RESEARCH BRIEF

Fatal Wrong-Way Crashes on Divided Highways

March 2021

Between 2004 and 2009, an average of 360 fatalities resulted from wrong-way crashes annually in the United States. Although relatively rare, wrong-way crashes are often severe and fatal as they are typically head-on collisions (NTSB, 2012).

This brief quantifies the number of fatal wrong-way crashes and the number of people killed in these incidents using data from the Fatality Analysis Reporting System (FARS). Characteristics of wrong-way drivers were compared with "right-way" drivers in the same crash to identify factors associated with increased odds of causing a fatal wrong-way crash.

Results of the analysis show that between 2010 and 2018, there were 3,885 deaths resulting from wrong-way driving crashes with over half of those killed (52.8%) being the wrong-way driver. Factors such as alcohol-impairment and older age increased the odds of being a wrong-way driver, while having passengers decreased the odds of being one.

Methods

Data on all fatal motor vehicle crashes that occurred in the United States between 2010 and 2018 were examined to quantify the number of fatal crashes that involved a driver traveling in the wrong direction on a divided highway prior to the crash. The number of fatal wrong-way crashes and the number of people killed in these crashes each year were tabulated. In order to identify factors associated with the risk of causing a fatal wrong-way crash, characteristics of wrong-way drivers were compared to those of the other drivers involved in the same crashes while driving in the correct direction.

Data source

Data from the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS) database was used to compute fatal wrong-way driving incidents occurring between 2010 and 2018. FARS is a census of all traffic incidents on U.S. public roadways resulting in at least one fatal injury within 30 days of the crash.

This study uses the National Transportation Safety Board's (NTSB) definition of wrong-way driving: a vehicular movement opposite the legal flow of traffic on high-speed divided highways or access ramps (NTSB, 2012). FARS does not have one specific variable that identifies wrong-way driving; thus ascertaining whether a crash involved wrong-way driving required information from multiple variables describing various aspects of the crash and factors that preceded it. For the purpose of the current study, a crash was classified as a wrong-way driving crash if it met the following criteria:

1. The crash occurred on an Interstate highway, a freeway, an expressway, or a principal arterial with physical separation between opposing directions of travel, or an entrance or exit ramp to or from such a road.
2. The crash involved a driver who was reportedly driving opposite the legal flow of traffic. (Note: crashes in which the driver was coded as having crossed the median were not classified as wrong-way crashes; only crashes in which the driver was actually driving in the wrong direction were included.)

Data Analysis

Counts of wrong-way fatal crashes on divided highways and the number of associated deaths were tabulated by year and by potential risk factors of interest. Factors investigated in this study included the following:

- Imputed Blood Alcohol Content (BAC)
- Driver's age
- Driver's gender
- License status
- Out-of-state licensure (a proxy for being less familiar with the roadway)
- Vehicle type (e.g., passenger vehicle, bus or large truck, motorcycle, other)
- Vehicle age (based on model year)
- Passenger presence

Since alcohol impairment is not known for all drivers in fatal wrong-way driving crashes, this study uses multiply imputed data in FARS to estimate driver BAC at the time of the crash.

To understand the relationship between various driver-related factors and the risk of wrong-way driving, characteristics of wrong-way drivers involved in fatal crashes were compared to those of the other drivers who were involved in the same crashes, but driving in the correct direction (identified as "right-way drivers"). This approach is similar to a matched case-control study where each wrong-way driver is matched with a right-way driver involved in the same crash, serving as a control. Drivers involved in the same crash were matched allowing environmental factors, including time of day, road conditions, weather, and lighting conditions, to be controlled for.

Conditional logistic regression was used to estimate univariate odds ratios to estimate the association between each factor of interest and the odds of being a wrong-way driver. Perneger and Smith (1991) used this approach to investigate the relationships of various factors contributing to crash initiation broadly; the current study adapts their conceptual approach but focuses specifically on the initiation of a crash caused by driving the wrong way on a divided highway. This approach assumes that right-way drivers involved in crashes with wrong-way drivers approximate a random sample of all drivers on the road at the time and place of the crash. Thus, odds ratios produced in this approach approximate ratios of rates of fatal wrong-way crashes.

Results

Results show that between 2010 and 2018 there were 2,921 fatal wrong-way crashes resulting in 3,885 deaths—an average of 430 deaths per year. Over half of these deaths were wrong-way drivers (52.8%), a small percentage were their passengers (5.7%), while about four in ten (41.1%) were occupants of other vehicles. Within this period, wrong-way crashes accounted for an average of 3.7% of all fatal crashes on divided highways. Table 1 breaks down fatal wrong-way crash data by year.

Table 1. Fatal wrong-way crash data by year, 2010-2018

Year	All Fatal Crashes	Fatal Crashes on Divided Highways	Wrong-Way Fatal Crashes on Divided Highways	Wrong-Way Fatal Crashes as Percentage of Fatal Crashes on Divided Highways	Wrong-Way Crash Fatalities
2010	30,296	8,075	276	3.42%	336
2011	29,867	7,835	289	3.69%	367
2012	31,006	7,867	288	3.66%	391
2013	30,202	8,109	300	3.70%	393
2014	30,056	8,220	292	3.55%	390
2015	32,538	9,369	345	3.68%	461
2016	34,748	10,152	368	3.62%	521
2017	34,560	10,204	394	3.86%	518
2018	33,654	9,996	369	3.69%	508

Table 2 presents the frequency and proportion of fatal wrong-way crash risk factors including blood alcohol concentration (BAC), license status, state licensure, vehicle type, vehicle age, and passenger status among wrong-way and right-way drivers. Between 2010 and 2018, there were 2,924 wrong-way drivers and 3,546 right-way drivers involved in fatal wrong-way crashes.

With respect to the role of alcohol, as BAC increases, so does the odds of being a wrong-way driver. Only 36.0% (n= 1053) of wrong-way drivers had BACs less than 0.01 g/dL, compared to 85.2% (n=3022) of right-way drivers. The majority of wrong-way drivers (60.1%) had BACs of 0.08 g/dL or higher, compared to few right-way drivers (11.0%).

Most drivers in fatal wrong-way crashes were licensed in the same state where the crash occurred. Wrong-way drivers were more likely to be licensed in-state than right-way drivers (84.1% vs 77.6%).

Compared to right-way drivers, there were more wrong-way drivers whose licenses were either suspended, revoked, or expired (13.5% vs 4.0% for right-way drivers).

Table 2. Frequency and proportion of wrong- and right-way drivers in relation to selected risk factors

	Right-Way Drivers (n= 3,546)	Wrong-Way Drivers (n =2,924)
Blood Alcohol Concentration (g/dl)		
BAC < 0.01	3022 (85.2%)	1053 (36.0%)
BAC 0.01 – 0.49	72 (2.0%)	62 (2.1%)
BAC 0.05 – 0.79	61 (1.7%)	52 (1.8%)
BAC ≥ 0.08	391 (11.0%)	1757 (60.1%)
Gender		
Male	2502 (70.8%)	2071 (70.9%)
Female	1034 (29.2%)	849 (29.1%)
License Status		
Valid	3246 (92.9%)	2297 (79.4%)
Suspended, revoked, expired	140 (4.0%)	389 (13.5%)
No license	108 (3.1%)	206 (7.1%)
State of Licensure		
In-State	2752 (78.0%)	2458 (84.6%)
Out-of-State	777 (22.0%)	449 (15.5%)
Vehicle Type		
Passenger vehicle	2874 (81.2%)	2827 (96.7%)
Bus or large truck	588 (16.6%)	33 (1.1%)
Motorcycle	77 (2.2%)	58 (2.0%)
Other	0 (0.0%)	5 (0.2%)
Vehicle Year		
0 to 5 years	743 (21.0%)	362 (12.4%)
6 to 10 years	827 (23.4%)	567 (19.4%)
11 to 15 years	1062 (30.1%)	865 (29.7%)
16 to 20 years	649 (18.4%)	680 (23.3%)
> 20 years	251 (7.1%)	443 (15.2%)
Passenger Status		
No passenger	2218 (62.6%)	2530 (86.7%)
With passenger(s)	1325 (37.4%)	389 (13.3%)

Figure 1 shows the age distribution of wrong- and right-way drivers. Because a wrong-way driver could involve more than one other vehicle in a crash, there are more right-way drivers than wrong-way drivers. Elderly drivers are over-represented as wrong-way drivers in these crashes. Of drivers aged 80 years and over, 91.9% were wrong-way drivers. More than two thirds of drivers aged 70 to 79 years were wrong-way drivers.

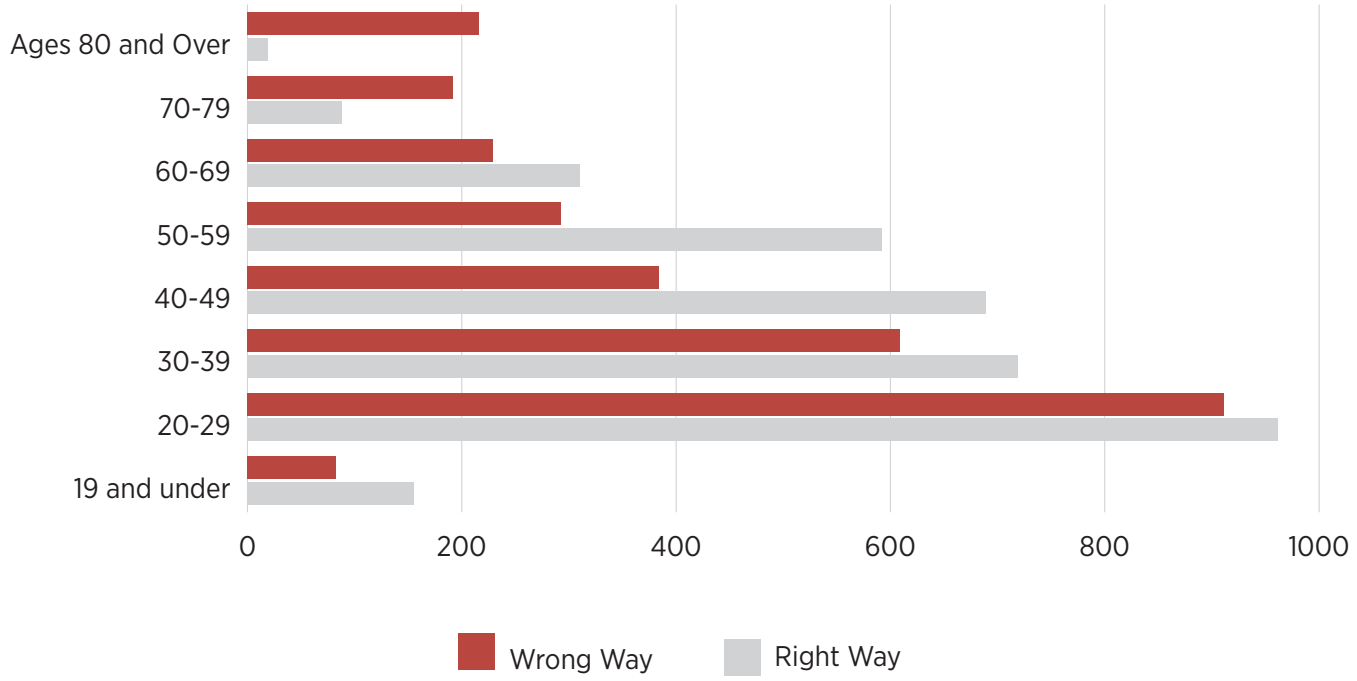

Figure 1. Age distribution of wrong- and right-way drivers involved in the same fatal crashes, 2010–2018

Table 3 shows the odds ratios (ORs) for the risk factors associated with being a wrong-way driver. BAC was a strong predictor for being a wrong-way driver. The increase in odds of being a wrong-way driver exhibited a dose-response relationship. As BAC increases, so do the odds of being a wrong-way driver. Compared to drivers with BACs less than 0.01 g/dL, drivers with BACs between 0.01 and 0.049 g/dL had an OR of 2.65, while those with BACs greater than or equal to 0.08 g/dL had an OR of 18.36.

Table 3. Odds of being a wrong-way driver in fatal wrong-way crashes in relation to selected risk factors

	OR	95% CI
Blood Alcohol Concentration (g/dL)		
BAC < 0.01	1	Ref
BAC 0.01 – 0.49	2.65	1.62 – 4.34
BAC 0.05 – 0.79	3.29	1.67 – 6.46
BAC ≥ 0.08	18.36	13.90 – 24.24
Gender		
Female	1	Ref
Male	0.96	0.85 – 1.07
License Status		
Licensed	1	Ref
Suspended, revoked, expired	4.00	3.21 – 4.97
No license	2.68	2.07 – 3.49
State of Licensure		
In-State	1	Ref
Out-of-State	0.59	0.51 – 0.68
Vehicle Type		
Passenger vehicle	1	Ref
Bus or large truck	0.05	0.04 – 0.08
Motorcycle	0.70	0.48 – 1.02
Vehicle Age		
0-5 years	1	Ref
6 to 10 years	1.53	1.28 – 1.84
11 to 15 years	1.88	1.58 – 2.24
16 to 20 years	2.41	1.99 – 2.91
> 20 years	4.26	3.39 – 5.36
Passenger Status		
No passenger	1	Ref
With passenger(s)	0.23	0.20 – 0.27

Table 3 also shows that compared to licensed drivers, drivers whose licenses were either suspended, revoked, or expired were more likely to be a wrong-way driver (OR=4.00). Those without a license were also more likely to be a wrong-way driver (OR= 2.68). Drivers licensed in a different state than where the crash occurred were less likely to be wrong-way drivers (OR= 0.59), compared to drivers licensed in the same state.

The odds of being a wrong-way driver also increases as vehicle age increases. Compared to those with newer model vehicles (0 to 5 years old), drivers with models between 6 and 10 years old were more likely to be wrong-way drivers (OR= 1.53). The odds of being a wrong-way driver continue to increase as vehicle age increases. Vehicles greater than 20 years old are more likely driven by wrong-way drivers (OR= 4.26). Drivers carrying passengers were also less likely to be wrong-way drivers (OR= 0.23). In addition, compared to passenger vehicles, buses and large trucks are less likely to be wrong-way drivers (OR= 0.05).

Being an older driver is also a strong predictor for being a wrong-way driver. As seen in Figure 2, the OR logarithms follows a j-shaped curve, with a sharp increase after the age of 70 years. Compared to drivers aged 50 to 59, drivers in the 70- to 79-year age category (OR= 4.32, 95% CI: 3.17–5.88) and those ages 80 and over (OR=27.94, 95% CI: 15.87–49.20) were more likely to be wrong-way drivers.

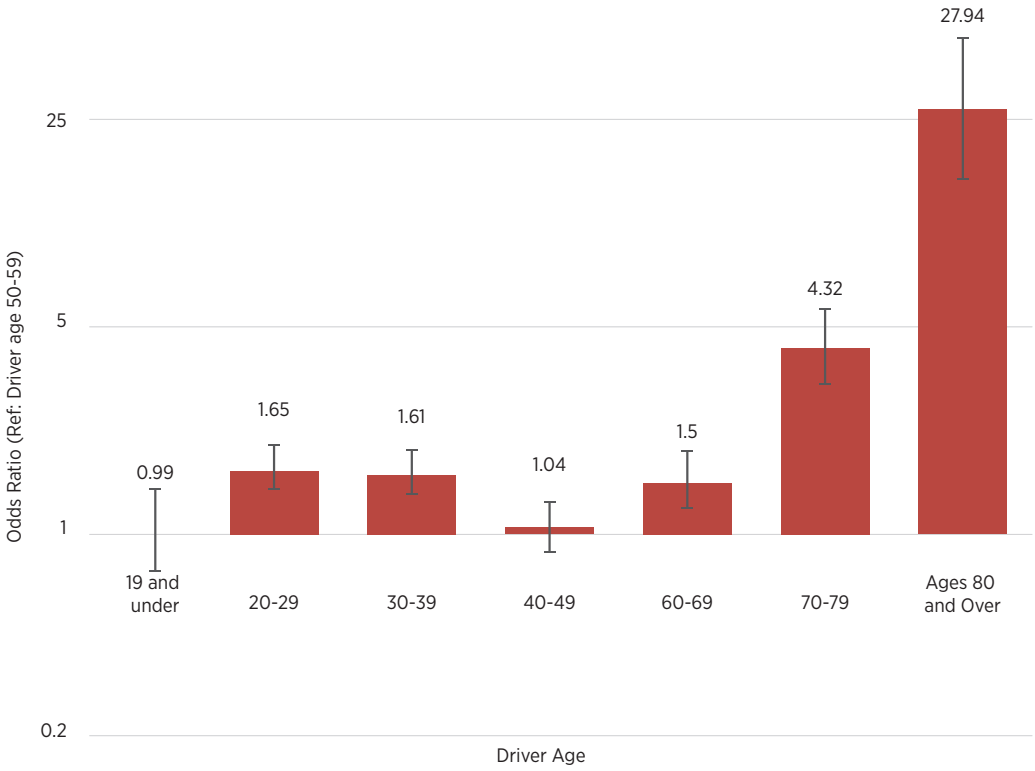

Figure 2: Bivariate matched odds ratios of being a wrong-way driver in a fatal wrong-way crash, by age

Discussion

This study analyzed fatal wrong-way crashes on divided highways and explored risk factors associated with being a wrong-way driver. As noted, between 2010 and 2018 there were an average 430 fatal wrong-way crash related deaths per year. This accounted for 3.7% of all fatal crashes on divided highways, an apparent increase from the 360 yearly deaths between 2004 to 2009 reported by NTSB (NTSB, 2012). This study also shows that alcohol impairment and old age dramatically increase the odds of being the wrong-way driver in these types of crashes. However, having a passenger reduces the odds of being a wrong-way driver.

Relation to other research

The original analyses conducted by NTSB noted that 2.8% of fatal crashes on divided highways involved wrong-way driving (NTSB, 2012). Baratian-Gorghi et al. (2014) found similar numbers between 2004 to 2011. Baratian-Gorghi et al.'s study also found that while overall fatal motor vehicle crashes were declining, the number of fatal wrong-way crashes remained steady. This study, however, found that there may have been an increase in wrong-way crashes in recent years.

This study builds on the analysis conducted by the NTSB in their 2012 report, but further explores the factors associated with wrong-way driving. The analyses were adapted from the approach of Perneger and Smith (1991) to compare right- and wrong-way drivers and produce odds ratio estimates. This study also explores other crash characteristics, such as vehicle age and passenger presence.

Passenger presence was found to have a protective effect against being a wrong-way driver. While the mechanism of this is not known at this time, passengers may alert drivers that they are entering a one-way road, either preventing them from entering the highway in the wrong direction, or alerting them to their error and thus helping the driver take corrective action before a crash occurs.

Most of the wrong-way driving risk factors investigated in this study were predictive of wrong-way driving. Similar to other studies (Baratian-Gorghi, 2014; NTSB, 2012; Zhou, 2014b; Zhou, 2012), this study found that alcohol impairment plays a large role in wrong-way crashes, with roughly 60% of wrong-way drivers in fatal crashes being alcohol-impaired. The current study also shows a

dose response relationship between BAC levels and the likelihood of wrong-way driving—with those over the legal limit of 0.08 g/dl being significantly more likely to be wrong-way drivers compared to non-alcohol-impaired drivers involved in the same crashes. Results of this study and others have found that older drivers are more at risk of wrong-way driving than their younger counterparts (NTSB, 2012; Pour-Rouholamin, 2016; Zhou, 2012).

The odds of being a wrong-way driver by age follows a j-shaped curve, sloping down towards middle adulthood and up at late adulthood. This is an interesting finding as research from the AAA Longitudinal Research on Aging Drivers (LongROAD) found that among older drivers (ages 65-79), the oldest age group (age 75-79) had the lowest driving exposure. This age group drove fewer miles, spent less time on the road, and drove fewer miles per trip compared to younger age groups (Molnar et al., 2019). In this study, drivers aged 50 to 59 were chosen as the reference group since they have the lowest odds, after the teenager group, of being wrong-way drivers. Teenagers were not used as the control group as, generally, they have the highest crash involvement rate per mile driven, which continues to decrease as they age; crash involvement then increases again for drivers age 70 and older (Tefft, 2017). It was somewhat surprising, however, that teenage drivers in this study had the lowest odds of being wrong-way drivers in fatal crashes, as teenagers tend to be over-represented in crashes.

The role of gender was explored and no evidence of an association between wrong-way driving and gender was found. Zhou et al. (2014) found that 67% of wrong-way drivers were male, similar to the proportion (71%) in this study. However, this study also found that males accounted for 71% of right-way drivers. Ponnaluri (2016) found that males have a higher likelihood than females of being involved in a wrong-way crash. Differences could have come from the different methodologies used. In particular, the Ponnaluri study compared those involved in wrong-way crashes and those who were in non-wrong-way crashes (i.e., different crashes, potentially at different times and different locations under different conditions), whereas this study compared whether the driver was a wrong-way driver or a right-way driver involved in the same crash.

State of licensure (i.e., whether the driver possessed a license issued in a different state than where the crash occurred) was initially added as a proxy to explore driver unfamiliarity with the roadway, which has been shown to be associated with crash risk generally (Ehsani & Tefft, in press), although not specifically with respect to wrong-way crashes. This study found that drivers licensed in a different state from where the wrong-way crash occurred were less likely to be the wrong-way drivers compared to those licensed in the same state. Ponnaluri (2016) also found similar results and suggested that drivers licensed in a different state may be more cautious due to their unfamiliarity with local roads.

Exploring vehicle type in this study showed that drivers of buses and large trucks are less likely to be wrong-way drivers compared to drivers of passenger vehicles. The literature on trucks and buses on wrong-way driving is sparse. However, according to a NHTSA report on alcohol-impaired driving, in 2017, 21% of passenger vehicle drivers involved in fatal crashes had a BAC greater than 0.08 g/dl, but only 3% of large truck drivers did (National Center for Statistics and Analysis, 2018). The age of the vehicle was also associated with the likelihood of being a wrong-way driver. The mechanism of this relationship in fatal wrong-way crashes is unclear. It is possible that vehicle age is correlated with other behaviors associated with the risk of wrong-way driving, but more investigation on this topic should be done.

Countermeasures

There are various countermeasures implemented to prevent wrong-way driving and/or mitigate the damage once a vehicle has proceeded in the opposite direction of traffic. Potential countermeasures include alterations and considerations in the design of the roads, enforcement strategies, and driver education (Zhou & Rouholamin, 2014a). Two of the biggest factors explored in this study are impaired driving and driver age. There are driver-based strategies that directly address these factors such as alcohol ignition interlocks, which are devices installed in vehicles that prevent them from starting if the driver has a BAC above a certain level (Zhou, 2014).

Even though most factors explored in this study are driver related, the most ubiquitous and widely used countermeasures are infrastructure based. Signs are among the least expensive and easiest to implement countermeasures (Zhou & Rouholamin, 2014). Signage can include directions such as “DO NOT ENTER,”

"WRONG WAY,""ONE WAY," "Keep Right," among others. Geometric design elements are also important preventive countermeasures. These include implementing strategies to improve a driver's field of view, raising medians, tightening the corner and control radius, and channelizing islands. These design elements lessen the confusion around the proper flow of traffic in an intersection. For example, Zhuo & Rouholamin (2014a) recommend using raised medians to discourage left turns onto exit ramps. In addition, having tighter turn radii will make it more difficult for drivers to maneuver onto the exit ramp whereas a larger more sweeping radius may encourage wrong-way driving (Zhou & Rouholamin, 2014a). Compared to signage, modifying existing roadways to conform with design elements aimed at lowering wrong-way driving are more costly and resource intensive.

A pilot program by Caltrans and UC Davis Advanced Highway Maintenance and Construction Technology (AHMCT) to evaluate countermeasures to reduce wrong-way driving events shows promise. The 15-month before and after study evaluated red retroreflective pavement markings on ramps, LED illuminated signs and pavement and other countermeasures. The pilot showed a 44% reduction of reported wrong-way driving events in areas where red retro reflective markers were placed in ramps. Sites with LED illuminated flashing wrong-way driving signs showed a 60% reduction of these events (Bucko, 2020).

Other countermeasures exist that are designed to prevent or mitigate wrong-way crashes by alerting the wrong-way driver, other drivers, and/or law enforcement authorities once a vehicle has proceeded in the wrong direction (Athey Creek Consultants, 2016). Examples include portable tire deflation devices, dynamic alert systems, and other detection alert instruments. When a vehicle enters a ramp through an exit, dynamic alert systems activate and notify other drivers on the roadway that there is a vehicle going the wrong direction. In conjunction with signage, red reflective flashing beacons can be activated around a "WRONG WAY" sign to further alert drivers. These systems are designed to capture the driver's attention. By using changeable message signs, other motorists can be alerted of a wrong-way driver and be advised to take caution. Law enforcement can also be alerted by the system via notifications sent to traffic management centers.

There are studies that explored the effectiveness of strategies to prevent wrong-way driving. Lin et al. (2018) conducted a study evaluating the effectiveness of countermeasures using intelligent transportation systems (ITS) in Florida and found that Red Rectangular Flashing Beacons (RRFBs) are one of the top countermeasures for reducing wrong-way driving. These beacons flash LEDs around a "WRONG WAY" sign when activated by a wrong-way driver.

Limitations

This study was not able to estimate the relative effects of lighting conditions, road conditions, time of day, or day of the week given that the environmental conditions of cases and controls were the same by virtue of being in the same crash. Another limitation of the study is that it does not use actual BAC data for all the participants. FARS alcohol imputation files were used to estimate driver BAC if BAC information was not available, thus lowering the precision of alcohol-related wrong-way driving crash rates.

Road design and geometry are important considerations in exploring the risk factors of wrong-way crashes. Road design, such as the partial cloverleaf interchange, diamond interchanges with continuous frontage roads, and trumpet interchanges are, according to some studies, more susceptible to wrong-way driving than other types of interchanges (Zhou, 2012; Zhou & Rouholamin, 2014). Unfortunately, the data used in this study does not include information on where and how wrong-way drivers entered the highway.

Distraction and drowsy driving were not explored due to data limitations. Driver distraction and drowsiness are assessed based on subjective police reports and thus, may be unreliable. Because of this, the role of distraction and drowsiness in crashes is likely widely underreported (Stutts, 2005). A challenge to understanding the prevalence of wrong-way driving is limited data on wrong-way driving events that do not lead to crashes or injuries (Athey Creek, 2016). Thus, the prevalence of wrong-way driving is largely unknown.

Although wrong-way driving crashes are relatively rare, these crashes tend to be severe and fatal. This brief has shown that certain driving factors such as alcohol-impairment and older age are associated with wrong-way driving events. However, roadway countermeasures have shown promise in mitigating and lowering these events.

References

Athey Creek Consultants. (2016). Countermeasures for Wrong-Way Driving on Freeways.

Baratian-Ghorghi, F., Zhou, H., & Shaw, J. (2014). Overview of wrong-way driving fatal crashes in the United States. ITE journal, 84(8), 41-47.

Blows, S., Ivers, R. Q., Connor, J., Ameratunga, S., Woodward, M., & Norton, R. (2005). Unlicensed drivers and car crash injury. Traffic Injury Prevention, 6(3), 230-234.

Bucko, T. R. (2020). Wrong Way Pilot Projects for Prevention of Wrong Way Collisions on Freeways.

Cooner, S. A., Cothron, A. S., and Ranft, S. E. (2004). Countermeasures for Wrong-Way Movement on Freeways: Guidelines and Recommended Practices. Texas Transportation Institute (TTI), College Station, TX.

DeYoung, D. J., Peck, R. C., & Helander, C. J. (1997). Estimating the exposure and fatal crash rates of suspended/revoked and unlicensed drivers in California. Accident Analysis & Prevention, 29(1), 17-23.

Ehsani, J. P., & Tefft, B. (in press). Crash risk and roadway familiarity. Chance.

Elder, R. W., Voas, R., Beirness, D., Shults, R. A., Sleet, D. A., and Nichols, J. L., Compton, R. (2011). "Effectiveness of Ignition Interlocks for Preventing Alcohol-Impaired Driving and Alcohol-Related Crashes: A Community Guide Systematic Review." American Journal of Preventive Medicine, 40(3), pp. 362–376.

FHWA, U. S. (2012). Manual on uniform traffic control devices for streets and highways. 2009 Edition, Rev. 2. Washington, DC: US Department of Transportation, Federal Highway Administration.

Finley, M. D., Venglar, S. P., Iragavarapu, V., Miles, J. D., Park, E. S., Cooner, S. A., & Ranft, S. E. (2014). Assessment of the effectiveness of wrong way driving countermeasures and mitigation methods (No. FHWA/TX-15/0-6769-1). Texas A&M Transportation Institute.

Lin, P. S., Ozkul, S., Guo, R., & Chen, C. (2018). Assessment of countermeasure effectiveness and informativeness in mitigating wrong-way entries onto limited-access facilities. Accident Analysis & Prevention, 116, 79-93.

Molnar, L.J., Eby, D.W., Vivoda, J.M., Kostyniuk, L.P., Bogard, S.E., Zakrajsek, J.S., St. Louis, R.M., Zanier, N., Ryan, L.H., LeBlanc, D.J., Smith, J., Yung, R., Nyquist, L., DiGuiseppi, C.G., Li, G., Mielenz, T.J.& Strogatz, D.S. (2019). Objectively Derived and Self-Reported Measures of Driving Exposure and Patterns Among Older Adults: AAA LongROAD Study. AAA Foundation for Traffic Safety.

National Center for Statistics and Analysis. (2018, November). Alcohol-impaired driving: 2017 data (Traffic Safety Facts. Report No. DOT HS 812 630). Washington, DC: National Highway Traffic Safety Administration.

National Transportation Safety Board. (2012) Highway Special Investigation Report: Wrong-Way Driving. Publication NTSB/SIR-12/01

Perneger, T., & Smith, G. S. (1991). The driver's role in fatal two-car crashes: a paired "case-control" study. American journal of epidemiology, 134(10), 1138-1145.

Ponnaluri, R. V. (2016). The odds of wrong-way crashes and resulting fatalities: a comprehensive analysis. Accident Analysis & Prevention, 88, 105-116.

Pour-Rouholamin, M., & Zhou, H. (2016). Analysis of driver injury severity in wrong-way driving crashes on controlled-access highways. Accident Analysis & Prevention, 94, 80-88.

Seitzinger, R., Fries, R., Qi, Y., & Zhou, H. (2016). A driving simulator study evaluating traffic sign mounting height for preventing wrong-way driving. In Transportation Research Board 95th Annual Meeting, Washington DC, United States.

Stamatiadis, N., & Deacon, J. A. (1997). Quasi-induced exposure: methodology and insight. Accident Analysis & Prevention, 29(1), 37-52.

Stutts, J. C., Knipling, R. R., Pfefer, R., Neuman, T. R., Slack, K. L., & Hardy, K. K. (2005). A guide for reducing crashes involving drowsy and distracted drivers. Vol. 14 of the NCHRP Report 500: Guidance for Implementation of the AASHO Strategic Highway Safety Plan.

Tefft, B. (2017). Rates of motor vehicle crashes, injuries and deaths in relation to driver age, United States, 2014-2015. AAA Foundation for Traffic Safety.

Zhou, H., Zhao, J., Fries, R., Gahrooei, M. R., Wang, L., Vaughn, B., Bahaaldin, K., and Ayyalasomayajula, B. (2012). Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways. Illinois Center for Transportation, Rantoul, IL.

Zhou, H., & Rouholamin, M. P. (2014a). Guidelines for reducing wrong-way crashes on freeways.

Zhou, H., Zhao, J., Fries, R., and Pour Rouholamin, M. (2014b). "Statistical Characteristics of Wrong-Way Driving Crashes on Illinois Freeways." 93rd Annual Meeting of Transportation Research Board, Washington, DC.

ABOUT THE AAA FOUNDATION FOR TRAFFIC SAFETY

The AAA Foundation for Traffic Safety is a 501(c)(3) nonprofit, publicly supported charitable research and education organization. It was founded in 1947 by the American Automobile Association to conduct research to address growing highway safety issues. The organization's mission is to identify traffic safety problems, foster research that seeks solutions, and disseminate information and educational materials. AAA Foundation funding comes from voluntary, tax-deductible contributions from motor clubs associated with the American Automobile Association and the Canadian Automobile Association, individual AAA club members, insurance companies and other individuals or groups.

SUGGESTED CITATION

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