Last updated: January 2022

This guide contains a compilation of research and analyses examining the phenomenon, statistics, risk factors, mitigation and prevention of wrong-way driving (WWD).

To explore the research cited here, look for footnote citations (here's an example[0]) and the "Recommended research" section below each topic. The footnotes cite research studies used to provide listed statistics for a topic. The "Recommended research" sections contain short lists of essential research reports and studies on that topic for you to bookmark and explore deeper.

Keep in mind this guide is not exhaustive. There is extensive research, both completed and ongoing, on WWD causes, mitigation and prevention. As more research is conducted, this research guide too will be updated.

Note: unless otherwise stated, the cited research and statistics are from the United States (US).

Recommended research

For an essential, comprehensive overview of WWD in the US:

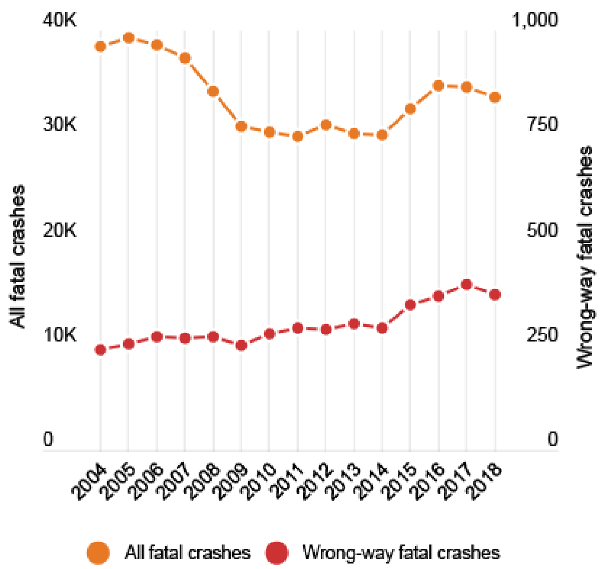
- "Wrong-Way Driving: Highway Special Investigation Report," *National Transportation Safety Board*. Report Number NTSB/SIR-12/01. Washington, DC. 2012.

This NTSB special investigative report is among the most cited studies on WWD in the US. It takes a wide and focused view into the causes and issues affecting WWD crashes, then introduces and evaluates the various safety countermeasures that help mitigate and prevent WWD.

Contents

WWD Statistics: Incidents and Fatalities

The US has a persistent problem with WWD crashes and fatalities. The graphs below, compiled from 2004-2018 crash data, show how WWD fatal crashes and fatalities compare to the overall fatal crash and fatality rates.



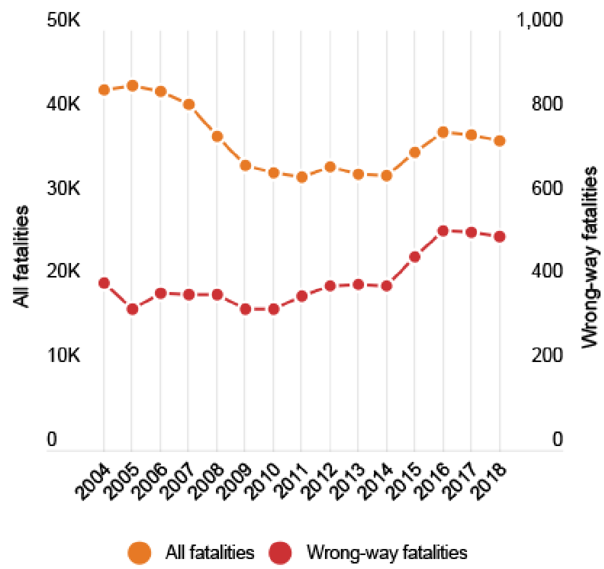


Figure 1: All vs. WWD fatal crashes / All vs. WWD total fatalities (2004-2018)[1]

Previous analysis showed that despite overall motor vehicle fatalities decreasing, the number of WWD-related fatalities remained steady. However, as the above recent data suggests, it appears wrong-way crashes and fatalities have been increasing over the 2010s.[2]

Recommended research

For the latest data on WWD crashes and fatalities:

- "Research Brief: Fatal Wrong-Way Crashes on Divided Highways," *AAA Foundation for Traffic Safety*. 2021.

This report from 2021 analyzes 2010-2018 crash and fatality from the Fatality Analysis Reporting System (FARS) database to determine how many WWD fatal crashes and fatalities occurred compared to other crashes. It then discusses WWD causes and references key research in the field.

[1] Data from:

- 2004-2011: "Overview of Wrong-Way Driving Fatal Crashes in the United States," Fatemeh Baratian-Ghorghi, Huaguo Zhou and Jeffrey Shaw. *ITE Journal*. August 2014. 41-47. Page 42.
- 2011-2018 (for all fatalities): "Early estimate of motor vehicle traffic fatalities for the first half (January–June) of 2021" (Crash Stats Brief Statistical Summary. Report No. DOT HS 813 199). National Center for Statistics and Analysis. *National Highway Traffic Safety Administration*. 2021.
- 2011-2018 (for WWD): "Research Brief: Fatal Wrong-Way Crashes on Divided Highways," *AAA Foundation for Traffic Safety*. March 2021.

[2] "Research Brief: Fatal Wrong-Way Crashes on Divided Highways," *AAA Foundation for Traffic Safety*. March 2021. Page 6.

State-by-state breakdown

WWD fatal crashes and fatalities do not occur in the same rates in all states. The table below shows the top 10 states with the highest rate of WWD fatalities. These 10 states account for over 50% the national totals.

State	% of US total
Texas	14%
California	10%
Florida	8%
Pennsylvania	4%
Missouri	4%
Illinois	3%
Georgia	3%
Mississippi	3%
Tennessee	3%
Arizona	3%

Table 1: US WWD fatalities by state, top 10 (2004-2011)[3]

Severity

WWD crashes tend to be far more severe than typical crashes. They tend to be head-on collisions occurring at highway speeds. **Studies have shown that wrong-way collisions are around 12[4] to 27[5] times more likely to result in a fatality than other types of crashes.**

Recommended research

For more information on WWD crash severity and how risk factors contribute:

- "Modeling Wrong-way Driving (WWD) crash severity on arterials in Florida," Cecilia Kadeha et al. *Accident Analysis and Prevention*, Volume 151. 2021.

This study analyzes 2012-2016 crash data on Florida arterials to determine the average severity of a WWD crash. The overall results find that of the 926 WWD crashes included, 26% resulted in severe or fatal injury, 39% resulted in minor injury, and the remaining 35% resulted in no injury. The authors then examine how risk factors increase or decrease severity. They end with a recommendation to states to leverage their existing traffic signals on arterials by adding a wrong-way vehicle detection and alert system.

[3] 2004-2011: "Overview of Wrong-Way Driving Fatal Crashes in the United States," Fatemeh Baratian-Ghorghi, Huaguo Zhou and Jeffrey Shaw. *ITE Journal*. August 2014. 41-47. Page 43.

[4] Cited in NTSB report from a study using California data: "Prevention of Wrong-Way Accidents on Freeways," FHWA/CA-TE-89-2, J. E. Copelan. *California Department of Transportation* and *Federal Highway Administration*. 1989.

[5] Cited in NTSB report from a study using Virginia data: "Measures for Preventing Wrong-Way Entries on Highways," Report Number VHRC 72-R41, N. K. Vaswani. *Virginia Highway Research Council*. 1973.

Risk Factors contributing to WWD

There are a variety of risk factors that correlate and contribute to WWD incidents and fatalities. These include driving impairment, driver age, time of day, roadway design, lighting conditions and more.

Recommended research

For an essential, comprehensive analysis of the risk factors involved in WWD crashes:

- "The odds of wrong-way crashes and resulting fatalities: A comprehensive analysis," Raj V. Ponnaluri. *Accident Analysis and Prevention*, Volume 88. 2016.

This analysis reviews around 1 million crash records across 2003-2010 from Florida and uses statistical models to determine the odds of WWD crashes due to several contributing risk factors, including driver age, gender, impairment and others. The author then recommends that states consider implementing advanced wrong-way detection and alert systems that notify local traffic authorities and help to prevent WWD events before they happen.

For more on the risk factors which may disproportionately contribute to fatal WWD crashes:

- "Multiple Correspondence Analysis of Wrong-Way Driving Fatal Crashes on Freeways," Yukun Song et al. *Transportation Research Record*, Volume 2675, No. 10. 2021.

This study examines 14 years (2004-2017) of WWD crash data from the Fatality Analysis Reporting System (FARS) database and determines four clusters of factors which contribute to fatal WWD crashes: (1) younger drivers, driving under the influence (DUI), midnight/early morning, lower speed limit (45–50 mph), urban areas, and street lighting; (2) older drivers, non-DUI drivers, and daylight; (3) dark/no light, 18:00 to 23:59 p.m., higher speed limits (65 mph or more), and rural areas; and (4) rain/snow/sleet/hail/fog, and wet road surface.

Driver impairment

Impairment from alcohol and other drugs is one of the top risk factors contributing to WWD fatalities. A systematic review from the NTSB found that **over 50% to nearly 75% of wrong-way drivers are impaired by alcohol**.[6] A 2021 review of 2010-18 national crash data (shown in the graph below) found that 60.1% of wrong-way drivers causing fatal crashes were impaired with a blood alcohol concentration (BAC) of 0.08 g/dL or higher, compared to 11% of right-way drivers.[7]

[6]. 2012. "Wrong-Way Driving: Highway Special Investigation Report," *National Transportation Safety Board*. Report Number NTSB/SIR-12/01. 2012. Page 40.

[7] "Research Brief: Fatal Wrong-Way Crashes on Divided Highways," *AAA Foundation for Traffic Safety*. March 2021. Page 3.

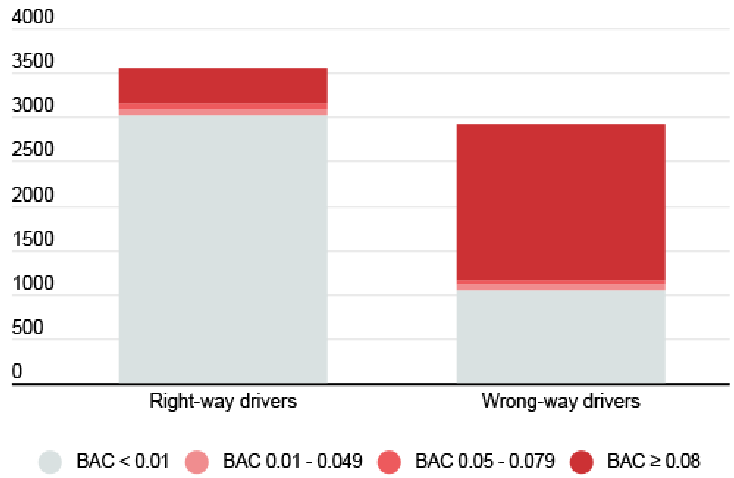


Figure 2: Right-way drivers vs. wrong-way drivers' blood alcohol concentration (BAC) involved in fatal crashes (2010-2018)[8]

Driver age

Elderly drivers (70+ years old) are disproportionately wrong-way drivers. A 2021 review of 2010-18 national crash data found that over two-thirds of drivers aged 70-79 years and involved in a fatal collision were wrong-way drivers, while 91.9% of drivers aged 80 years and older were wrong-way drivers.

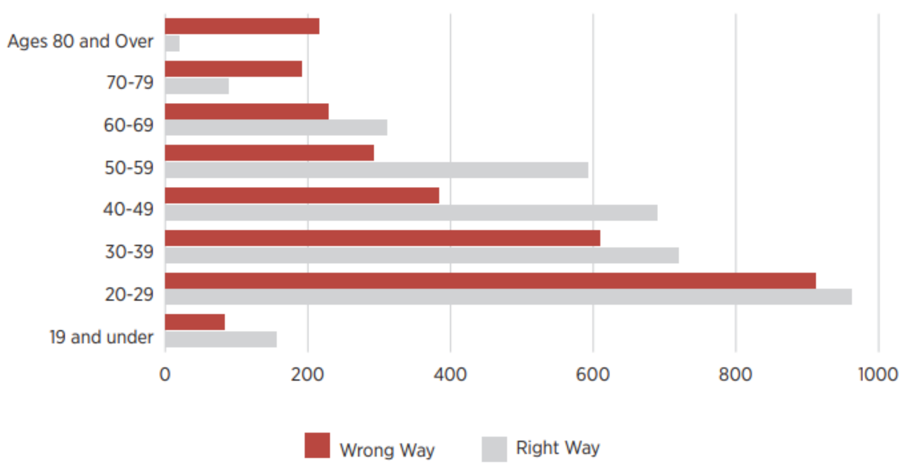


Figure 3: Age distribution of wrong-way and right-way drivers involved in fatal crashes (2010-2018)[9]

This is likely due to age-related fatigue, illness, dementia or other factors.[10]

[8] "Research Brief: Fatal Wrong-Way Crashes on Divided Highways," *AAA Foundation for Traffic Safety*. March 2021. Page 3.

[9] Ibid. Page 4.

[10] "The odds of wrong-way crashes and resulting fatalities: A comprehensive analysis," Raj V. Ponnaluri. *Accident Analysis & Preventio*n, Volume 88. 2016. 105–116. Page 110.

Driver gender

Males are disproportionately wrong-way drivers. A 2021 review of 2010-18 national crash data found that approximately 70% of wrong-way drivers are male, while 29% are female.

	Right-way drivers	Wrong-way drivers
Male	2502 (70.8%)	2071 (70.9%)
Female	1034 (29.2%)	849 (29.1%)

Table 2: Gender distribution of right-way and wrong-way drivers involved in fatal crashes (2010-2018)[11]

One reason for this may be that "a higher percentage of males were driving at excessive speeds, following vehicles too closely, and disregarding traffic signal indications."[11] However, other research has found no statistically significant relationship between gender and WWD crashes.[12]

Time of day/week

Most wrong-way crashes, especially those that result in fatalities, occur during the dark hours of the day. An FDOT study of 2009-2013 data found that 55% WWD crashes occur between midnight and 6 a.m., while 70% of the fatal WWD crashes occurred in that same time period.[13] A review of 2004-2009 WWD crash data from Illinois found that about 51% of WWD crashes occurred between midnight and 5 a.m.[14]

Increased prevalence of WWD at night also points to inadequate roadway lighting. One study analyzing 15 years of crash data from Illinois and Alabama noted that inadequate lighting at intersections increases the likelihood of more severe injuries, especially in rural areas.[15]

Weekends tend to see more wrong-way crashes. Despite slight variations, most research around the US reflects this. An FDOT study of 2009-2013 data found that 61% of crashes occurred on Friday, Saturday or Sunday.[16] A similar review of 2004-2009 WWD crash data from Illinois found that around 43% of WWD crashes occurred on weekends.[17]

Type of interchange

Certain interchange types are more prone to WWD entry. For example, an analysis of 2011-15 data from Florida found that trumpet and directional interchanges tended to have a higher chance of WWD entry when compared to partial and full cloverleaf style interchanges.[18]

However, a particular interchange type's risk of a WWD entry can vary between different states. A comparative analysis examining 2009-13 data from Alabama and Illinois found that 40% of the studied full-diamond

[11] "The odds of wrong-way crashes and resulting fatalities: A comprehensive analysis," Raj V. Ponnaluri. *Accident Analysis & Prevention*, Volume 88. 2016. 105–116. Page 111.

[12] "Wrong-Way Driving Crashes: A Multiple Correspondence Approach to Identify Contributing Factors," Mohammad Jalayer, Mahdi Pour-Rouholamin & Huaguo Zhou. *Traffic Injury Prevention*. 2017. Page 12.

[13] "Statewide Wrong Way Crash Study," *Florida Department of Transportation*. 2015. Page 25.

[14] "Statistical Characteristics of Wrong-Way Driving Crashes on Illinois Freeways," Huaguo Zhou, Jiguang Zhao, Mahdi Pour-Rouholamin and Priscilla A. Tobias. *Traffic Injury Prevention*, Volume 16, Issue 8. 2015. 760-767. Page 761.

[15] "Wrong-Way Driving Crashes: A Multiple Correspondence Approach to Identify Contributing Factors," Mohammad Jalayer, Mahdi Pour-Rouholamin and Huaguo Zhou. *Traffic Injury Prevention*. 2017. Page 13-14.

[16] "Statewide Wrong Way Crash Study," *Florida Department of Transportation*. 2015. Page 25.

[17] "Statistical Characteristics of Wrong-Way Driving Crashes on Illinois Freeways," Huaguo Zhou, Jiguang Zhao, Mahdi Pour-Rouholamin and Priscilla A. Tobias. *Traffic Injury Prevention*, Volume 16, Issue 8. 2015. 760-767. Page 761.

[18] "Modeling Wrong-Way Driving Entries at Limited Access Facility Exit Ramps in Florida," Md Imrul Kayes et al. *Journal of the Transportation Research Board*. 2019. 567-576. Page 573.

interchange ramps from Alabama experienced wrong-way entries compared to 14% in Illinois. For partial cloverleaf interchanges, 24% of Alabama's studied ramps experienced wrong-way entries compared to 14% in Illinois. These differences are due to a variety of factors, including variations in state design and usage requirements for geometric roadway features (presence of medians, ramp intersection angle, median width, etc.) and traffic control devices (placement of WW signs and additional visibility enhancements, such as red retroreflective tape).[19]

Recommended research

For a ranking of various interchange types:

- "Statistical Characteristics of Wrong-Way Driving Crashes on Illinois Freeways," Huaguo Zhou et al. *Traffic Injury Prevention*, Volume 16. 2015.

This study analyzes 2004-2009 WWD crash data from Illinois to determine temporal distributions, geographical distributions, roadway characteristics and crash locations. The authors found that compressed diamond interchanges ranked highest for WWD crash rates, followed by single-point diamond interchanges (SPDIs), partial cloverleafs and freeway feeders.

Crash location

Fatal wrong-way events are most common on limited-access facilities, but they also often occur on arterials and undivided rural roadways. One overview of 2004-2011 data highlighted that 56.5% of fatal WWD crashes occurred in urban areas, while 43.5% occurred on rural roads.[20]

A review of 2004-2009 WWD crash data from Illinois found that the overwhelming majority of wrong-way crashes (86%) occur in the traveling lanes of divided highways, as opposed to the off-ramp or shoulders—of these, 59% occurred on the most inside lane.[21] This helps explain why WWD crashes tend to be more severe, because they occur after the wrong-way driver has entered highway and is traveling at high speeds.

[19] "A Comparative Analysis of Exit Ramp Terminal Design Practices to Deter Wrong-Way Driving in Different States," Md Atiquzzaman and Huaguo Zhou. *Transportation Research Board* Annual Meeting 97. 2018. Page 13-14.

[20] "Overview of Wrong-Way Driving Fatal Crashes in the United States," Fatemeh Baratian-Ghorghi, Huaguo Zhou and Jeffrey Shaw. *ITE Journal*. August 2014. 41-47. Page 44.

[21] "Statistical Characteristics of Wrong-Way Driving Crashes on Illinois Freeways," Huaguo Zhou, Jiguang Zhao, Mahdi Pour-Rouholamin and Priscilla A. Tobias. *Traffic Injury Prevention*, Volume 16, Issue 8. 2015. 760-767. Page 762.

WWD Prevention

While WWD is a difficult problem with no single solution, there are many traditional and emerging countermeasures that help to reduce and prevent WWD incidents.

These countermeasures can include: improving the roadway design of ramps and other common wrong-way locations; adding street-level enhancements like street lighting, additional pavement markings and signs, detection systems and others; engaging in education and enforcement related to drinking-and-driving and other common issues; and others.

While driver education and enforcement are invaluable tools to reduce WWD, the most widely used countermeasures are infrastructure-based, so this guide will focus on those.

Recommended research

For an overview of the historical evolution of traffic control devices for deterring wrong-way driving:

- “Traffic control devices for deterring wrong-way driving: Historical evolution and current practice,” Fatemeh Baratian-Ghorghi and Huaguo Zhou. *Journal of Traffic and Transportation Engineering*, Volume 4, Issue 3. 2017.

This report provides a historical look at federal Manual on Uniform Traffic Control Devices (MUTCD) requirements for WWD traffic control measures. The authors then explore state efforts to deter WWD, and then provide countermeasure recommendations for future MUTCD revisions.

For best practices on designing a implementable road safety program and policy framework that can address wrong-way driving:

- “Addressing wrong-way driving as a matter of policy: The Florida Experience,” Raj V.Ponnaluri. *Transport Policy*, Volume 46. 2016.

This analysis presents a policy-oriented framework toward addressing WWDs in a systematic manner. It focuses on the leadership of the Florida Department of Transportation that made its wrong-way prevention strategy into reality, including implementing pilot projects, streamlining data collection and synthesis, transforming recommendations to design guidance and working with engineers and municipal/state planners to implement successful countermeasures.

Roadway design

While geometric modifications can be effective in reducing WWD events, they are rarely implemented because they tend to be far more expensive than other infrastructure treatments. These countermeasures provide physical barriers that prevent drivers from taking incorrect paths on the road.

Example countermeasures include installing curb medians, channelized medians and islands, reducing wrong-way turning radius, requiring ramps to intersect with crossroads at obtuse rather than 90° or acute angles and others.[22] The ideal geometric countermeasure will depend on the type of interchange being modified.

[22] “Investigation of Contributing Factors regarding Wrong-Way Driving on Freeways,” Huaguo Zhou et al. *Illinois Center for Transportation*. October 2012.

Recommended research

For off-ramp design best practices:

- "A Comparative Analysis of Exit Ramp Terminal Design Practices to Deter Wrong-Way Driving in Different States," Md Atiquzzaman and Huaguo Zhou. *Transportation Research Board*, Annual Meeting No. 97. 2018.

This analysis compares WWD crash rates for Illinois and Alabama with a focus on difference in exit ramp terminal design. The authors develop recommendations and best practices for states and local transportations agencies to apply to their off-ramp terminal designs that help prevent WWD entries.

Signs and pavement markings

Less expensive than other countermeasures, signs and pavement markings are a versatile and, when applied diligently, effective treatment to mitigating WWD. Their goal is to provide clear guidance and warning to drivers, letting them know they should not turn onto and continue the wrong way along a one-way road. Unlike other treatments mentioned, wrong-way signs and pavement markings are generally mandated by the MUTCD and state regulations to be installed on ramps and other one-way streets.

Examples of signs include DO NOT ENTER, WRONG WAY, ONE WAY, NO RIGHT/LEFT TURN and KEEP RIGHT. Ways to enhance the effect of signage include:

- Positioning them to clearly face the intended driver
- Adding supplemental signs
- Installing larger, oversized signs
- Using a lower mounting height closer to a driver's eyeline
- Enhancing the conspicuity of signs with added red retroreflective strips or flashing LEDs

Researchers in Texas found, in a 22-month study, **that installing LED enhanced wrong-way signs led to a 38% reduction in WWD events.**[23]

Examples of pavement markings include in-lane arrows, stop lines and longitudinal travel lines that help drivers follow the appropriate travel direction. Pavement markings can also be enhanced for conspicuity with raised, retroreflective pavement markers.

Recommended research

For sign and pavement marking installation best practices:

- "**Guidelines for Reducing Wrong-Way Crashes on Freeways**"

This report provides extensive, comprehensive guidance for implementing traditional and advanced safety countermeasures to help reduce wrong-way crashes on freeways. The authors detail a variety of considerations and guidelines to ensure signs and pavement markings are optimally installed to deter potential wrong-way movements.

[23] "Assessment of the Effectiveness of Wrong-Way Driving Countermeasures and Mitigation Methods," Melisa D. Finley et al. *Texas A&M Transportation Institute*. December 2014.

- **State-specific regulations and MUTCDs**

  Many states have expanded their own wrong-way-specific regulations beyond the federal FHWA's MUTCD requirements. Look into your state DoT's regulations to see what they recommend for sign placement, size, pavement markings and more.

However, these countermeasures still rely on drivers to self-correct and, alone, are often not sufficient in stopping WWD events.

Roadway lighting

While much research focus has been dedicated to reducing WWD in urban areas, rural arterial roads also have high instances of WWD crashes which must be properly understood as well. Since most wrong-way incidents occur in dark, poorly lit conditions, adding roadway lighting, especially in targeted areas, can help deter potential wrong-way incidents.

Driver education

A variety of educational programs can help reduce WWD fatalities. Examples include: emphasizing WWD concerns at defensive driving training sessions, dispensing WWD literature and warnings at alcohol dispensing facilities, senior road programs to help educate and promote alternative forms of transportation, and more.[24]

Enforcement

Targeted enforcement of key WWD-likely areas through local and state policing partnerships can help reduce WWD.[25] Enforcement countermeasures can be even more effective when paired with WWD detection systems.

Vehicle Detection Systems for WWD Prevention

Vehicle detection systems—which are sometimes referred to as intelligent transportation systems (ITS)—are an emerging technology that is becoming more common as a WWD countermeasure.

Unlike a static sign or flashing beacon, a wrong-way vehicle detection system will detect drivers who enter the roadway going the wrong direction and then activate an enhanced warning message—usually high-intensity flashing LED embedded signs, red rectangular light bars or circular flashing beacons. Advanced detection systems can also record these WWD events, analyze whether the driver self-corrected or continued the wrong way and alert local traffic management centers (TMCs) that a wrong-way driving event occurred, allowing the authorities to react and respond accordingly. This response can include deploying emergency personnel, warning right-way drivers on nearby dynamic message signs (DMS) and more.

[24] "The odds of wrong-way crashes and resulting fatalities: A comprehensive analysis," Raj V. Ponnaluri. *Accident Analysis & Prevention*, Volume 88. 2016. 105–116. Page 113-4.

[25] Ibid. Page 114.

While many states are still experimenting with these advanced treatments, initial research shows their efforts are succeeding. **Nevada DOT noted that their recent wrong-way detection, warning and alert system pilot project appears to be 80% effective in stopping wrong-way drivers.**[26]

Recommended research

For an essential overview of wrong-way detection and warning systems:

- "**Detection and Warning Systems for Wrong-Way Driving**," FHWA-AZ-15-741, 2015.

This technical report provides an excellent overview of wrong-way detection and warning systems, including their history, effectiveness and more. It also analyzes 2004-2014 crash data from Arizona to determine where a potential system would work best and then proposes a pilot development to help mitigate WWD events.

Detection technologies

These systems can use a variety of passive detection technologies to detect drivers without interfering with other traffic systems. Examples include:

- In-pavement detectors:
  - Induction loop
  - Magnometers
- Above-ground detectors:
  - Doppler radar
  - Microwave
  - Video cameras
  - Thermal cameras

Ensuring high detection accuracy is a crucial factor to consider when evaluating potential technologies for WWD mitigation. Some systems employ multiple detection technologies (e.g., Doppler radar and video cameras) for built-in redundancy and to ensure every wrong-way driver is accurately and correctly detected.

Technologies like Doppler radar tend to be popular as they have a proven track record of being used on roads for decades, have high detection accuracy and are relatively low cost compared to other technologies.

Recommended research

For a review of the various detection technologies used in vehicle detection systems:

- "**Investigation on Wrong Way Driving Prevention Systems**," **2021**

This study investigates and tests several wrong-way detection systems from various manufacturers. It evaluates the most commonly employed detection technologies used in WWD systems and provides pros and cons for each.

[26] "Wrong Way Driver System," *Nevada Department of Transportation*. https://www.dot.nv.gov/safety/wrong-way-driver-system

Optimizing vehicle detection systems

While vehicle detection systems and other ITS solutions have been proven to reduce WWD, they unfortunately cannot be deployed on all highway ramps due to their cost. Some researchers have begun developing various algorithms and frameworks to analyze frequent WWD ramps and optimize the best exits for vehicle detection and alert system deployment. This continuing research will help agencies around the country install reliable and intelligent wrong-way countermeasures where they will be most effective in reducing WWD events and for cost.

Recommended research

For optimizing intelligent wrong-way prevention systems:

- "A Wrong-Way Driving Crash Risk Reduction Approach for Cost-Effective Installation of Advanced Technology Wrong-Way Driving Countermeasures," Adrian Sandt and Haitham Al-Deek. *Journal of the Transportation Research Board*, Volume 2672, Issue 14. 2018.

This paper develops an approach to analyze WWD crash risk reduction with an optimization algorithm to help agencies determine where to best install WWD countermeasures. The authors use the Central Florida Expressway Authority toll road network as a hypothetical example, showing how the algorithm can provide significant cost savings compared with equipping entire road segments.

- "An optimization approach for deployment of intelligent transportation systems wrong-way driving countermeasures," Adrian Sandt and Haitham Al-Deek. *Journal of Intelligent Transportation Systems*, Volume 24, Issue 1. 2019.

This paper builds on the earlier work cited above.