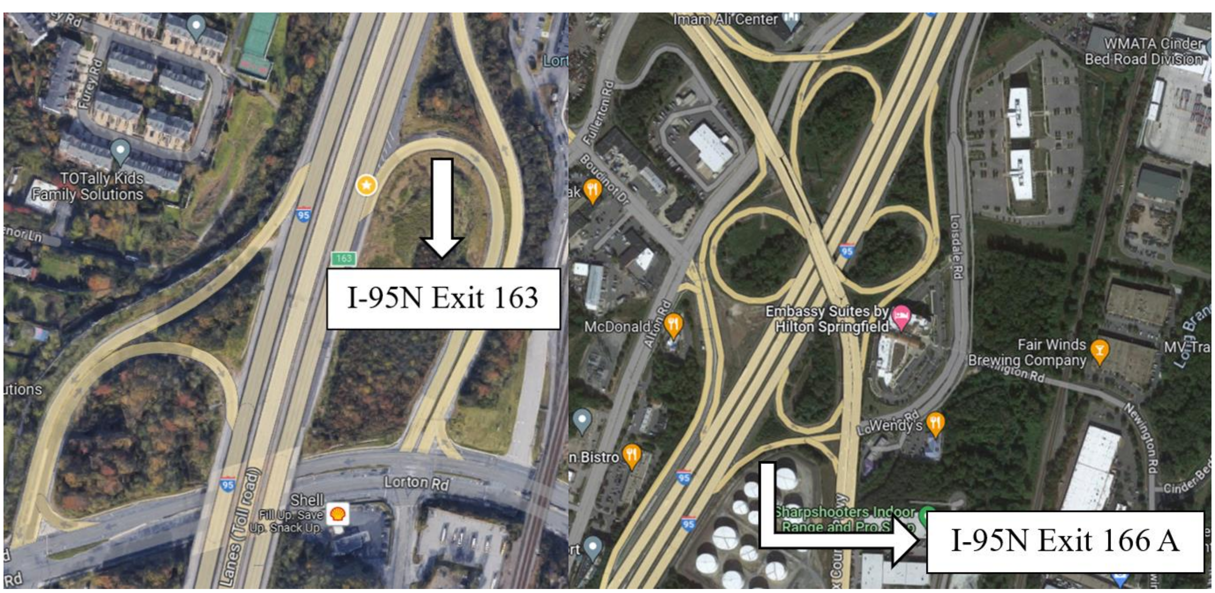


Figure 16. I-95 North Exits 163 (left) and 166A (right) (Google Maps)

Table 10. Number of Weighted WWD 911 Calls per 100 Interchanges per Year

Interchange Type	Number of Weighted WWD 911 Calls per 100 Interchanges per Year
Buttonhook	521.1
Partial Cloverleaf - AB3	99.5
Partial Cloverleaf - AB2	70.3
SPDI	68.9
Collector-Distributor	62.5
Trumpet	58.6
Diamond	45.0
Partial Cloverleaf - B4	44.4
Half Diamond	41.3
Diverging Diamond	40.2
Partial Cloverleaf - A	38.9
Partial Cloverleaf - A4	37.9
Partial Cloverleaf - B	36.7
System	33.2
Partial Cloverleaf - A2	30.6
Partial Cloverleaf - AB4	29.9
Cloverleaf	29.2
HOV Access	15.3
Express Lane Access	11.2
Wayside	9.6
Weigh Station	6.9
Rest Area	6.8

WWD = wrong-way driving.

Also highlighted by the screening process is a trumpet interchange on the George Washington Parkway (Figure 17).

Figure 17. I-495 South Exit 43 (Google Maps)

Screening Method Two from the *NCHRP WWD Handbook* was also employed to rank interchange types by the number of 911 calls likely to have occurred at those intersections (Table 10). This ranking method normalizes weights by the number of each interchange type in the interstate system. The number of 911 calls attributed to I-64 Exit 272 contributed to the buttonhook interchange being the #1 ranked interchange type in Table 10. If that interchange was excluded, the buttonhook weighted 911 call rate would drop to 27.7 and the buttonhook would rank 17th. Partial cloverleaf interchanges (particularly AB3 and AB2), single point diamond interchanges (SPDI), collector-distributors, and trumpet interchanges ranked as the most susceptible to WWD based on 911 calls. Compared with Table 7, weighted WWD scores for crashes, partial cloverleaf – AB3, trumpet and collector-distributor are the three interchange types in the top six of both 911 and crash WWD scores.

Review of WWD on Selected Multilane Divided Highways

DTE Survey

A key output from the DTE survey was a list (Table 11) of multilane divided roads to review for WWD activities using 911 data.

Table 11. Summary Multilane Divided Roads Locations for Review

District	Location
Northern Virginia	US 50 west of Middleburg in a short, divided highway stretch.
Hampton Roads	Route 58 and Route 615 (Adams Grove Road)
Salem	Route 220 at Route 40 (Rocky Mount)
	Route 58 at Route 685 (Martinsville Bypass)
Staunton	Route 50 in Frederick County
Richmond	Route 58, Mecklenburg and Brunswick Counties
	US 60 through Powhatan

911 Data Applied to Survey Results

Northern Virginia District

The Northern Virginia District identified a short, divided stretch of road west of Middleburg on Route 50 (Figure 18) as being of potential concern for WWD. All 911 calls on Route 50 in Loudon or Fauquier County were considered for analysis. Seven calls were reported on Route 50; four were west of Middleburg, but all were approximately 13–18 miles away, not on the section of road identified. There was one crash reported on the stretch of road just west of Middleburg, but otherwise no significant pattern was observed.

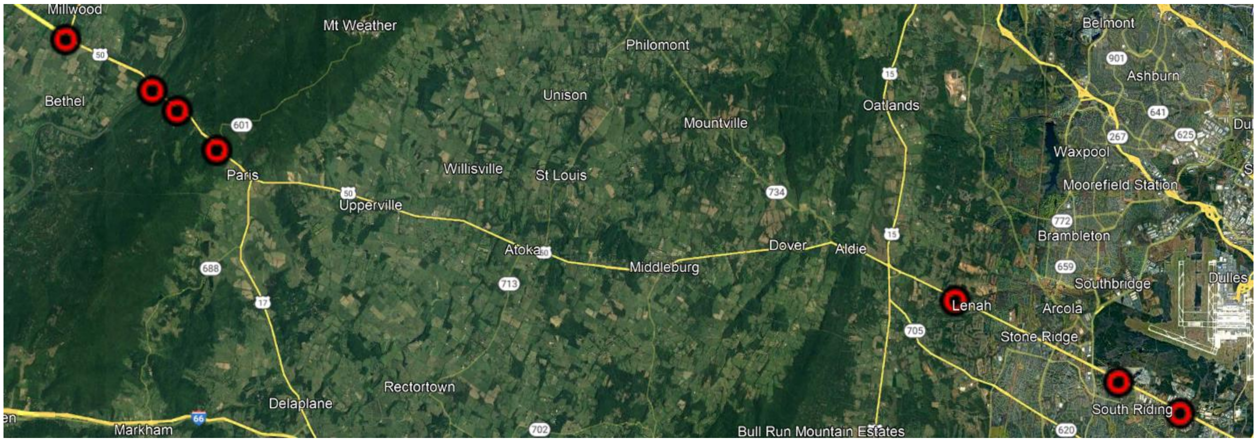


Figure 18. Wrong-Way Driving 911 Calls on Route 50 in Loudon and Fauquier Counties (Google Earth). Red Circles Indicate Approximate Location Referenced in 911 Call

Hampton Roads District

The Hampton Roads District highlighted the intersection of Route 58 and Route 615 (Adams Grove Road) as being a potential location of concern (Figure 19). To assess this, all 911 calls on Routes 615 and 58 in Southampton County were pulled from the dataset. There was one call reported at the intersection of interest in 2016, and another call from 3 miles west of the intersection in 2020. There were no other calls for Adams Grove Road in this county and 9 calls for Route 58 in the county, but those were farther than 10 miles from the intersection of concern. The researchers observed no significant pattern of WWD based on the available data.

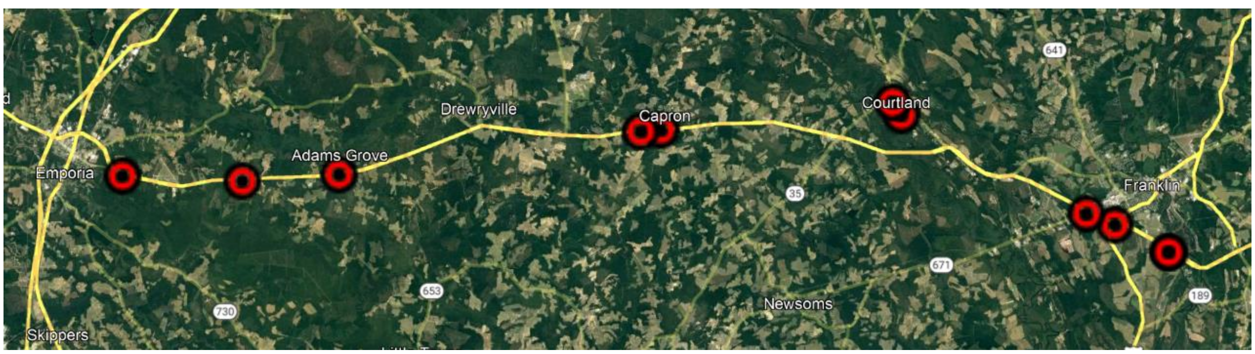


Figure 19. Wrong-Way Driving 911 Calls on Route 58 and Route 615 in Southampton County (Google Earth). Red Circles Indicate Approximate Location Referenced in 911 Call

Salem District

The Salem District identified two possible locations of interest for WWD. The first is the intersection of Route 220 and Route 40, and the second is the intersection of Routes 58 and 685. To analyze the intersection of Route 220 (also known as Virgil H Goode Highway) and Route 40 (also known and Tanyard Road or Old Franklin Turnpike), all 911 calls with a county code of Franklin County and that mentioned Route 40 were pulled from the dataset. This resulted in 143 calls for review. For 107 calls, the location variable was clear enough to identify an approximate latitude and longitude (Figure 20). Two calls were geolocated at the intersection of Route 40 and Route 220, 5 calls were within 1 mile of that intersection, and 28 calls were within 5 miles of the intersection. The team determined that a significant number of 911 calls occurred near the Route 220/40 intersection, but other intersections may be greater generators of WWD activity. A review of Routes 220 and 40 within 5 miles of the Route 220/40 intersection may be considered.

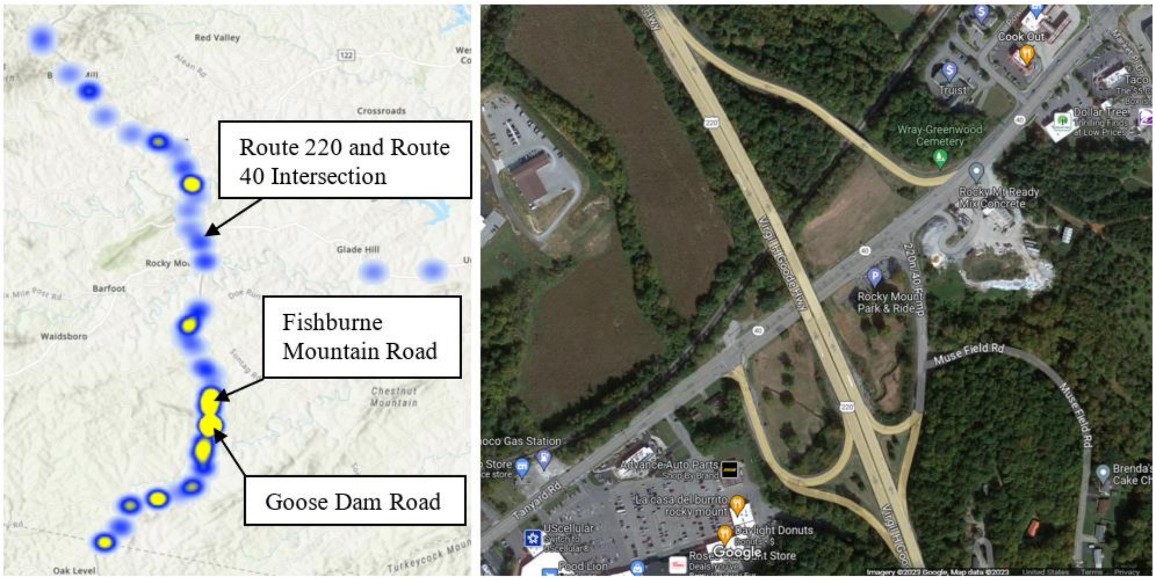


Figure 20. Heatmap of 911 Calls for Route 40 or Route 220 in Franklin County (left) and the Intersection of Route 40 and Route 220 (right) (Google Earth). Yellow Indicates Hotspots of Densely Located 911 Calls

In reviewing the 911 calls for Route 40 and Route 220 in Franklin County, hotspots were identified 7 to 9 miles south of the Route 220/40 intersection near the intersection of Fishburne Mountain Road and Route 220 (Figure 21), as well as near the intersection of Goose Dam Road and 220 at the Pit Stop Market & Deli (Figure 22). Based on the number of 911 calls in this area, those two locations appear to be hotspots for WWD on the 220 corridor than the Route 220/40 intersection. Fourteen 911 calls were flagged near the intersection of Goose Dam Road and Route 220, six at the intersection of Fishburne Road and Route 220, and a total of 62 calls were located within 5 miles of Goose Dam Road. WW countermeasures currently consist of ONE WAY signs on either side of the road at both intersections (Figure 21). A review of this section of 220 may be considered for signage and visibility.

Figure 21. Intersection of Route 220 and Fishburne Mountain Road (Google Street View, August 2023)

Figure 22. Intersection of Route 220 and Goose Dam Road (Google Street View, August 2023)

The second location highlighted by the Salem District was the intersection of Route 58 and Route 685, part of the Martinsville Bypass. This portion of Route 58 is access controlled. To assess this region, all 911 calls for 58 and 685 in the city of Martinsville and Henry County were analyzed. Route 220 overlaps with 58 on the bypass, so 911 calls containing 220 were also included. Then those outside of the bypass were removed. This initially included 170 911 calls, 87 of which were retained in the dataset and could be approximately geolocated based on the location description. Several hotspots could be identified based on this data, including the intersection of Route 685 and Route 58 on the Martinsville Bypass (a partial cloverleaf), Route 58 near Axton, and Route 58 in Horse Pasture near the Old Country Store (Figure 23). There is evidence to warrant review of hotspot locations to ensure standard WWD prevention measures are in place.

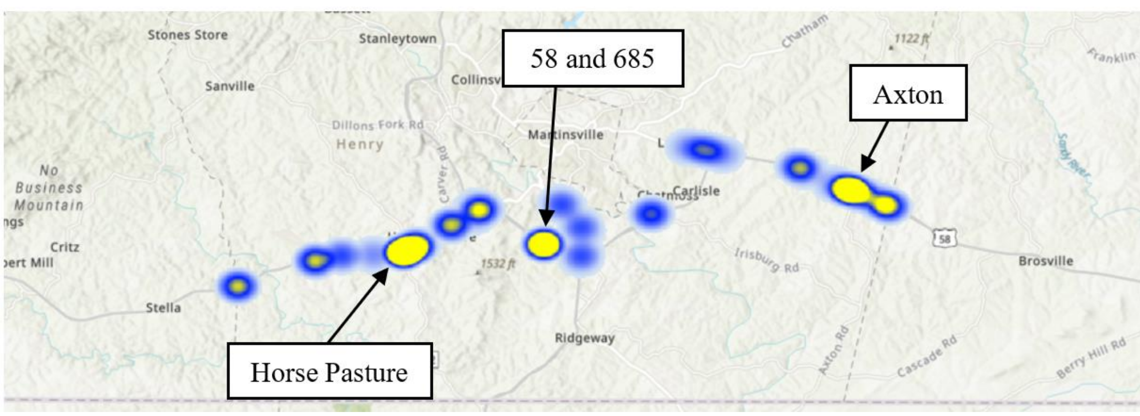


Figure 23. Heatmap of 911 Calls in the City of Martinsville and Henry County on Route 58 and Route 685. Yellow Indicates Hotspots of Densely Located 911 Calls

Thirty-five 911 calls were reported within 5 miles of the intersection of Route 58 and Route 685 and ten within one mile. Twenty 911 calls were reported within one mile of the Old Country Store/Fire Department in Horse Pasture (Figure 24) and 13 within a mile of the Axton Elementary School (Figure 25).

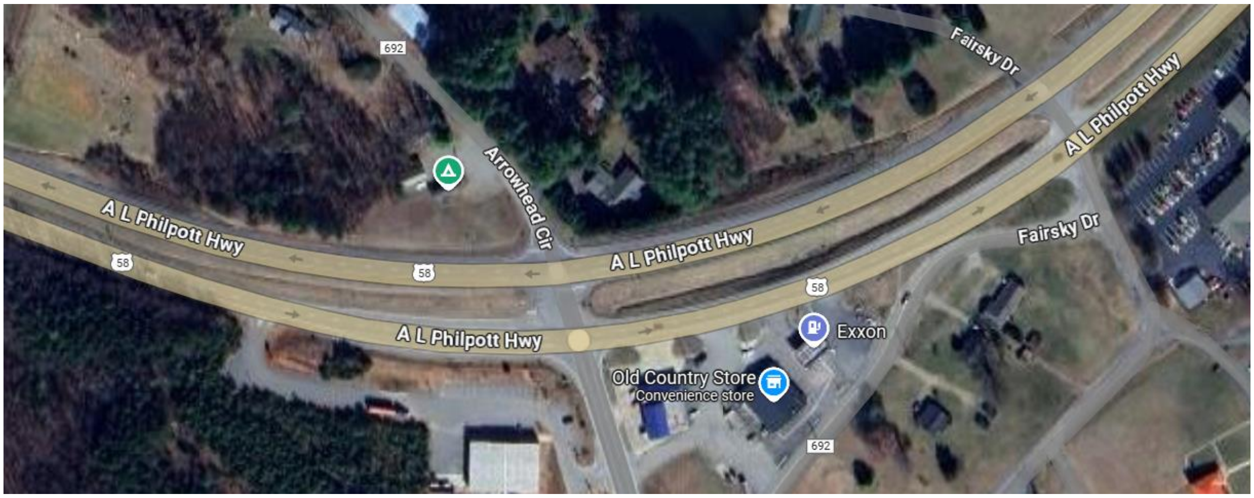


Figure 24. Intersection Adjacent to the Old Country Store on Route 58. Wrong-Way Driving Countermeasures Visible Include Dual Mounted DO NOT ENTER and WRONG WAY Signs and ONE WAY Signs in Median (Google Maps, July 2023)

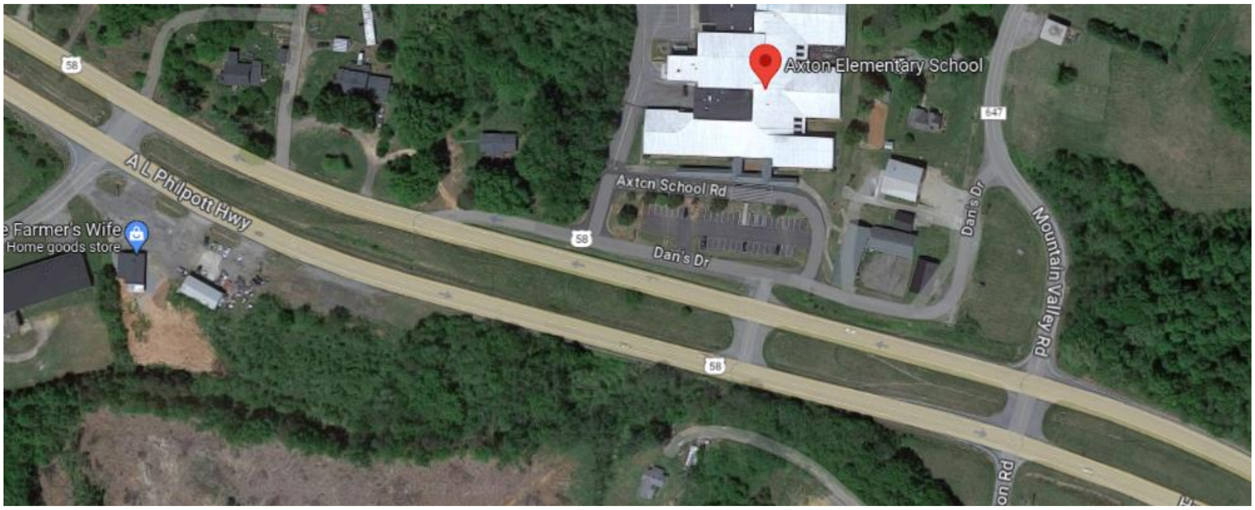


Figure 25. Intersections in Front of the Axton Elementary School. Wrong-Way Driving Countermeasures Include ONE WAY Signs on the Far Sides of the Intersection (Google Maps, August 2023)

Staunton District

The Staunton District suggested Route 50 in Frederick County (Figure 26) as a potential problem area for WWD. To investigate the area, all 911 calls for Route 50 or Route 17 (which overlaps with Route 50 in this region) in Frederick County were flagged and geolocated. Nine calls were identified, five of which were located near a partial cloverleaf interchange for I-81. The exit ramps on this I-81 interchange did not rank highly in the screening analysis, using 911 call data. Based on the available 911 data, no clear patterns of WWD were present.

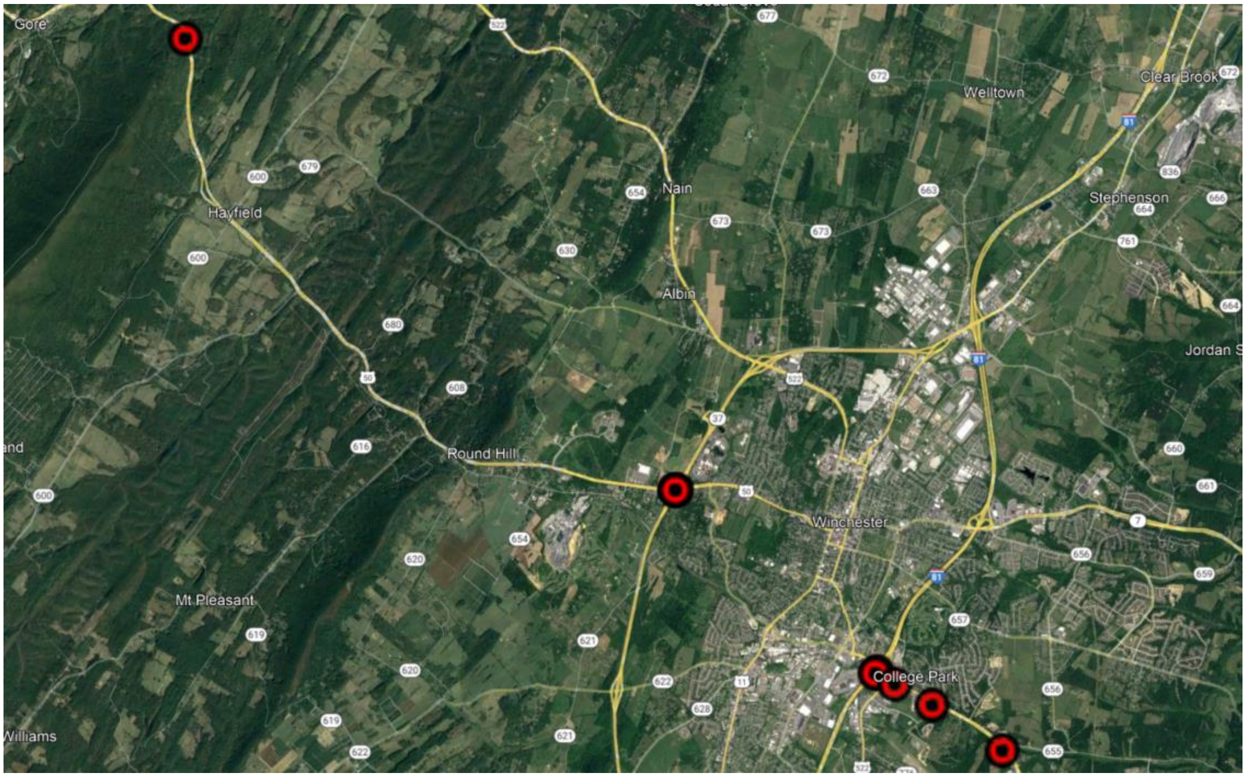


Figure 26. Wrong-Way Driving 911 Calls on Route 50 in Frederick County (Google Earth). Red Circles Indicate Approximate Location Referenced in 911 Call

Richmond District

The Richmond district identified two corridors where WWD may be a concern. The first is on Route 58 in Mecklenburg and Brunswick Counties, and the second is on Route 60 through Powhatan.

For the first region, all 911 calls mentioning Route 58 in Mecklenburg and Brunswick Counties were flagged in the dataset, a total of 158 calls. Of these, 123 included enough information to identify an approximate location of each call. Many of the calls were spread out across the two counties; however, one hotspot was identified at the intersection of Reedy Creek Road (Figure 27). Twenty-eight calls mentioned Reedy Creek (or Freemans Crossroads) specifically, and 46 were located within 5 miles of this intersection. Based on Google Maps updates, between 2022 and 2023, the WWD countermeasures at this intersection were addressed (Figures 28–30).

Figure 27. Heat Map of 911 Call Locations on Route 58 in Mecklenburg and Brunswick Counties. Yellow Indicates Hotspots of Densely Located 911 Calls

Figure 28. Route 58 Westbound at the Reedy Creek Road Intersection Showing Dual Mounted DO NOT ENTER and WRONG WAY Signs (Google Street View, March 2023)

Figure 29. Route 58 Eastbound at the Reedy Creek Road Intersection Showing DO NOT ENTER and Dual Mounted WRONG WAY Signs (Google Street View, March 2023)

Figure 30. ONE WAY Signs in Median (Google Street View March 2023)

As it appears that some updates have been made to the intersection of Reedy Creek Road and Route 58, some other locations to consider for updates include the intersection of Route 58 and Route 85 (15 calls within 5 miles), the intersection of 58 and Buggs Island Road (9 calls within 5 miles), and the intersections around the Clarksville Bypass (16 calls within 5 miles of the center of the Clarksville Bypass bridge over the Roanoke River).

The second location identified by the Richmond district was Route 60 in Powhatan (Figure 31). For this section, 911 calls were reviewed by selecting any call referencing route 60 in Powhatan County. There were six 911 calls for this stretch of road recorded during the 6½-year timeframe, all within a 5-mile section. Between the intersections of Route 60/Dorset Road and Route 60/County Line Road. Based on the available data, researchers could not determine whether there is a specific problematic location.

Figure 31. 911 Calls on Route 60 in Powhatan (Google Earth). Red Circles Indicate Approximate Location Referenced in 911 Call

The following Table 12 summarizes hotspot locations identified after reviewing the above recommended multilane divided highways. This analysis did not constitute a comprehensive review of multilane divided highways statewide. The analysis assessed select locations identified via the DTE survey previously described.

Table 12. Locations that May Be Considered For Further Review Based on a Review of Selected Multilane Divided Highways

District	Location
Salem District	The intersection of Route 40 and Route 220 (28 calls within 5 miles)
	The section of Route 220 near Fishburne Mountain Road and Goose Dam Road (62 calls within 5 miles of Goose Dam Road)
	The intersection of Route 685 and Route 58 on the Martinsville Bypass (35 calls within 5 miles)
	Route 58 near the Axton Elementary School (13 calls within 1 mile)
	Route 58 in Horse Pasture near the Old Country Store (20 calls within 1 mile)
Richmond District	The intersection of Route 58 and Route 85 (15 calls within 5 miles)
	The intersection of 58 and Buggs Island Road (9 calls within 5 miles)
	The intersections around the Clarksville Bypass (16 calls within 5 miles of the center of the Clarksville Bypass bridge over the Roanoke River)

WWD Countermeasures and Examples

This section briefly describes (1) common WWD countermeasures, (2) examples from VDOT districts' experiences installing countermeasures to deter WWD, (3) the use of WWD detection systems by two state DOTs, (4) estimated costs for WWD countermeasures including conventional ones and WWD flashing signs, activation and detection systems, and (5) an example of education as a potential WWD countermeasure.

WWD Countermeasures

There are several good sources of countermeasure options, including the *NCHRP WWD Handbook*, which includes extensive guidance on signs, pavement markings and signals (chapter 3), advanced technologies (chapter 4), geometric design elements (chapter 5), and enforcement and education (chapter 7). Additionally, the *NCHRP WWD Handbook* provides appendices with a Wrong-Way Entry Checklist Field Inspection Sheet and a Wrong-Way Driving Road Safety Audit Prompt List. The MUTCD, VA supplement, and other VDOT documents including a 2017 Traffic Engineering Division (TED) briefing report with informal guidance on WWD strategies are also very useful. These documents are highly recommended as references. Appendix B includes excerpts from these documents of information and guidance on using WWD signs and markings.

The emphasis or scope of this section is on existing locations where changes in signing, markings, and minor changes in traffic signal and geometric features may be considered to deter WWD. Refer to the *NCHRP WWD Handbook* for more details in chapters 3, 4 and Appendix B.

Based on VDOT staff using the MUTCD and the VA supplement to the MUTCD, there is some consistency statewide in VDOT signing and markings to reduce WWD. The primary traditional countermeasures are DO NOT ENTER (DNE) signs, WRONG WAY (WW) signs, ONE WAY signs, stop bars, WW arrows, and lane use arrows. The information on them is listed below as items to consider without the detail that is provided in the documents. Additional information is in Appendix B including some typical sign layouts and the 2017 TED briefing report on WWD strategies.

List of traffic control devices:

1. DO NOT ENTER (R5-1)
2. WRONG WAY (R5-1a)
3. ONE WAY Signs (R6-1, R6-2)
4. Freeway entrance signs (see Section 2D.46)
5. Divided highways keep right symbol or word sign (R4-7c or R4-7b)
6. No Left (R3-2) and right turn (R3-1) symbol signs
7. Route shield markings to denote proper lanes to access routes
8. Turn lane arrows and/or Wrong Way arrows on mainline and ramps
9. Green straight-ahead (instead of circular green) traffic signal indications to denote no turning left or right.

Tips:

- Angle Keep Right and Do Not Enter signs to face towards potential wrong-way drivers, instead of perpendicular to the offramp
- Dual mount
- Larger signs where appropriate
- Mount signs lower.

Options:

- Retroreflective strips on signpost
- Emphasis on signs on right side
- "Puppy track" markings for delineating turns.

Geometric features include the sample below:

1. Raised median
2. Corner/turn radius
3. Access point near ramp
4. Channelization:
   - Painted island
   - Extend double yellow centerlines past median or painted median
   - Use post mounted delineators (with or without an asphalt median) to extend traffic separation/deter left turns past island
5. Properly-designed intersection lighting at the offramp terminus (Review existing lighting to ensure it illuminating the onramp but not the offramp side of a trumpet or partial-cloverleaf intersection; this could have the unintended effect of drawing drivers to the wrong side of the median (a "moth to flame" type effect).

One problem area to address is a multilane divided road with a grade in the median (or the two directions are at different elevations) so that the far side road is not visible at night; ONE WAY signs on the far side right shoulder and the near side median is one suggestion to deter WWD. Location specific measures are highly recommended.

Figure 32 shows an example of the DNE/WW mounted on the same post on both sides of the ramp, ONE WAY sign and WW arrow. Figure 33 shows a stop bar, WW arrow and a slight variation in the signing.

Figure 32. DO NOT ENTER and WRONG WAY Signs, Dual Mounted ONE WAY Signs, and Wrong Way Arrow (Google Street View)

Figure 33. DO NOT ENTER and WRONG WAY Signs, ONE WAY Sign, Stop Bar and Wrong Way Arrow (Google Street View)

DTE Survey and WWD Countermeasures

The DTE survey as part of task 4 also included a review of VDOT activities related to WWD and countermeasures that are worth noting. This presents a snapshot of countermeasures that have already been installed for WWD in Virginia.

Four locations in the Hampton Roads district were noted for actions to address WWD. On an I-64 WB offramp to 15th View St., Exit 272, a gate was installed for the I-64 onramp that is activated from 12:30–6:30pm. Drivers were found to be intentionally driving up the offramp to I-64 WB toward the tunnel. Mitigation measures were to install more positive traffic control devices including delineation and barriers. This is the location with the most 911 calls described above in the 911 hotspot analysis and shown in Figure 14. At I-264 at Lynnhaven Parkway, two new DO NOT ENTER and WW signs were installed closer to the gore with new WW pavement marking arrows in each lane. At I-664 at 27th Street, at the base of the ramp, a McDonalds Restaurant has a right in right out driveway where some drivers turned left then travel northbound in the southbound lanes. Three WW arrow pavement markings and ONE WAY and No Left Turn signs were installed. At Route 58 and Adams Grove Rd, dual indicated DO NOT ENTER and WW signs were installed in both directions on Route 58.

In Salem District, there were WWD issues in the past on Route 460 at Rich Creek, VA. Drivers intending to turn left onto EB 460 from Old Virginia Avenue or a gas station would occasionally turn into the WB lanes. About 10 to 12 years ago, VDOT installed micro-loops to detect WW drivers and activate flashing beacons with WW signage (Figure 34). This seemed to be effective anecdotally based on feedback from district staff and the local sheriff's office.

Figure 34. Wrong-Way Driving Detection System on Route 460 at Rich Creek in Salem District (Google Street View)

In 2022, Culpeper District staff reviewed WWD incidents on Route 211 in Rappahannock County. The sheriff's department provided 911 data. After the review of 53 WWD incidents during a 4-year period, VDOT staff developed plans to install ONE WAY and DO NOT ENTER signs at 5 intersections.

Fredericksburg District staff noted that actions taken for WWD included upgrading median crossover signage and lowering DNE signage on the ramp.

In the Richmond District, a review of all interchanges was conducted by a consultant. This was initiated after three to four WWD crashes occurred during a 2-month period in 2018. The goal was a systemic improvement plan with a consistent signing message. The cost for the review was $114,000. Staff worked with an on-call consultant to develop a no plan assembly for contract. The estimated cost for installing the recommended treatments is $1.1 million for all interstate and primary route limited access interchanges in the district.

Use of WWD Detection Systems by FDOT and IA DOT

At least 14 state DOTs (FL, IA, CT, RI, CA, TX, MA, AZ, DE, OH, OK, MI, CO, and NV) are known to have piloted or implemented WWD detection systems. Since VDOT staff expressed interest in WWD detection systems, there is some limited discussion below based on their use in Florida and Iowa as well as WWD in general.

Florida DOT (FDOT, personal communications virtual meeting, July 10, 2023)

During the past 10 years, FDOT has completed multiple research efforts on WWD with a focus on using WWD detection systems on limited access highways. After experimenting with several lighting patterns that are activated on WW signs when a WWD is detected on a ramp, FDOT chose a WW sign with flashing LED lights along its border (termed border LED signs). The cost per ramp for a WW video detection system varies from $30,000 to 200,000. Figure 35 is a typical layout used by FDOT showing the second set of WW signs with antennas/flashers. Items such as utility and fiber access, the number of installations on a contract, and location specific needs especially in urban areas affect the cost. Annual operating and maintenance costs are in each district's ITS maintenance contract as a unit cost item; no dollar value was available. Good data logs are important to confirm that system is operating properly as well as regular monitoring/review by the traffic management centers, TMCs. FDOT currently has five WWD detection systems on the approved product list and has a comprehensive field acceptance testing plan.

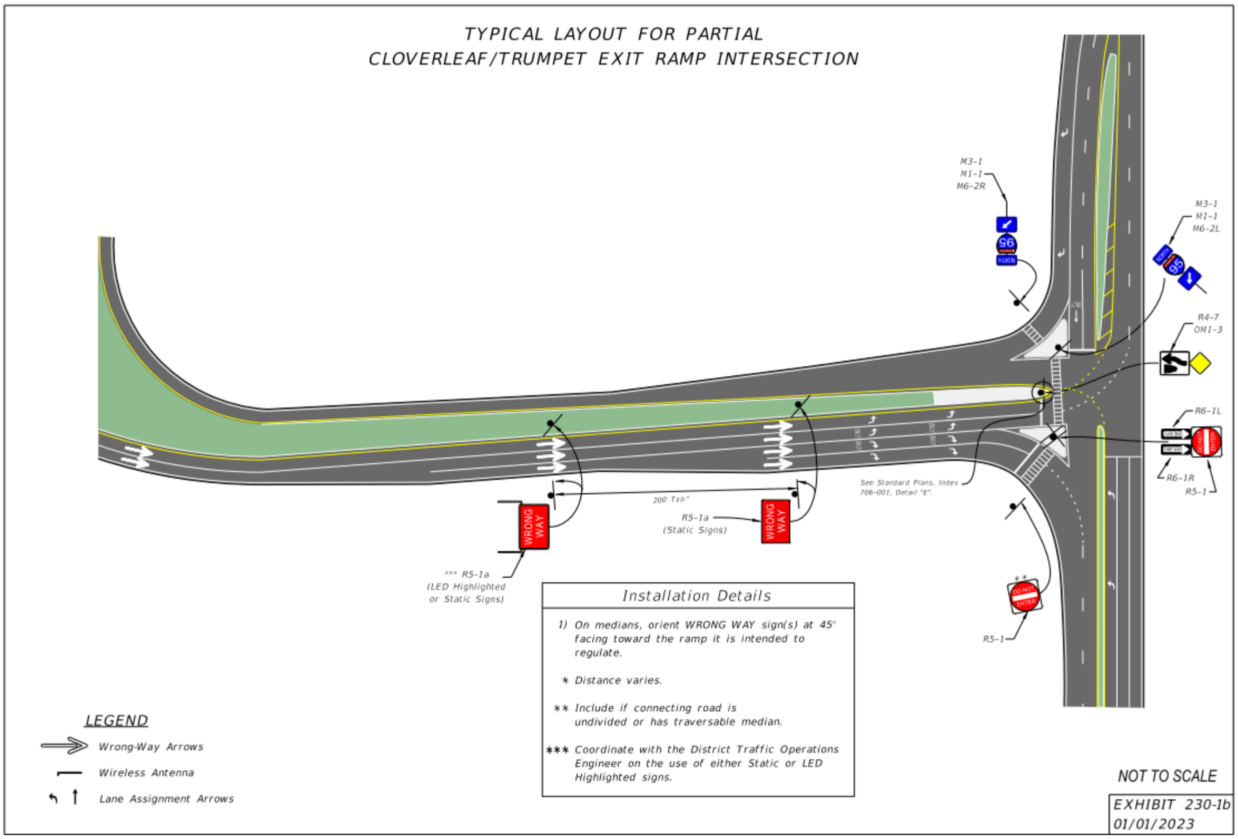


Figure 35. FDOT Typical Layout for Wrong-Way Driving Detection System Signing and Markings (FDOT Design Manual, 2023). Used with permission.

The typical protocol for WWD detection system operations is:

1. 95% of WW drivers self-correct (at the first flashing sign) so no additional action is needed.
2. For WWD drivers who do not self-correct, an alert on the WW ramp incident is sent to the Traffic Management Center (TMC). Photos of the rear of the WW vehicle are sent to the TMC and/or sent by phone to those who are to be alerted to confirm the WWD incident. The TMC staff notifies police and/or the Florida highway patrol. A police pursuit begins and other confirmation is provided by TMC cameras or 911 calls. The

nearest Dynamic Message Signs (DMSs) are activated to display a WW caution message. Patrols stops the WW driver while moving. Figure 36 describes the operations in general terms.

The district takes the lead and practice varies some by district.

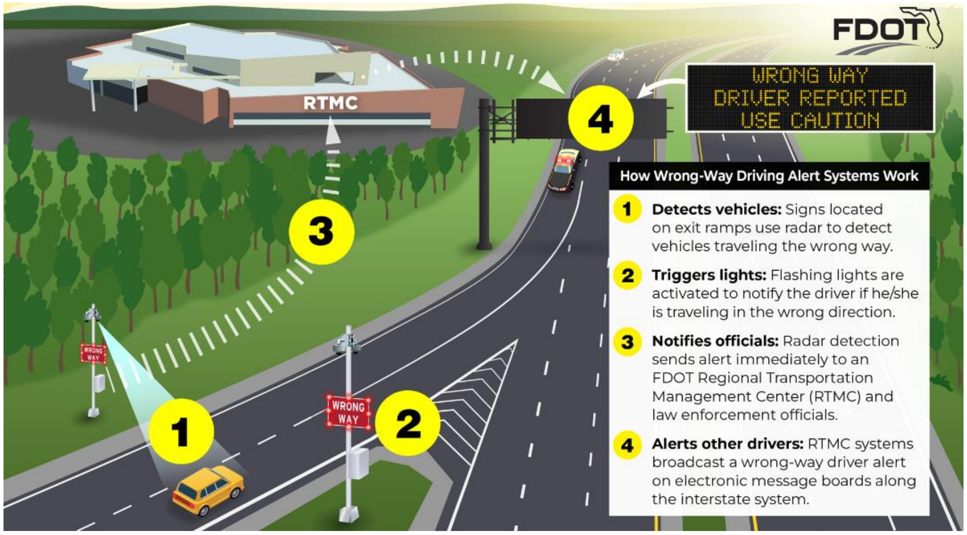


Figure 36. FDOT Wrong-Way Driving Detection System Operations (FDOT, 2023). Used with permission.

Iowa DOT (Sorenson, 2023; AASHTO, 2023)

Iowa DOT (IADOT) conducted network screening that prioritized 165 locations: 129 interchanges and 36 at grade intersections for WWD potential. Their approach was to deploy WWD detection systems to verify WWD problems and then determine what countermeasures would be most effective at addressing the underlying cause of WWD. IADOT obtained 62 cameras with video analytics for WWD detection. Fifty-nine cameras were installed at some of the priority locations. Three cameras are on trailers are temporarily positioned at priority locations. The cost per trailer about $35,000 to $40,000 (not including the cost to integrate the equipment and if DOT staff perform the integration). This approach was suggested with the expectation that a turnkey system to meet these needs was not available on the open market. When a WWD incident is detected, an email including a photo and information such as a location, date, time, etc. is sent to staff to alert and record the event. If the detector has 4 detection zones, then 4 emails are sent for one event. The video records have also helped to increase internal awareness of the problem. From the video analysis, some examples of the countermeasures installed and the subsequent reduction in WWD incidents are (AASHTO, 2023):

- Enhanced signing (size and placement) and pavement markings for partial cloverleaf interchanges—93% reduction in WWD events
- Enhanced signage (DO NOT ENTER and RAMP signs in post-anchored perforated square steel tube legs) placed at ramp terminal—91% reduction in WWD events

- Enhanced signage (change left turn arrow to straight arrow in advance of exit ramp)—76% reduction in WWD events
- Enhanced signage at entrance ramp terminal (MUTCD Treatment 2B-19)—62% decrease in WWD events
- Disconnect power to a luminaire at four-lane divided highway at-grade intersection—55% reduction in WWD events during the night. The disconnected luminaire was one of five at an intersection and was on the mainline approach where drivers were turning left onto the wrong section (the near side as opposed to beyond the median). Lighting the near side had the "moth to flame" effect, especially for drunk drivers. Figure 37 shows the five luminaires at this location; luminaire number 5 was turned off to deter WWD.
- Design changes to partial cloverleaf interchanges to avoid inadvertently creating WWD opportunities, whereby the on and offramps are changed from placement next to one another, only separated by paint to placement 50 feet apart, separated by a depressed median.
- Enhanced signage and pavement markings for partial cloverleaf interchanges have been incorporated into design standards.
- All WWD calls that come into the traffic management center now get coded specifically as WWD events, which increases awareness. WWD alerts are posted to all dynamic message signs within a 10-mile radius.

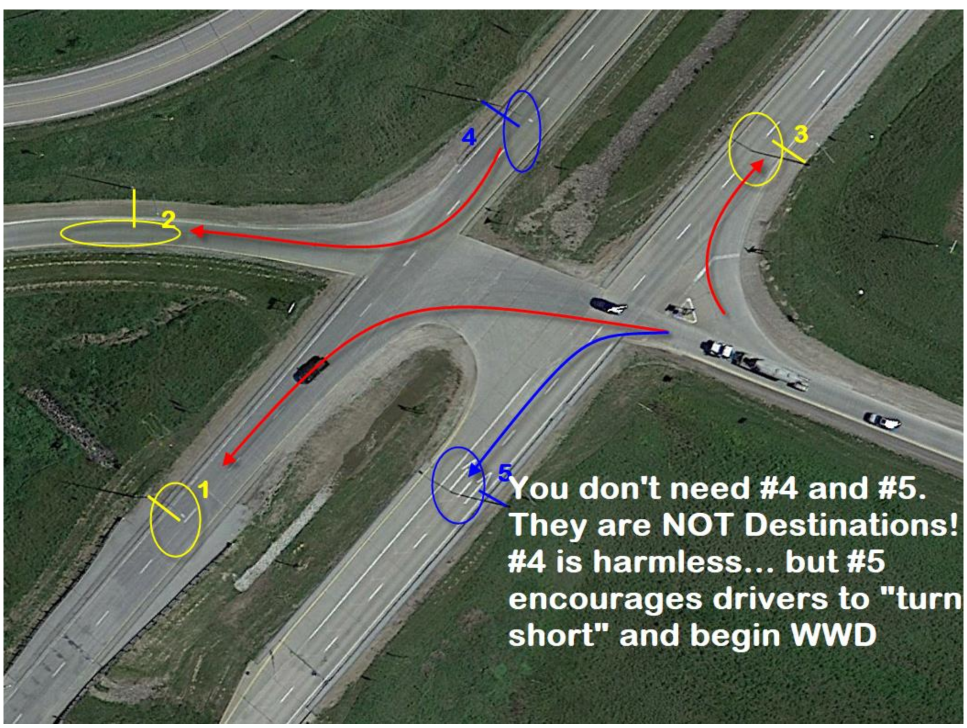


Figure 37. IADOT Location with Luminaire Turned off to Deter Wrong-Way Driving (Sorenson, 2023). Used with permission.

IADOT staff typically monitors a site for more than 6 months, make changes then observes the impact on WWD incidents; then make more changes until the incidents are reduced.

Plans are in place to relocate some permanent cameras from locations where the WWD incidents have been reduced and are no longer a concern to other locations.

Monitoring WWD Incident Detection with a Mobile Camera on a Trailer

A camera mounted on a pole on a trailer for data collection or monitoring of WWD incidents at a site is estimated to be about $35,000 to $40,000 based on information from IADOT (Sorenson, 2023). The other option is to contract with a data collection firm to provide such services.

WWD Signs, Arrows, and Detection Systems Costs

VDOT cost estimates and a vendor's cost estimates for some WWD countermeasures are summarized in Table 13 and below. All costs are in 2023 dollars.

Table 13. Summary of VDOT Estimated Cost for Wrong-Way Driving Countermeasures

Signs	**Cost**
Large DNE (R5-1) 36 in x 36in and WW (R5-1a) 42in x 30in	$1,330
Small DNE (R5-1) and WW (R5-1a)	$1,130
Large DNE (R5-1)	$900
Small DNE (R5-1)	$900
Large WW (R5-1a)	$900
Small WW (R5-1a)	$900
ONE WAY Sign (R6-1, R6-2) R6-1 (36in x 12in)	$710
ONE WAY Sign R6-2 (24in x 30in)	$790
Divided highway, keep right symbol, or word sign R4-7b (24in x 30in)	$790
Divided highway, keep right symbol, or word sign R4-7c (18in x 30in)	$740
No Left (R3-2) and right turn (R3-1) symbol sign R3-1 or R3-2 (24in x 30in)	$790
Markings	
20 ft. Stop Bar	$200
Wrong-Way Arrow	$850
Single turn arrow (i.e., left arrow or right arrow)	$230
Double turn arrow (i.e., left/straight, right/straight, or right/left)	$600
Triple turn arrow (i.e., left/straight/right)	$900
Route shield marking (to denote proper lane to access a route)	$5,000
Delineators	
Flexible post mounted delineators in the median	$140

DNE = DO NOT ENTER; WW = WRONG WAY. (Payne, 2023)

The following provides estimated costs at one ramp as an example.

- Two Large DNE/WW on one post: $1,325 x 2 = $2,650.
- 20 ft. stop bar per location, $195 Stop Bar: $9.75 per linear foot.
- WW Arrow: $850 each.

- Two large WW signs: $1000 x 2 = $2,000.
- Two ONE WAY signs: $800 x 2= $1,600.
- Total estimate: $7,700 to $8,500.

DNE/WW sign combination with one red beacon flasher system like that installed in the Salem district (see Figure 33), with radar detection and electric service costs about $40,000 to $50,000. This cost is likely to be lower if solar power is used instead of electric power (Knight, 2023).

Wrong-Way Signs with Flashing Lights, Activation, and Detection

The following estimates are from a vendor (round up to nearest $100) (Mueller, 2023) and are based on its signs and detection systems.

All WW signs are the 30 in x 42 in. The sign with flashing LEDs has flashing LEDs along the border. The 24/7 signs flash continually and all signs are solar powered.

1. Two solar, 24/7 WW with flashing LEDs signs $8,200.
2. Two solar, 24/7 WW static signs with flashing red beacons (two on each sign mounted above and below the sign) $11,700.
3. Two solar WW internally illuminated signs with flashing LEDs and radar activation $14,200.
4. Two Solar WW internally illuminated signs with flashing LEDs with thermal detection $33,500.

Internally illuminated signs with LEDs can be useful to improve visibility especially where the signs can be visible at night from an angle, for example, where vehicle headlights are aimed ahead and the WW signs are to the left. An internally illuminated sign with flashing LEDs is about $1,000 more than a regular sign with flashing LEDs.

These estimates do not include the communications and data management element that can send alerts to a TMC and others and record WW incident events. A ballpark estimate for item four in the preceding list, internally illuminated signs with flashing LEDs with thermal detection and the communications system is $50,000 to $75,000. In addition, preventive maintenance service is estimated at $6,800 to $7,600 per year. The above costs are estimates and may be lower based on size of the order or economies of scale.

Since FDOT noted that 95% of WW driver self-correct when the WWD system is activated with flashing LEDs in the WW sign, installing a WW sign with LED flashing 24/7 is a lower cost option that does not require the detection system to activate the flashing.

Education: FDOT Example (Alluri et al., 2018)

FDOT encourages drivers to stay right at night to avoid WWD. The Florida Department of Highway Safety and Motor Vehicles (FDHSMV) has been leading extensive education efforts to reduce WWD incidents. FDHSMV is using *#StayRightatNight* to urge drivers to "Stay Right at Night" and avoid a crash while driving the WW. This campaign has generated significant interest on social media. On its website and through several avenues, the FDHSMV offers the following safety tips to avoid WWD crashes.

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

IADOT also encourages driver to stay right at night but in a less formal way through a one-time blog posting and WWD presentations.

Development of Guidance and a Proposed Plan for WWD Countermeasures

Guidance

In discussions during the conduct of the research, the researchers and technical review panel, TRP agreed that for the first set of WWD signs for exit ramps, both a DNE and WW sign on the same post mounted on both sides of the ramp are preferred as the standard for limited access highways (see Figure 31). A major benefit is the increased target area with two signs per post. TOD should consider adding this when the VA Supplement is updated in response to the next version of the MUTCD. Moreover, in general, VDOT has many signs and markings in place to counter WWD. The *NCHRP WWD Handbook* should be used as a reference. VDOT can use the VA Supplement to the MUCTD and the TOD 2017 WWD briefing document to formalize WWD guidance. Some suggested guidance is included in Appendix B. Use of these references are encouraged; there was no attempt to reproduce the bulk of that information in this report.

Proposed Plan

1. Plan and conduct a strategic review of WWD signing on interstate and multilane divided highways as resources permit. Begin with locations with known concerns or issues as a priority from this study and other sources. The review of the locations listed in Tables 8-12, and A1 to A8 that were identified in tasks 3 and 4 may serve as a starting point. Also, since left-turn access at partial cloverleaf, trumpet and diamond interchanges have shown possibility for safety improvement in terms of WWD, these interchanges should also be reviewed. If desired, data on WWD incidents could be gathered using a camera system on a trailer or other traffic monitoring system at specific high priority locations.
2. Review and revise traffic control and channelization as needed.

3. Consider using 24/7 WW signs with flashing beacons or signs with flashing LED borders and other enhancements as deemed necessary. Given that WWD drivers often self-correct after seeing the first flashing beacon or LEDs, beacons or signs that flash 24/7 without WWD detection may be a simpler and less expensive solution than those with WWD detection system and communications to the TOC. There is an option to program the 24/7 WW signs with flashing beacons or with flashing LED borders to flash only during darkness or at night. WWD detection systems are an option as well if deemed appropriate although expensive.
4. Consider a general protocol for maintenance of WW signs. Since they face the opposite direction of most signs, they may be excluded for normal maintenance and inspection.
5. Engage the Location & Design Division for aspects of the plan involving geometric design and new construction. Chapter 5 on geometric design in the *NCHRP WWD Handbook* should be considered as a reference.
6. Consider outreach to law enforcement on aspects of WWD crash reporting and others such as the Virginia Department of Motors Vehicles on education.

Benefit/Cost of Potential Plan

Two case studies from the *NCHRP WWD Handbook* provide some indication of the potential B/C to be derived from WWD countermeasures since crash modification factors were not available. For the first case study, wigwag flashing beacons with WW sign and the extension of longitudinal channelizing devices in the median were installed at one location. The countermeasure costs included the initial construction costs of $50,000 for the wigwag flashing beacons and $17,520 for the longitudinal channelizing devices for the median extension and an annual maintenance cost of $1,300 for the wigwag flashing beacons. A service life of 10 years and a discount rate of 3% were assumed. The B/C ratio was 23.11. In the second case study, Rectangular Rapid Flashing Beacons (RRFBs) with WW signs were installed at an exit ramp. The initial deployment costs, including equipment, design, and construction, were $127,030; the annual maintenance costs were $6,450. The construction and maintenance costs were considered as the average values of the costs reported. The B/C ratio was 8.92.

In the researchers' opinion, case study one's B/C ratio is higher likely because of the inclusion of the channelizing devices to physically prevent the WWD. This represents the higher end treatment with traffic control devices and channelization. For countermeasures focused on traditional signing without flashing beacons or LEDs, we assume a B/C of ½ the B/C ratio of the case study with RRFBs or 4.46, rounded down to 4. This provides a ballpark estimate of the potential benefit of countermeasures for WWD. Based on this information and the two case studies, the potential planning level B/C ratio can range from 4 to 23.

DISCUSSION

- This study developed an approach to identify and review WWD crashes. Interstate WWD crashes were matched to possible entry points (offramps) to identify interchange related risk factors. Although assuming the nearest offramps were WWD entry points was logical, WWD entry seems unlikely in some cases based on the geometrics. One possible reason may be due to an intrinsic error of locations (mile markers) of crash data or interchange influence data. When using the automated function of Excel to find an interchange point downstream of the WWD crash location, if the WWD crash occurred very close to the interchange and the WWD crash mile marker is greater than that IC's gore point, it is assigned to the downstream interchange. For example, in Figure 10, the most upstream (left) WWD crash; 18A, was assigned to the downstream interchange 19A. Also, insufficient information on the crash description in the crash report may also affect the analysis. Even stating "vehicle #1 was traveling in the wrong direction" may not be WWD if that vehicle passed through the median but was not described as doing so.
- Very few crash reports and 911 calls identify the WW entry point in the event description. Not knowing the entry point for WWD is a problem. The WWD weighted scoring method assumes that the interchanges closest to the crash are the likely entry points; there is uncertainty about that assumption, but this method is the best available. One possible solution is to use cameras to monitor WWD activity at suspect locations where WWD may occur. The cost for camera monitoring can be weighed against the cost to update signing and markings and to add channelizing devices as needed to deter WWD crashes.
- In contrast to past systemic research efforts, this review did not have the benefit of using existing safety performance functions and large numbers of crashes to analyze locations. Consequently, although this study started with a systemic approach, the plan developed focuses on a review of potential hotspots or locations where there is a concern for WWD based on the crash and 911 data analyses.
- The availability and analysis of 911 data proved useful for this safety study especially since WWD crash data are a challenge to identify and are limited. 911 data have the potential for being valuable to VDOT for safety analyses but there is a need to improve the geolocation elements. If interested, TOD staff may engage the VSP staff responsible for 911 data to explore opportunities for improving the geolocation elements and using 911 data for safety analyses. District staff may also consider requesting 911 data for WWD or other safety studies where it may be useful.

Based on the above, there is no definitive, accurate means to identify ramps and intersections that may have WWD issues and needs. Using the crash and 911 data, most WWD crash or incident records do not clearly identify the exit ramp or intersection where the initial WWD maneuver occurred.

CONCLUSIONS

- *Wrong-way driving (WWD) crashes on interstates in Virginia are relatively small in number, but more severe than other crash types.*
- *Due to the small numbers of WWD crashes and limitations on identifying WWD entries, systemically analyzing interchange (IC) types or offramps on interstates was not successful.* However, it was found that left-turn access at partial cloverleaf, trumpet, and diamond interchanges have shown a possibility for safety improvement in terms of WWD.
- *The 911 data provided a snapshot of WWD incidents that usually did not result in a crash*. The *NCHRP WWD Handbook* Screening Method Two was applied to the 911 data to develop a ranked list of WWD susceptible interstate exit ramps statewide. Additionally, a detailed review of selected multilane divided highways was undertaken to identify local WWD hotspots.
- *A major limitation of WWD crash and 911 data was the lack of WWD entry point information.* Crash data records included the location of the crash but rarely provided information about the entry point of the WW driver. 911 data records provided a location but typically no context for whether the location indicated the WW driver entry point, the current location of the WW driver, or some other location.
- *Guidance and a plan for using WWD countermeasures were developed with a focus on low-cost countermeasures and a potential review of select locations, corridors or interchange types as needed.* The planning level B/C ratio estimate range 4-23.

RECOMMENDATIONS

1. *VDOT's TOD should implement the guidance and proposed plan described above in the **Development of Guidance and a Proposed Plan for WWD Countermeasures** section to provide guidance on WWD strategies and improve safety for WWD.*

IMPLEMENTATION AND BENEFITS

The researchers and the technical review panel (listed in the Acknowledgments) for the project collaborated to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

The VDOT TOD's TCD Engineering Management Program Manager has agreed to implement the guidance portion related to WWD strategies in Recommendation 1. TOD will develop a plan to implement the results of this study within 18 months of the publication of this report.

The TOD Assistant Division Administrator for Safety has agreed to implement the proposed plan portion in Recommendation 1. TOD will develop a plan to conduct a strategic review of WWD at select locations, corridors and interchange types that were identified in this study. This plan will be done within 18 months of the publication of the report.

VTRC staff will assist TOD staff as needed to support implementation.

Benefits

This study will potentially reduce the number of WWD incidents, which in turn could result in the following benefits: Reduced risk of serious injury and/or fatality due to WWD. The plan developed in this study provides consistent application of countermeasures across the state as well as balancing this with customize countermeasures to address site specific needs The low-cost approach enables more sections to be treated in a comprehensive manner. Based on the case study examples, potential B/C estimates may range from 4 to 23.

ACKNOWLEDGMENTS

The authors acknowledge the contributions of the following people: Marc Lipschultz and Ritchie Robbins for serving as the project champions and being members of the technical review panel; the other members of the technical review panel, Jay Knight, Don Logan, Ryan Krunz, Stephen Read and Lance Dougald; Drew Melusen for reviewing WWD crash data; Tony Payne and other VDOT DTE staff that provided information and VTRC staff who provided assistance, Michael Fontaine and Michael Fitch.

REFERENCES

AASHTO. *Systemic Approach to Wrong Way Driving Safety: Effective Practices Brief: Iowa DOT*, AASHTO, Washington, D.C., 2023.

Alluri, P., Wu, W., Nafis, S. and Hagen, L. 2018. A Data-Driven Approach to Implementing Wrong-way Driving Countermeasures. Prepared for Florida Department of Transportation [fdot-bdv29-977-36-rpt.pdf (windows.net)] last accessed October 2, 2023

Atiquzzaman, M., and Zhou, H. (Modeling the Risk of Wrong-Way Driving Entry at the Exit Ramp Terminals of Full Diamond Interchanges. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2672, 2018, pp.35–47.

Atiquzzaman, M., and H. Zhou. Modeling the risk of Wrong-Way Driving at the Exit Ramp Terminals of Partial Cloverleaf Interchanges. *Journal of Safety Research*, Vol. 81, 2022, pp. 249-258.

Federal Highway Administration, *Manual of Uniform Traffic Control Devices. 2009 Edition with Revision Numbers 1, 2, and 3,* U.S. Department of Transportation, Washington, D.C., 2022.

Florida Department of Transportation. 2023. FDOT Design Manual Section 230. 2023fdm230spavtmarkings.pdf (windows.net) Last accessed October 4, 2023

Florida Department of Transportation website. Wrong-Way Driving (fdot.gov) Last accessed September 28, 2023

Iowa Department of Transportation. Signing Typicals for Wrong Way Driving. September 2023

Jalayer, M., M. Pour-Rouholamin, and H. Zhou. Wrong-Way Driving Crashes: A Multiple Correspondence Approach to Identify Contributing Factors. *Traffic Injury Prevention*, Vol. 19, 2018, pp. 35-41.

Kayes, M.I., Sandt, A., Al-Deek, H., Uddin, N., Rogers, J. H., Jr., and Carrick, G. Modeling Wrong-Way Driving Entries at Limited Access Facility Exit Ramps in Florida. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2673, 2019, pp. 567–576.

Knight, J. Email to B. Cottrell, , September 1, 2023.

Lathrop, S.L., Dick, T.B., Nolte, K.B. Fatal Wrong-Way Collisions on New Mexico's Interstate Highways, 1990–2004, *Journal of Forensic Sciences*, Vol. 55, No. 2, March 2010, pp. 432-437.

Mueller, L. Emails to B. Cottrell,September 13, 2023,September 28,2023 and October 2, 2023.

Payne, A. Emails to B. Cottrell, September 1, 2023, and September 26, 2023.

Pour-Rouholamin, M., Zhou, H., Zhang, B., and Turochy, R.E. Comprehensive Analysis of Wrong-Way Driving Crashes on Alabama Interstates. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2601, 2016, pp. 50–58.

Rogers, J. H., Jr., Sandt, A., Al-Deek, H., Alomari, A.H., Uddin, N., Gordin, E., Dos Santos, C., Renfrow, J. and Carrick, G. Wrong-Way Driving: Multifactor Risk-Based Model for Florida Interstates and Toll Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2484, 2015, pp.119–128.

Rogers, J.H., Jr., Al-Deek, H., Alomari, A.H., Gordin, E., and Carrick, G. Modeling the Risk of Wrong-Way Driving on Freeways and Toll Roads. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2554, 2016, pp. 166–176.

Sandt, A. and Al-Deek, H. An Optimization Approach for Deployment of Intelligent Transportation Systems Wrong-Way Driving Countermeasures. *Journal of Intelligent Transportation Systems*, Vol. 24, 2020, pp. 40-53.

Sandt, A., Al-Deek, H., and Rogers, J.H., Jr. Identifying Wrong-Way Driving Hotspots by Modeling Crash Risk and Assessing Duration of Wrong-Way Driving Events.

Transportation Research Record: Journal of the Transportation Research Board, No. 2616, 2017, pp. 58–68.

Sandt, A., Al-Deek, H., Blue, P., and McCombs, J. Statewide Application of Wrong-Way Driving Crash Risk Modeling and Countermeasures Optimization Algorithm to Identify Optimal Locations for Countermeasure Deployment on Florida Limited Access Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2675, 2021, pp. 252–264.

Simpson, S. and Bruggeman, D. *Detection and Warning Systems for Wrong-Way Driving*. FHWA-AZ-15-74. Federal Highway Administration, United States and Arizona Department of Transportation, Phoenix, AZ, 2015.

Sorenson, W. Emails to B. Cottrell, September 22, 2023 and August 3, 2023

Virginia Department of Transportation, Virginia Supplement to the 2009 Manual on Uniform Traffic Control Devices (MUTCD), Richmond, Va.

Virginia Department of Transportation, Traffic Engineering Division. Wrong Way Driving (WWD) Strategies (Briefing for 9/19/17 DTE Meeting). Richmond, Va.

Zhou, H., Chang, Q., Song, Y., Jalayer, M., Hosseini, P., Lin, P. Chen, C., Tobias, P. A. *Wrong-Way Driving Solutions Handbook*, NCHRP Research Report 1050. Transportation Research Board; Washington, D.C. 2023

Zhou, H., Zhao, J., Pour-Rouholamin, M., and Tobias, P.A. Statistical Characteristics of Wrong-Way Driving Crashes on Illinois Freeways. *Traffic Injury Prevention,* Vol. 16, No. 8, June 2015, pp. 760-767.

Villavicencio, L.I., Añorve, V., and Arnold, L.S. *Researcg Brief: Fatal Wrong-Way Crashes on Divided Highways.* AAA Foundation for Traffic Safety, Washington, D.C., 2021.

APPENDIX A

INTERSTATE WWD CRASHES BY DISTRICT (JANUARY 2016 TO JULY 31, 2022)

Table A1. Staunton District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-64E	21.025	37.78784	-79.8957	1.K
I-81N	178.477	37.65302	-79.5465	1.K
I-81N	208.941	37.97107	-79.1923	1.K
I-81N	215.407	38.04289	-79.1228	1.K
I-81N	296.688	39.00719	-78.3736	1.K
I-81N	300.788	39.00679	-78.3043	1.K
I-81N	317.592	39.20432	-78.1351	1.K
I-81S	219.009	38.07982	-79.0833	1.K
I-81S	274.331	38.76037	-78.6369	1.K
I-81S	311.183	39.12365	-78.1889	1.K
I-81S	221.278	38.1073	-79.0628	2.A
I-66W	9.405	38.94736	-78.1528	3.B
I-81N	293.475	38.98103	-78.4201	3.B
I-81N	323.56	39.27737	-78.0909	3.B
I-81N	323.937	39.28247	-78.0885	3.B
I-81S	246.975	38.43133	-78.8737	3.B
I-81S	258.644	38.56034	-78.7461	3.B
I-81S	309.988	39.10839	-78.2011	3.B
I-81S	325.018	39.29523	-78.0817	3.B
I-81N	265.199	38.64224	-78.6799	5.O
I-81S	230.276	38.21935	-78.9878	5.O
I-81S	246.281	38.42233	-78.8811	5.O

Table A2. Richmond District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-195N	0.622	37.55781	-77.4894	1.K
I-295S	14.047	37.3283	-77.3411	1.K
I-64W	219.52	37.48398	-76.9411	1.K
I-95N	45.712	37.14789	-77.355	1.K
I-95N	57.653	37.30237	-77.392	1.K
I-95N	62.346	37.3682	-77.4036	1.K
I-95S	56.928	37.29194	-77.3907	1.K
I-295N	1.32	37.17536	-77.3396	2.A
I-295S	51.128	37.66991	-77.5824	2.A
I-64E	150.043	37.87402	-78.0188	2.A
I-64E	Ramp 186B	37.58646	-77.4759	2.A
I-64E	Ramp 192B	37.55525	-77.4092	2.A
I-64W	193.655	37.5467	-77.3957	2.A
I-95N	74.97	37.5402	-77.4268	2.A
I-95S	67.609	37.43742	-77.4302	2.A
I-95S	74.022	37.52687	-77.429	2.A
I-95S	82.169	37.61957	-77.4441	2.A
I-95S	Ramp 98A	37.84214	-77.4515	2.A
I-295N	Ramp 28D	37.52208	-77.2698	3.B
I-295S	7.549	37.24898	-77.3031	3.B
I-64W	186.609	37.59159	-77.4803	3.B
I-64W	191.119	37.55086	-77.4286	3.B
I-85N	15.828	36.75555	-78.0901	3.B
I-85N	53.194	37.07552	-77.5693	3.B
I-85S	59.201	37.14946	-77.5141	3.B
I-95S	Ramp 74C	37.54058	-77.4273	3.B
I-295N	29.598	37.53456	-77.2762	5.O
I-295N	48.763	37.68085	-77.5412	5.O
I-295N	51.31	37.66905	-77.5874	5.O
I-64W	164.748	37.73322	-77.8269	5.O
I-85N	38.257	36.92502	-77.7559	5.O
I-85S	12.512	36.71315	-78.1138	5.O
I-95N	Ramp 74C	37.54015	-77.4264	5.O
I-95S	53.394	37.24462	-77.3936	5.O
I-95S	75.941	37.55081	-77.4379	5.O
I-95S	76.999	37.55886	-77.4523	5.O
I-95S	86.733	37.68445	-77.4522	5.O

Table A3. Hampton Roads District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-264E	3.89	36.81899	-76.3432	1.K
I-264E	24.413	36.84639	-75.9985	1.K
I-564W	1.571	36.93407	-76.2979	1.K
I-64W	227.702	37.41993	-76.8179	1.K
I-664N	12.209	36.88529	-76.4298	1.K
I-664S	4.404	36.98731	-76.4274	1.K
I-264E	13.223	36.84584	-76.1883	2.A
I-264E	14.845	36.84005	-76.1619	2.A
I-264R	12.708	36.84674	-76.1956	2.A
I-464S	5.048	36.8269	-76.2844	2.A
I-64E	279.336	36.90289	-76.239	2.A
I-64R	3.344	36.88794	-76.2288	2.A
I-64W	279.34	36.90287	-76.238	2.A
I-64W	286.151	36.82316	-76.1946	2.A
I-664N	4.708	36.98501	-76.4271	2.A
I-95N	4.341	36.6066	-77.564	2.A
I-264E	18.88	36.8388	-76.0928	3.B
I-264E	20.498	36.8359	-76.0657	3.B
I-264W	10.127	36.84581	-76.2464	3.B
I-64E	228.049	37.41768	-76.8125	3.B
I-64E	268.365	37.01685	-76.3278	3.B
I-64E	279.513	36.90165	-76.2365	3.B
I-64E	281.318	36.88269	-76.2175	3.B
I-64E	298.485	36.77324	-76.3658	3.B
I-64E	299.858	36.77889	-76.3871	3.B
I-64R	3.345	36.88793	-76.2287	3.B
I-64R	3.447	36.88671	-76.2277	3.B
I-664E	Ramp 15A	36.78781	-76.3989	3.B
I-664N	4.409	36.98928	-76.4262	3.B
I-664N	5.949	36.96899	-76.4163	3.B
I-664W	Ramp 6B	36.98006	-76.4233	3.B
I-264W	3.152	36.81002	-76.353	4.C
I-64W	232.778	37.37175	-76.7512	4.C
I-95N	18.525	36.76937	-77.4658	4.C
I-264E	6.094	36.82942	-76.3081	5.O
I-264E	15.306	36.83635	-76.1558	5.O
I-264E	18.505	36.83722	-76.1011	5.O
I-264E	18.569	36.83783	-76.0993	5.O
I-264E	24.557	36.84628	-75.9957	5.O
I-264W	8.581	36.8446	-76.2731	5.O

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-264W	21.048	36.83733	-76.0588	5.O
I-264W	Ramp 16A	36.83887	-76.1588	5.O
I-264W	Ramp 7A	36.83114	-76.3029	5.O
I-64E	277.132	36.91723	-76.2676	5.O
I-64E	279.238	36.90322	-76.2414	5.O
I-64E	299.5	36.7778	-76.3814	5.O
I-64U	Ramp 243A	37.23635	-76.6349	5.O
I-64W	226.516	37.42772	-76.8377	5.O
I-64W	247.056	37.21466	-76.5906	5.O
I-64W	275.671	36.93887	-76.2653	5.O
I-664N	1.103	37.02041	-76.3822	5.O
I-664N	2.858	37.00228	-76.4048	5.O

Table A4. Northern Virginia District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-495N	11.316	38.91865	-77.2168	1.K
I-95S	174.844	38.80288	-77.107	1.K
I-95S	Ramp 166B	38.7433	-77.1894	1.K
I-395N	8.544	38.86024	-77.0695	2.A
I-395S	3.995	38.81884	-77.1316	2.A
I-495N	11.56	38.92278	-77.2156	2.A
I-495S	13.958	38.95155	-77.1966	2.A
I-66E	72.162	38.89075	-77.1036	2.A
I-66E	73.583	38.89667	-77.0827	2.A
I-66W	52.717	38.84203	-77.4426	2.A
I-95N	174.2	38.80148	-77.1123	2.A
I-95N	177.572	38.79348	-77.0521	2.A
I-95S	Express Ramp 0A	38.79557	-77.0605	2.A
I-395N	1.943	38.80227	-77.1632	3.B
I-395R	2.203	38.80451	-77.1605	3.B
I-395R	3.579	38.81556	-77.1384	3.B
I-395S	3.916	38.86739	-77.0488	3.B
I-495S	Ramp 51B	38.866	-77.224	3.B
I-66E	74.097	38.89858	-77.0715	3.B
I-66W	70.506	38.87946	-77.1354	3.B
I-66W	Ramp 43B	38.79968	-77.5926	3.B
I-95R	29.995	38.68251	-77.2295	3.B
I-95S	149.212	38.53093	-77.36	3.B
I-95S	171.252	38.79103	-77.1703	3.B
I-95S	Ramp 173A	38.79649	-77.1395	3.B
I-395N	1.501	38.79751	-77.1687	4.C

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-395N	Ramp 10A	38.87085	-77.045	5.O
I-395R	6.921	38.84033	-77.0852	5.O
I-395R	7.437	38.84623	-77.0797	5.O
I-395R	9.014	38.8659	-77.0669	5.O
I-395S	3.179	38.86699	-77.0596	5.O
I-395S	5.661	38.8327	-77.106	5.O
I-395S	7.602	38.84832	-77.0785	5.O
I-495S	11.253	38.91726	-77.2175	5.O
I-495S	11.949	38.92702	-77.2139	5.O
I-495S	12.761	38.93788	-77.2072	5.O
I-495S	Express Ramp 6A	38.9206	-77.2167	5.O
I-66E	64.232	38.8825	-77.2304	5.O
I-66U	Ramp 43B	38.79804	-77.6067	5.O
I-66W	24.08	38.89228	-77.9098	5.O
I-95N	156.274	38.6192	-77.2971	5.O
I-95N	163.138	38.69135	-77.2265	5.O
I-95N	Ramp 169C	38.773	-77.1819	5.O
I-95R	Ramp 158A	38.65869	-77.2797	5.O
I-95S	173.18	38.79646	-77.136	5.O
I-95S	Ramp 173A	38.79671	-77.1395	5.O

Table A5. Culpeper District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-64E	113.644	38.03502	-78.61695	1.K
I-64E	159.748	37.78027	-77.88768	1.K
I-66W	35.177	38.83229	-77.73681	1.K
I-64E	124.547	38.02077	-78.42806	2.A
I-64E	158.003	37.79773	-77.91196	2.A
I-64W	124.73	38.02159	-78.42438	2.A
I-64W	129.111	38.00155	-78.35123	2.A
I-64W	161.84	37.76288	-77.86587	2.A
I-64W	145.113	37.92388	-78.08123	5.O

Table A6. Fredericksburg District Interstates Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-95S	124.63	38.21299	-77.49814	1.K
I-95S	137.067	38.37789	-77.45912	1.K
I-95N	125.331	38.22636	-77.49931	2.A
I-95N	143.149	38.45516	-77.40787	2.A
I-95S	117.901	38.11793	-77.51756	2.A
I-95S	140.821	38.42244	-77.42225	2.A

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-95S	107.908	37.97557	-77.49252	4.C
I-95R	11.352	38.46551	-77.40751	5.O
I-95S	108.421	37.97372	-77.492521	5.O

Table A7. Salem District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-81N	156.115	37.45293	-79.84701	2.A
I-81S	102.119	37.08725	-80.64317	2.A
I-77N	12.789	36.72111	-80.74701	3.B
I-81S	103.45	37.08696	-80.61867	3.B
I-77N	1.604	36.58546	-80.74182	5.O
I-81S	127.544	37.22295	-80.25606	5.O
I-81S	133.875	37.26366	-80.16	5.O
I-81S	Ramp 143A	37.34112	-79.99759	5.O
I-81S	Ramp 98B	37.08141	-80.69068	5.O

Table A8. Bristol District Interstate Wrong-Way Driving Crashes

Route Name	Crash Mile Point	Latitude	Longitude	Severity
I-81S	39.932	36.80959	-81.61471	2.A
I-81S	74.966	36.9459	-81.04644	2.A
I-381S	0.868	36.61921	-82.18245	3.B
I-77N	65.559	37.24291	-81.11285	3.B
I-81N	15.117	36.69371	-82.01136	3.B
I-81N	53.476	36.87785	-81.39582	3.B
I-81N	85.198	36.9552	-80.86258	3.B
I-81N	9.073	36.64091	-82.0962	5.O
I-81N	31.882	36.7813	-81.73924	5.O

APPENDIX B

WWD TRAFFIC CONTROL DEVICE INFORMATION

The following design guidelines for signs and markings are adapted from the *NCHRP WWD Handbook*.

Design Guidelines for Signs

General Considerations

- Ensure that signs are positioned to face drivers and are clearly visible.
- Consider the optional use of oversized and supplemental signs assembled on the same signpost to enhance their visibility and conspicuity.
- Consider using a lower mounting height for DNE and WW signs where appropriate.
- Consider various optional enhancements to increase the conspicuity of signs at night, including red retroreflective strips on signposts, flashing light-emitting diode (LED) borders, or flashing beacons.
- Reduce the complexity of the ramp terminal by providing better directional signs.

Table B1. *NCHRP WWD Handbook* Design Guidelines for Signs

Sign	Guidelines
"Do Not Enter" (DNE)	• DNE sign should be angled to face potential WW drivers. • Use the DNE sign on the left and right sides of offramp terminals and unsignalized intersections on multilane highways. • Use the DNE sign at the end of one-way frontage roads that lead from freeway offramps. • DNE signs can be mounted on the same signpost with supplemental signs (e.g., OW sign, WW sign).
"Wrong Way" (WW)	• Place at least one WW sign along offramps. • Place the first set of WW sign(s)/arrow(s) within 100 ft. of the potential WWD starting point (Chang et al., 2019; Atiquzzaman and Zhou, 2020). • Consider using a second set of WW signs or additional WW signs on the back side of existing signage along offramps closer to the freeway mainline at high-risk locations (Chang et al., 2019) • Place WW signs) along one-way frontage roads that lead from freeway offramps. • Ensure the WW sign faces potential WW drivers and avoids facing right-way drivers.
"One Way" (OW)	• Place at least one set of OW signs at intersections of offramps and crossroads parallel to one-way ramps facing each direction of travel on crossroads. • Use the OW sign at ramp terminals for higher visibility at night.
"Keep Right"	• Use the "Keep Right" sign at the median for parallel on and offramps and multilane highways with a wide median. • Consider oversized "Keep Right" signs at large intersections.
"No Right Turn"/ "No Left Turn" (turn prohibition)	• Place turn prohibition signs where road users intending to make WW movements will most easily see them. • Add turn prohibition signs adjacent to traffic signal indications where appropriate.

Sign	Guidelines
	• Install additional turn prohibition signs at the right or left corner facing potential right- or left-turning WW drivers. • Consider oversized or light-emitting diode turn prohibition signs at high-risk locations.

Design Guidelines for Pavement Markings

General Considerations

- Ensure that pavement markings complement the geometry of the location and provide positive guidance to drivers about proper direction and movement.
- Ensure that pavement markings and signs are consistent to reinforce the information conveyed to drivers.
- Consider various optional pavement marking enhancements to increase conspicuity (particularly at night).

Table B2. ***NCHRP WWD Handbook*** **Design Guidelines for Pavement Markings**

Sign	Guidelines
In-lane arrow	• Place appropriate lane-use arrows on the approach to ramps and at intersections with ramps. • Avoid placing lane-use arrows where they can be misunderstood and possibly result in wrong-way (WW) maneuvers. • Use at least one set of WW arrows along offramps. • Place the first set of WW arrows before the first set of WW signs. • Consider using the second set of WW arrows before the second set of WW signs.
Longitudinal lines	• Use longitudinal lines to help drivers recognize the appropriate direction of travel. • Use lane line extensions to guide vehicles through ramp terminals with large turn radii or with adjacent on- and offramps.
Stop line	• Place stop lines at the end of offramps. • Consider using a 24-in.-wide stop line. • Move the stop lines for left turns on the crossroad forward at two-way ramp terminals. • Move the stop lines for right-turns on the crossroad backward to prevent WW right turns onto offramps.
Enhanced delineation	• Use red retroreflective raised pavement markers to enhance the visibility of pavement markings (lines, arrows, etc.) on offramps. • Use barrier delineators to warn WW drivers. • Use painted islands between on- and offramps.
Other pavement markings	• Consider using advanced WW-related pavement markings on offramps, such as Interstate route shield pavement markings, LaneAlert 2X, and directional rumble strips.

Multilane Divided Highways Sign Layouts

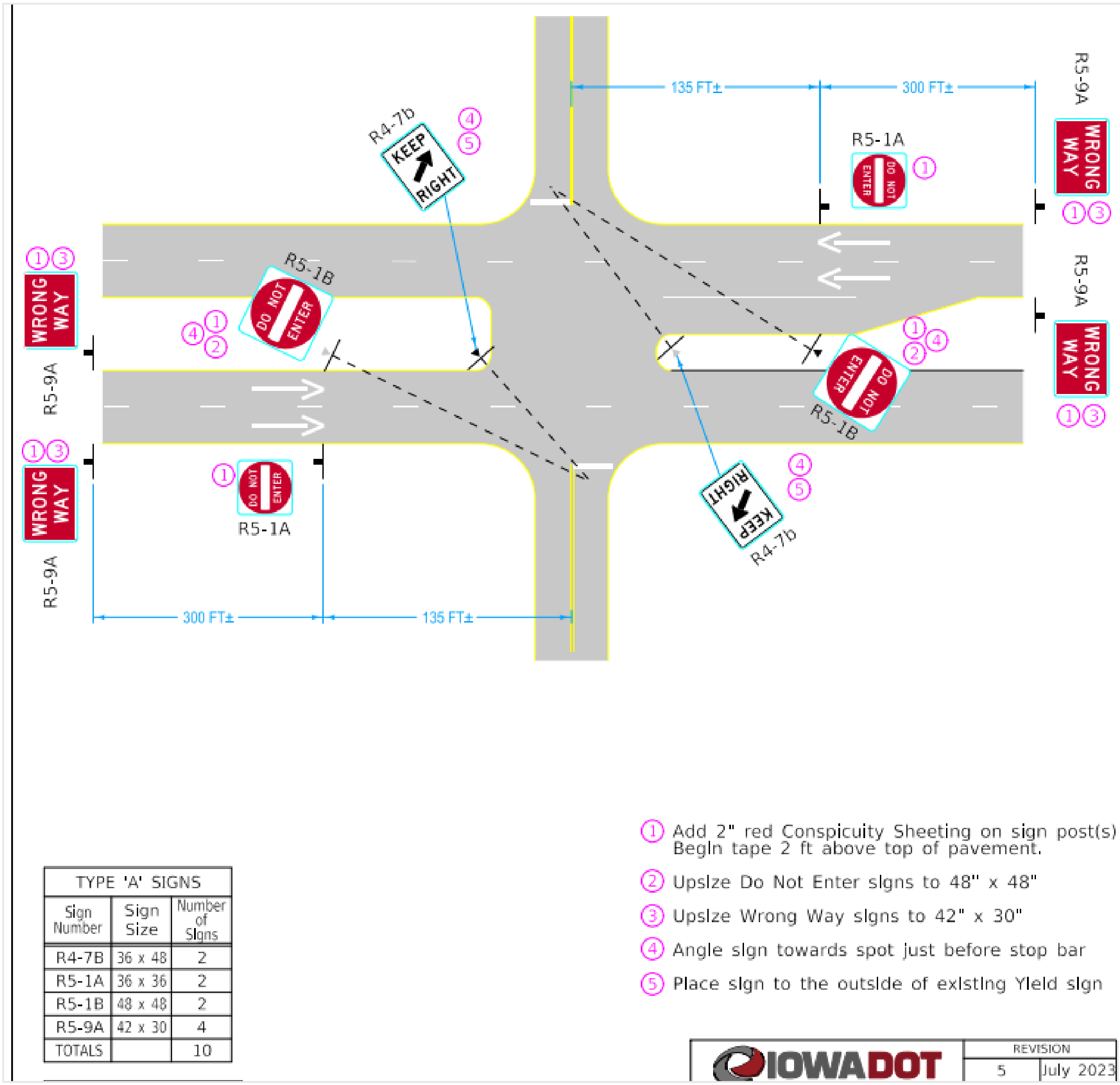


Figure B1. Iowa DOT Signing typical for Wrong-Way Driving at Multilane Divided Intersections (Iowa DOT, 2023). Used with permission.

Iowa DOT recently changed from the graphic version of KEEP RIGHT (R4-7c) to the text version (R4-7b) on a hunch it would be better (against the commonly held belief that graphics are better). The effectiveness of this change is being studied at 5 locations using the WWD detection camera.

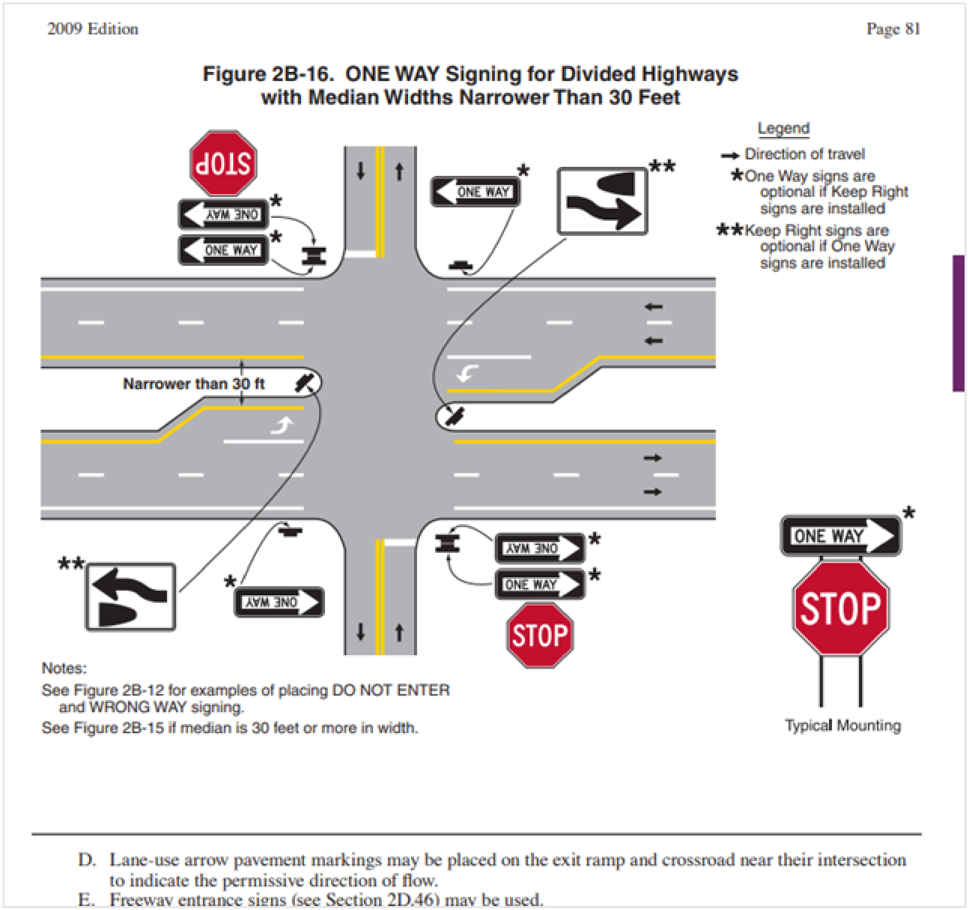


Figure B2. MUTCD Guidance for ONE WAY Signing for Medians Less Than 30 Feet

Limited Access Highways Sign Layouts

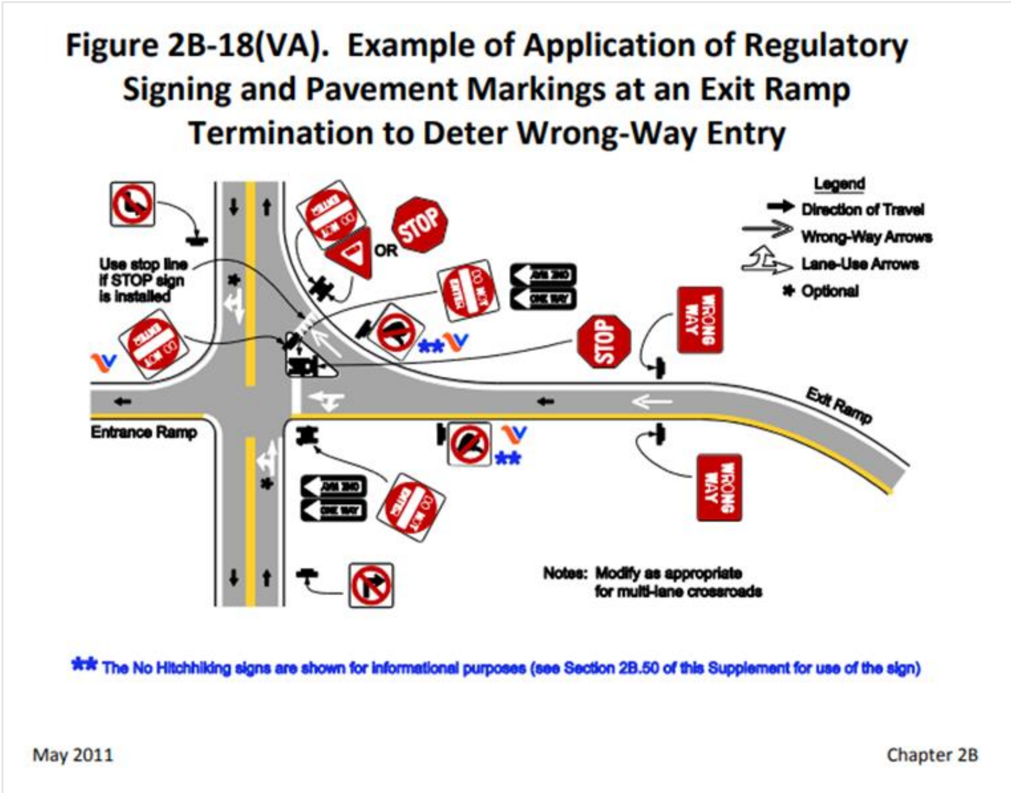


Figure B3. VA Supplement MUTCD Example for Wrong-Way Driving Sign at Exit Ramp

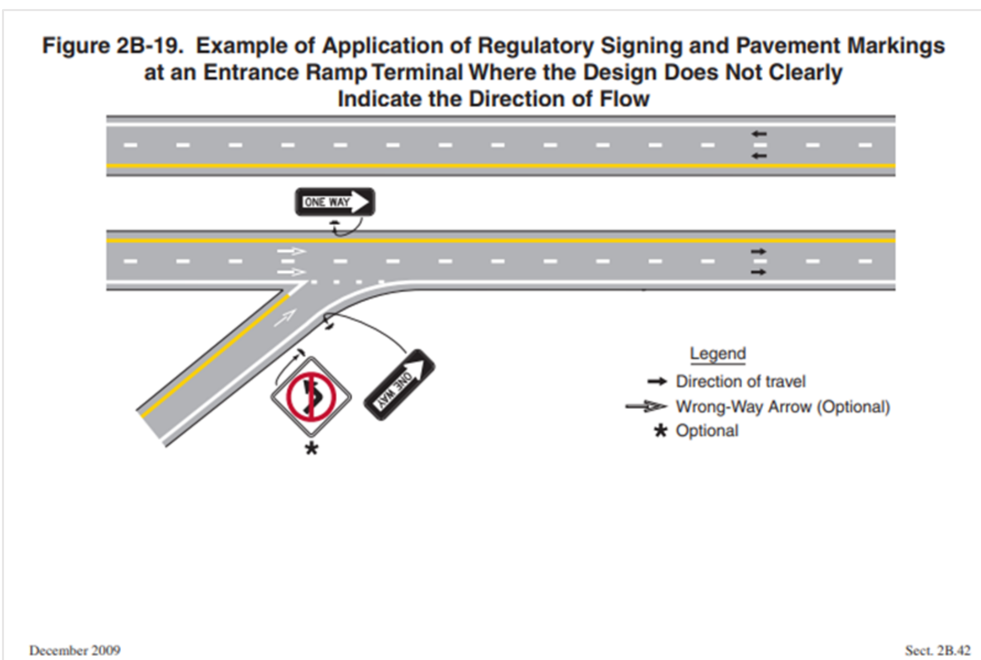


Figure B4. MUTCD Entry to Mainline