Characterization of Opposite-Direction Road Departure Crashes in the United States

Kristofer D. Kusano and Hampton C. Gabler

Opposite-direction crashes can be extremely severe because opposing vehicles often have high relative speeds. The objective of this study was to characterize the overall frequency of opposite-direction crashes as well as the frequency of crashes involving fatalities and serious injuries. The results of the study will guide future research and investment in infrastructure-based countermeasures to opposite-direction crashes, such as centerline rumble strips. The study used data from the National Automotive Sampling System (NASS) General Estimates System for 2010, the NASS Crashworthiness Data System for 2006 to 2010, and the Fatality Analysis Reporting System for 2010. The most common opposite-direction crash scenario was a driver departing the road driving over the centerline or the road edge to the left, which accounted for only 5% of noninterchange vehicle-to-vehicle crashes but 44% of serious injury and 49% of fatal crashes of the same type. Of the cross-over-to-left crashes, 72% of fatal crashes occurred on rural, undivided, two-lane roads and accounted for 1,659 fatal crashes in 2010. In cross-over-to-left crashes on rural two-lane roads, the driver was going straight or negotiating a curve in 88% to 94% of the crashes. The driver was overtaking another vehicle in only 2% of serious injury crashes and 6% of fatal crashes. Cross-over-to-left crashes on curves were to the outside of the curve more often than to the inside of the curve. This research suggests that countermeasures to opposite-direction crashes should focus on rural two-lane roads.

Opposite-direction crashes have the potential to be extremely severe because opposing vehicles often have high relative speeds. The AASHTO Strategic Highway Safety Plan (SHSP) was developed between 1997 and 2004 (1). At that time, opposite-direction crashes were 18% of noninterchange, nonjuncton fatal crashes (2). The SHSP lays out two goals for addressing the problem of opposite-direction crashes: (a) keeping vehicles from departing into the opposite lane and (b) minimizing the likelihood of crashing into an oncoming vehicle (1). Strategies for addressing the first aim include installing centerline rumble strips on two-lane roads, providing wider cross sections, providing center two-way left-turn lanes, and reallocating lanes and shoulders to include a narrow buffer median. Strategies for addressing the second aim include using alternating passing lanes and installing median barriers for narrow-width medians on multilane roads.

FHWA has made roadway departure crashes one of three areas of emphasis through its Focused Approach to Safety program (3). The other two areas of emphasis are pedestrian and intersection crash prevention. The focus areas were identified on the basis of state and national data as having overrepresented risk for injury and fatality compared with their exposure.

Centerline rumble strips (CRS) provide haptic and auditory feedback to drivers who encroach onto a milled, rolled, or raised surface near the centerline. Recently, Torbic et al. investigated the placement and efficacy of centerline and shoulder rumble strips (4, 5). Using data from three states, these researchers developed crash modification factors for the use of centerline and shoulder rumble strips. The researchers found that on urban two-way roads, CRS reduced crashes by 40% and fatal or incapacitating injury crashes by 64%. On rural two-way roads, they found a 9% reduction in all crashes and 12% reduction in fatal or incapacitating injury crashes. Target crashes on rural roads—that is, opposite-direction and sideswipe crashes—were reduced by 30%, and target fatal or incapacitating injury crashes were reduced by 44%. Many states have begun to install CRS on an experimental basis; a 2009 study found at least 13 states regularly installing CRS on two-lane undivided roads (6).

There are several possible impacts of CRS on road operations, such as the impact on ambient noise; road users such as bicyclists, motorists, and wide vehicles; lateral placement of vehicles in the lane; and passing maneuvers (6). One study using a driving simulator found that 27% of drivers steered incorrectly (i.e., to the left) when encountering a CRS; such a response decreases the effectiveness of this countermeasure (7). In the same study, the authors suggest that CRS treatments should be made to deliver a unique feedback to drivers that is different from shoulder rumble strips. However, on the basis of recorded video of real-world drivers, other researchers found that drivers did not exhibit incorrect steering when encountering CRS (6).

Median barriers placed between median-separated traffic lanes are another countermeasure that many states are adopting. Crossmedian crashes are more costly and severe than other types of departure crashes (8). Installing a median barrier has been shown to decrease opposite-direction crashes but increase single vehicle collisions, which are in general less severe (8–12). Many states have developed warrants for the placement of median barriers on the basis of factors such as median width and traffic volume (13).

A configuration with alternating passing lanes, also called a two-plus-one (2+1) road, is a popular design in Europe and has been...
The study utilized three U.S. national crash databases: (a) the National Automotive Sampling System (NASS) General Estimates System (GES), (b) the Fatality Analysis Reporting System (FARS), and (c) the NASS Crashworthiness Data System (CDS). All three databases are maintained and collected by NHTSA in the United States and are publicly available (15). Table 1 summarizes each data source.

TABLE 1 Description of National Crash Databases

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Years</th>
<th>Description</th>
<th>Approximate Number of Cases per Year</th>
<th>Weighted Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASS–GES</td>
<td>2010</td>
<td>National sample of police-reported crashes</td>
<td>45,000</td>
<td>Yes</td>
</tr>
<tr>
<td>FARS</td>
<td>2010</td>
<td>Census of traffic-related fatalities</td>
<td>30,000</td>
<td>No</td>
</tr>
<tr>
<td>NASS–CDS</td>
<td>2006–2010</td>
<td>National sample of crashes in which at least one passenger vehicle was towed from the scene</td>
<td>5,000</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The objective of this study was to use national crash databases to characterize opposite-direction crashes on U.S. roads. The results of the study can be used to guide future research and investment in countermeasures to opposite-direction crashes.

METHODOLOGY

Data Sources

The study utilized three U.S. national crash databases: (a) the National Automotive Sampling System (NASS) General Estimates System (GES), (b) the Fatality Analysis Reporting System (FARS), and (c) the NASS Crashworthiness Data System (CDS). All three databases are maintained and collected by NHTSA in the United States and are publicly available (15). Table 1 summarizes each data source. Cases in NASS CDS are investigated in depth by field investigation teams. These in-depth investigations provide detailed information on vehicle damage and occupant injuries not available in NASS GES or FARS. Data in NASS GES and FARS are compiled from police accident reports and do not contain the same depth of information as CDS cases. The goal of GES is to provide an estimate of crash frequency while FARS provides a census of all fatal crashes.

For this study, data for 2010 from GES and FARS were used to estimate annual exposure and fatal crashes; 5 years of data from CDS (2006 to 2010) were used to estimate the characteristics of serious injury crashes. These were defined as crashes in which at least one vehicle occupant sustained injuries that rated 3 or greater on the Abbreviated Injury Scale (AIS). The AIS scale is a threat-to-life scale that classifies injuries in categories from 1 (minor) to 6 (not survivable) (16). An injury with an AIS score of 3 or greater is considered to be serious. In 2010, NHTSA implemented a standardization of GES and FARS (17). The changes in standardized data definitions make it easier to compare data between the two. This study did not use FARS or GES for years prior to 2010 because they do not have all the required data.

For a crash to be included in the CDS database, at least one passenger vehicle must have been towed from the scene as a result of damage. As a result, crashes involving only heavy vehicles and crashes involving a vehicle and a pedestrian or cyclist are not included in the CDS. Thus, for comparison of CDS data with GES and FARS data, the analysis included only crashes involving at least one passenger vehicle.

All three databases are released online to the public by the NHTSA (ftp://ftp.nhtsa.dot.gov). Revisions are occasionally made to the data sources. For this study, GES 2010 data were dated October 11, 2011. CDS data were dated July 20, 2007, for 2006 data; June 29, 2009, for 2007 data; December 1, 2011, for 2008 data; September 20, 2010, for 2009 data; and September 11, 2011, for 2010 data. The FARS 2010 data were dated July 31, 2012.

Crash Scenarios

Coded variables were used to identify opposite-direction crashes in all three databases. Figure 1 shows a schematic of the selection process. First, all cases were separated into those that occurred in or near a junction or interchange and those that did not. Junction and interchange crashes are often turning or crossing-path collisions. Next, cases in which the most harmful event in the collision was a vehicle-to-vehicle impact were selected. Of all vehicle-to-vehicle collisions, crashes that were front-to-front, angle, or sideswipe opposite direction were excluded. Front-to-rear, sideswipe same direction, and other crash types were excluded at this step. For the two vehicles involved in the first vehicle-to-vehicle event, an opposite-direction scenario was determined on the basis of three variables: the precrash critical event, precrash movement, and accident type. The striking vehicle,
NASS GES and NASS CDS are both sampled data sets that utilize clustering and stratification in their sample designs. To make the samples representative of all crashes, a sample weight that corresponds to the number of similar collisions that occurred during the sample period is assigned to each crash. Traditional variance estimation methods underestimate variance for data with a complex design. To account for the design of the sample, variance was estimated with Taylor series linearization, which weights the variance in each cluster and strata in the data. The survey procedures in the statistical software SAS version 9.2 were used to estimate variance for NASS CDS. Variance estimates were computed with a technique described in the *GES Analytical User’s Manual*, which applies regression equations to standard error estimates based on Taylor series linearization (20).

**RESULTS**

The methodology used to analyze the three national crash databases was a top-down approach. First, the opposite-direction crash problem was quantified in terms of all severity, serious injury, and fatal crashes. The analysis showed that opposite-direction crashes were most overrepresented on rural two-lane roads. Finally, cross-over-to-left opposite-direction crashes were compared with opposite-direction loss-of-control and wrong-side-of-road crashes.

### Opposite-Direction Scenarios

Figure 2 shows examples of four opposite-direction crash scenarios: cross-over-to-left, loss-of-control, traveling on the wrong side of the road, and cross-over-to-right. The schematic shows a two-lane undivided road, but the scenarios could occur on any road configuration.

Land use where the crash was located was defined differently in each database. In FARS, the roadway functional class is assigned for each crash (e.g., rural principal arterial or urban collector). In GES, the population of the jurisdiction of the crash is used to classify land use. No land use variable is collected in NASS CDS. Instead, land use can be inferred from the 24 primary sampling units. In many road safety applications, the average daily number of vehicles that travel on a road is better correlated to crash frequency than land use. In this study, the land use variables available in the data were used to classify crashes as occurring on either rural or urban roads, because traffic data were not available.

#### Statistical Methods

The analysis estimated confidence intervals for percentages. Because FARS is a census of crashes, the assumption was that variance could be modeled by a multinomial distribution. Although categorical data are ubiquitous for these types of crash databases, many statistical packages do not have native support for estimating multinomial confidence intervals. Instead, the packages assume that the observations in each category are independent of each other and estimate variance assuming a binomial distribution. The assumption in this study was that a multinomial distribution was more appropriate than a binomial distribution if the number of categories was greater than two (18).

For a categorical variable with k levels, the upper and lower bounds on the percentages with significance level α are found with the following equation:

\[
\pi_i^\alpha = \frac{A + 2n_i \pm A \left( A + 4n_i \frac{(N - n_i)}{N} \right)}{2(N + A)}
\]

where

- \( A = \text{upper 100} \left( 1 - \alpha/k \right) \text{ percentage points of } \chi^2 \text{ distribution, as proposed by Goodman (19);} \)
- \( n_i = \text{number of observations in category } i; \) and
- \( N = \text{total number of observations.} \)

### Table 2: Summary of Data Sources for Crashes Involving at Least One Passenger Vehicle

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Label</th>
<th>Years</th>
<th>No. of Cases</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASS–GES</td>
<td>All severities</td>
<td>2010</td>
<td>44,722</td>
<td>5,241,570</td>
</tr>
<tr>
<td>NASS–CDS</td>
<td>Serious injury</td>
<td>2006–2010</td>
<td>4,695</td>
<td>361,811</td>
</tr>
<tr>
<td>FARS</td>
<td>Fatal crashes</td>
<td>2010</td>
<td>28,698</td>
<td>28,698</td>
</tr>
</tbody>
</table>

*Note: No. = number.*
at all levels of severity (48.7%). Front-to-front, angle, and sideswipe opposite-direction collisions accounted for more fatal and serious injury crashes (63.5% and 73.3%, respectively) as compared with crashes at all levels of severity (16.0%). In collisions at all levels of severity, the majority (60%) had a front-to-rear configuration (not shown in the table). Front-to-rear damage accounted for 22% of serious injury and 19% of fatal vehicle-to-vehicle crashes that occurred away from a junction.

Table 4 shows the frequency of crash scenarios for front-to-front, angle, and sideswipe opposite-direction damage in nonjunction and noninterchange vehicle-to-vehicle crashes. The cross-over-to-left scenario constituted 5.0% of nonintersection, vehicle-to-vehicle collisions at all levels of severity, yet it accounted for 44% of serious injury crashes and 49% of fatal crashes. Overall, the cross-over-to-left crash scenario accounted for 8.7% of all serious injury crashes (within 95% confidence interval 7.0% to 10.4%) and 9.4% of all fatal crashes (within 95% confidence interval 9.0% to 9.9%). Loss of control was the second most common crossover scenario, followed by vehicles traveling on the wrong side of the road.

Because FARS is a census of fatal traffic-related crashes, the data allow for comparison of fatal crash trends by region or state. The number of fatal cross-over-to-left crashes per 100 million annual vehicle miles traveled (VMT) for each state is shown in Figure 3. VMT estimates are from FHWA’s Highway Statistics 2009 (21). The national average for 2010 was 0.108 fatal crashes per 100 million annual VMT. Pennsylvania and Nebraska were the states closest to the national average. The greatest number of fatal crashes normalized to annual VMT occurred in Arkansas, Wyoming, Kentucky, West Virginia, and South Carolina. The fewest crossover fatal crashes per annual VMT occurred in Maryland, Massachusetts, Rhode Island, Arizona, and Colorado.

Table 5 shows the road configuration for cross-over-to-left opposite-direction crashes. The most common road configuration for all data sets was a two-way undivided roadway. Median-divided roads with no barrier accounted for 6.3% of serious injury and 9.6% of fatal crashes.

On two-way undivided roads, 60% of crashes of all severity, 44% of crashes involving serious injury, and 72% of fatal crashes were on two-lane roads in rural areas. Cross-over-to-left crashes on two-lane rural roads accounted for 0.7% of all crashes, 3.6% of serious injury crashes, and 5.8% of fatal crashes, and there were 1,659 fatal crashes annually.

### Table 3: Frequency of Crashes by Relationship to Junction and Manner of Collision

<table>
<thead>
<tr>
<th>Description of Collision</th>
<th>All Severities (GES)</th>
<th>Serious Injury (CDS)</th>
<th>Fatal Crashes (FARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>%</td>
<td>%±</td>
</tr>
<tr>
<td>Relationship to Junction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonjunction–noninterchange</td>
<td>2,336,255</td>
<td>44.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Nonjunction, vehicle-to-vehicle collisions</td>
<td>1,137,809</td>
<td>48.7</td>
<td>6.5</td>
</tr>
<tr>
<td>Manner of Collision of Nonjunction, Vehicle-to-Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front to front</td>
<td>39,816</td>
<td>3.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Angle</td>
<td>100,960</td>
<td>8.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Sideswipe (opposite direction)</td>
<td>41,498</td>
<td>3.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>182,274</td>
<td>16.0</td>
<td>2.9</td>
</tr>
</tbody>
</table>

### Table 4: Frequency of Crash Scenarios for Front-to-Front, Angle, and Sideswipe Opposite-Direction Crashes in Nonjunction, Noninterchange, Vehicle-to-Vehicle Crashes

<table>
<thead>
<tr>
<th>Scenario</th>
<th>All Severities (GES)</th>
<th>Serious Injury (CDS)</th>
<th>Fatal Crashes (FARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>%V2V</td>
<td>%±</td>
</tr>
<tr>
<td>Cross to left</td>
<td>57,164</td>
<td>5.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Control loss</td>
<td>39,737</td>
<td>3.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Wrong side of road</td>
<td>3,917</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Same direction</td>
<td>40,273</td>
<td>3.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Cross to right</td>
<td>18</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other crossover</td>
<td>5,397</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Vehicle from parking</td>
<td>10,636</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Other–unknown</td>
<td>25,132</td>
<td>2.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Total head-on, angle, sideswipe</td>
<td>182,274</td>
<td>16.0</td>
<td>3.8</td>
</tr>
<tr>
<td>All other V2V</td>
<td>955,536</td>
<td>84.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Total</td>
<td>1,137,809</td>
<td>100</td>
<td>71,151</td>
</tr>
</tbody>
</table>

Note: V2V = vehicle to vehicle.
Cross-Over-to-Left Opposite-Direction Crashes on Two-Lane Rural Roads

The analysis in this section pertains to opposite-direction crashes in which the precrash scenario was cross-over-to-left occurring on rural two-lane roads. This type of crash accounted for 28,894 crashes of all severity, approximately 2,573 serious injury crashes annually (12,865 over 5 years), and 1,659 fatal crashes.

Figure 4 shows the distribution of precrash maneuvers for the driver of the striking vehicle in cross-over-to-left crashes on rural two-lane roads. In all data, traveling straight or negotiating a curve was the most common precrash maneuver. Overtaking another vehicle accounted for 4% of crashes of all severity, 2% of serious injury crashes, and 6% of fatal crashes. Figure 5 shows the roadway alignment for the striking vehicle in cross-over-to-left crashes on rural two-lane roads. Straight roads were the majority in all three crash groups. The second most common alignment in all three groups was curve right (i.e., a departure to the outside of the curve), followed by curve left (i.e., departure to the inside of the curve).

The proportion of cross-over-to-left departures in which the driver was alcohol impaired is shown in Figure 6. Alcohol impairment was determined from police-administered blood alcohol concentration (BAC) tests. The driver was considered alcohol impaired if the reported BAC was 0.08% or greater, which is the legal limit in many states. Drivers who were not tested or who had a reported BAC of less than 0.08% were labeled as not impaired or not tested. Alcohol impairment was low in GES crashes (1.9%); however, the GES had the highest rate of unknown BAC test results. In serious injury and fatal crashes, alcohol impairment was a factor in 13.8% and 17.1% of the crashes, respectively. For perspective, in FARS, alcohol impairment was a factor in 22% of all crashes and in 24% of serious injury crashes for the same time period.

Figure 7 shows the distribution of speed limits for cross-over-to-left departures on rural two-lane roads. Fatal and serious injury crashes primarily occurred on roads with speed limits above 50 mph; crashes of all severity occurred on roads with a wider range of speed limits. The state of Washington has given priority to installing center-line rumble strips on roads with speed limits of 45 or 55 mph (22), a practice supported by the results of this study.

Comparison of Cross-Over-to-Left, Loss-of-Control, and Wrong-Way Opposite-Direction Crashes

The previous section examined only cross-over-to-left opposite-direction crashes that occurred on rural two-lane roads. This section examines the differences between nonjunction vehicle-to-vehicle crashes in which the opposite-direction scenario was cross over to left, loss of control, or wrong way. These are the three most frequent scenarios in opposite-direction crashes. There were 100,818 crashes of all severity levels, 8,373 serious injury crashes annually (41,867 over 5 years), and 3,545 fatal crashes in these three categories (see Table 4).

Wrong-side-of-road crashes were more likely to occur on straight roads than were cross-over-to-left and loss-of-control crashes. Fatal wrong-side-of-road crashes occurred on straight roads 80% of the time.
Road alignments and speed limits were similar for cross-over-to-left and loss-of-control crashes. Loss-of-control crashes occurred on roads with wet, icy, or snow-covered surface conditions more often than cross-over-to-left crashes. In fatal cross-over-to-left crashes, 81% of road surfaces were dry compared with only 34% of fatal loss-of-control crashes. This trend in surface conditions was similar for collisions of all severity levels as well as serious injury collisions.

**CONCLUSIONS**

In 2003, AASHTO released its SHSP with the goal of halving highway fatalities within two decades. The AASHTO plan addressed head-on collisions as a major source of highway fatalities. The results of this study suggest that future infrastructure-based countermeasures to opposite-direction crashes should focus on two-lane rural roads. This paper has shown that the most common opposite-direction crash scenario was a driver crossing over the centerline or the road edge to the left. Cross-over-to-left crashes accounted for only 5% of all vehicle-to-vehicle crashes that did not occur near a junction, but they accounted for 44% of serious injury crashes and 49% of fatal crashes, which were 9% of all serious injury and fatal crashes. Furthermore, 44% of serious injury crashes and 72% of fatal cross-over-to-left crashes occurred on rural, undivided, two-lane roads. The majority of driver precrash maneuvers in the cross-over-to-left crashes on rural two-lane roads were going straight or negotiating curves; overtaking another vehicle accounted for only 2% of injury and 6% of fatal crashes.

A decade after the initial AASHTO strategic plan was published, opposite-direction crashes are still overrepresented among serious injury and fatal crashes with respect to their exposure. The results of this study will guide future research on opposite-direction crashes and countermeasures to these crashes, as well as influence policy to address opposite-direction crashes as part of strategic state highway safety plans.

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REFERENCES


The Roadside Safety Design Committee peer-reviewed this paper.