# Wrong-Way Driving and Injury Risk on a Rural Four-Lane Corridor: A Descriptive and Spatial Analysis of US Highway 10, 2019–2024

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## ABSTRACT

**Introduction:** Motor vehicle collisions (MVCs) on rural highways pose unique challenges due to high speed limits, limited access points, and varied environmental conditions. This study aimed to describe crash characteristics, identify predictors of injury and fatality, and evaluate geospatial trends along a rural segment of US Highway 10 in Wisconsin.

**Methods:** We conducted a retrospective analysis of MVCs reported on US Highway 10 from January 1, 2019, to March 1, 2024. Incident-level dispatch data were analyzed with corresponding environmental and temporal factors using descriptive statistics, geospatial analysis, and logistic regression. Geospatial mapping was used to identify high-risk roadway segments, and descriptive statistics and logistic regression were used to identify factors associated with injury or fatality.

**Results:** Among 239 MVCs, 21.3% (n = 51) involved injury or death. Angle collisions were significantly associated with increased odds of injury or fatality (OR 2.52; 95% CI, 1.04–6.09, *P* = .04). Wrong-way driving, though rare, was associated with a higher proportion of injury-producing crashes. Deer-related crashes comprised 38.0% of events but rarely resulted in injury (4.3%). Environmental factors, including lighting conditions, road surface conditions, and weather, were not independently predictive. Spatial clustering was observed near major intersections, transition zones, and roadway merging areas.

**Conclusions:** Collision mechanism, particularly angle collisions and wrong-way crashes, are key predictors of injury on this rural 4-lane highway corridor. In contrast, deer-related collisions were common but infrequently associated with injury. These findings support targeted roadway-engineering improvement, enhanced signage, and behavioral interventions to reduce crash-related injury along rural corridors such as Highway 10.


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## INTRODUCTION

Motor vehicle collisions (MVCs) continue to be a leading cause of injury and death in the United States, with rural areas experiencing disproportionately high fatality rates due to factors such as excessive speed, prolonged emergency medical services (EMS) mobilization and response times, and limited access to trauma care facilities.[1-5] In Wisconsin, there is a high proportion of rural residents (32.9%), and the age-adjusted injury mortality rate exceeds the national rate, highlighting ongoing geographic disparities in injury risk and outcomes.[6] Rural highways such as US Highway 10 present unique hazards, including long stretches without interruption, high speed limits, limited lighting, and increased wildlife crossings, all of which contribute to crash risk and severity.[7,8] Despite widespread public health initiatives aimed at improving rural roadway safety, injury prevention efforts are often reactive and lack precise geospatial targeting.[9] Wrong-way driving incidents, though rare, have become particularly dangerous due to resulting high-speed, head-on collisions.[10] In Wisconsin, deer-related crashes are common on rural highways, particularly in wooded or agricultural corridors. While wildlife-vehicle collisions account for a substantial proportion of total crashes, they are less often associated with serious injury than multivehicle or angle collisions.[11-13]

The objective of this study was to identify environmental, temporal, and mechanistic factors linked to injury or death resulting from MVCs along a rural section of US Highway 10 in Wisconsin

from 2019 to 2024. We also analyzed the spatial clustering of high-risk crash locations to support targeted infrastructure improvements and prevention efforts.

## METHODS

### Study Design and Data Source

This retrospective cohort study analyzed motor vehicle collisions (MVCs) on the 4-lane rural segment of US Highway 10 in Wood County, Wisconsin, from January 1, 2019, to March 1, 2024. Incident-level data were collected from Wood County Sheriff's Office dispatch face sheets, which record real-time crash details including time, location, environmental conditions, crash mechanism, vehicle involvement, and EMS response.

Data abstraction was limited to events occurring within the designated Highway 10 corridor. Eligible cases included any reported MVC involving motorized vehicles (eg, passenger cars, trucks, and commercial vehicles) with complete information on crash location and outcome. Events involving only nonmotorized participants or those lacking injury or location data were excluded. For regression modeling, deer-related collisions were excluded to avoid attenuating associations between predictor variables and injury outcomes because of the high frequency and low severity of these events.

Dispatch records were reviewed manually for consistency and coded for variables including lighting (daylight, dawn/dusk, dark-unlit), road surface conditions (dry, wet, icy, or snowy), weather, direction of travel, number of vehicles, and crash type (eg, angle, front-to-rear, or wrong-way). When available, records also included information on alcohol or drug involvement and EMS response times.

This study was determined to be exempt from oversight by the [RHO10124] Institutional Review Board under institutional policies and federal guidelines for minimal-risk research. Analyses adhered to the principles of the Declaration of Helsinki and were reported according to the STROBE guidelines (Supplementary Table 1).

### Outcomes of Interest

The primary outcome was whether an MVC resulted in an injury or fatality, based on dispatch documentation indicating medical evaluation or death at the scene or during transport. Crashes were classified as injury/fatality or noninjury events. Secondary outcomes included environmental, temporal, and mechanistic predictors of injury, as well as the geospatial distribution of injury-producing crashes along the study corridor (Figure).

### Statistical Analysis

Descriptive statistics were used to summarize crash characteristics. Categorical variables were presented as frequencies and percentages, and continuous variables were reported as means, medians, and interquartile ranges. Group comparisons between injury/fatality and noninjury crashes were conducted using chi-square tests for categorical variables and Wilcoxon rank-sum tests for continuous variables. Analyses were conducted using R version 4.4.1 (R Core Team, 2023). A descriptive geospatial analysis was performed in Power BI Desktop (version 2.143.878.0, Microsoft) to visualize crash clustering and identify high-frequency roadway segments.

Multivariable logistic regression was used to identify factors independently associated with injury or fatality. To minimize confounding from frequent but low-severity events, deer-related collisions were excluded from the regression model. Predictor variables included environmental, mechanistic, and temporal factors such as lighting conditions, road surface conditions, weather, direction of travel, and collision type. Variables were screened for multicollinearity using tolerance testing (threshold, > 0.5). Regression analyses were conducted using SPSS version 28 (IBM Corp). Model results were expressed as odds ratios (OR) with 95% confidence intervals (CI); significance was set at $P < .05$.

## RESULTS

### First Analysis: Crash Characteristics

A total of 239 MVCs were reported along the designated rural segment of US Highway 10 during 2019-2024. Of these, 51 crashes (21.3%) resulted in injury or fatality. Deer-related collisions accounted for 38.0% (n = 91) of all MVCs, while the remaining 61.9% (n = 148) were non-deer-related. Although deer collisions were common, they were significantly less likely to cause injury or death than non-deer-related MVCs (4.3% vs 31.7%, $P < .01$). See Table 1.

Crash timing showed a bimodal distribution in injury outcomes, with injury/fatality crashes peaking in 2021 (25.4%) and again in 2024 (17.6%). The mean crash time was 13:54 (SD, 6:05), with no significant difference between injury/fatality and noninjury groups ($P = .06$). EMS response time did not differ significantly between injury/fatality and noninjury groups (mean, 12:57 vs 13:30, $P = .69$).

Most crashes (69.0%) involved a single vehicle; however, 2-vehicle collisions were more likely to result in injury or fatality, although the association was not significant (62.7% vs 20.7%, $P = .06$). Nearly all deer-related crashes involved a single vehicle (97.8%).

Collision type was significantly associated with injury severity. Angle collisions accounted for 33.3% of injury/fatality events compared with only 7.4% of noninjury crashes ($P = .01$). Wrong-way collisions were rare (n = 5); however, 4 of the 5 events resulted in injury or fatality. Although the number of events was small, this finding suggests a potential association between wrong-way driving and injury risk that warrants further study.

Environmental factors also showed notable trends. Crashes occurring under dark or unlit conditions were more common among injury/fatality events (27.4% vs 21.8%, $P < .01$). Although dry roads were the most common overall, they were disproportion-

**Table 1.** Descriptive Characteristics of Motor Vehicle Crashes on US Highway 10, 2019–2024

| | | Environmental Hazard | | | Injuries and Fatalities | | |
|---|---|---|---|---|---|---|---|
| | **Total N = 239** | **MVC-No Deer N = 148 (61.9%)** | **Deer-related MVC N = 91 (38.1%)** | ***P* value** | **Incidents With Injury/Death N = 51 (21.3%)** | **Survived (N = 188)** | ***P* value** |
| Year, n (%) | | | | | | | |
| 2019 | 29 (12.1) | 22 (14.9) | 7 (7.7) | .14 | 11 (21.6) | 18 (9.6) | <.01 |
| 2020 | 32 (13.4) | 22 (14.9) | 10 (11.0) | .51 | 8 (15.7) | 24 (12.8) | <.01 |
| 2021 | 59 (24.7) | 35 (23.6) | 24 (26.4) | .74 | 13 (25.5) | 46 (24.5) | <.01 |
| 2022 | 37 (5.5) | 18 (12.2) | 18 (19.8) | .10 | 2 (3.9) | 34 (18.1) | <.01 |
| 2023 | 31 (13.0) | 23 (15.5) | 9 (9.9) | .36 | 8 (15.7) | 24 (12.8) | <.01 |
| 2024 | 51 (21.3) | 28 (18.9) | 22 (24.2) | .49 | 9 (17.6) | 41 (21.8) | <.01 |
| Crash time, n = 234; mean, median [SD] IQR | 13:54, 14:15 [6:05] 11:24 | 13:19, 13:14 [5:19] 8:29 | 14:48, 17:22 [6:21] 14:02 | .07 | 13:27, 13:14 [5:12] 7:03 | 14:00, 14:58 [6:20] 11:44 | .06 |
| Elapsed arrival time, n = 148; mean, median [SD] IQR | 0:37, 0:13 [2:17] 0:14 | 13:29, 13:10 [5:16] 8:26 | 12:15, 12:50 [9:21] 13:37 | .69 | 12:57, 13:00 [5:06] 7:37 | 13:30, 13:36 [5:36] 10:13 | .69 |
| Vehicles involved, n (%) | | | | | | | |
| 1 vehicle | 165 (69.0) | 76 (51.3) | 89 (97.8) | <.01 | 18 (35.3) | 147 (78.2) | .03 |
| 2 vehicles | 71 (29.7) | 71 (48.0) | 0 (0) | — | 32 (62.7) | 39 (20.7) | .06 |
| 3 vehicles | 1 (0.4) | 1 (0.7) | 0 (0) | — | 1 (2.0) | 0 (0) | — |
| Total injured, n (%) | 51 (21.3) | 47 (31.8) | 4 (4.4) | .78 | — | — | — |
| Total killed, n (%) | 7 (2.9) | 7 (4.7) | 0 (0) | — | — | — | — |
| Event location, n (%) | | | | | | | |
| On roadway | 199 (83.3) | 108 (73.0) | 91 (100) | <.01 | 42 (82.4) | 157 (83.5) | <.01 |
| Roadside | 17 (7.1) | 17 (11.5) | 0 (0) | - | 3 (5.9) | 14 (7.4) | <.01 |
| Manner of collision, n (%) | | | | | | | |
| No collision with vehicle in transport | 165 (69.0) | 76 (51.3) | 89 (97.8) | <.01 | 19 (37.2) | 146 (77.7) | .06 |
| Angle | 31 (13.0) | 31 (20.9) | 0 (0) | — | 17 (33.3) | 14 (7.4) | .01 |
| Front to rear | 15 (6.3) | 15 (10.1) | 0 (0) | — | 6 (11.7) 11.8 | 9 (4.8) | <.01 |
| Wrong-way driver | 5 (2.1) | 5 (3.4) | 0 (0) | — | 3 (5.9) | 2 (1.1) | <.01 |
| Lighting condition, n (%) | | | | | | | |
| Dark/Unlit | 55 (23.0) | 48 (32.4) | 7 (7.7) | <.01 | 14 (27.4) | 41 (21.8) | <.01 |
| Dawn | 7 (2.9) | 6 (4.0) | 1 (1.1) | .81 | 3 (5.8) | 4 (2.1) | <.01 |
| Daylight | 87 (36.4) | 87 (58.8) | 0 (0) | — | 32 (62.7) | 55 (29.3) | .06 |
| Dusk | 4 (1.7) | 4 (2.7) | 0 (0) | — | 2 (3.9) | 2 (1.1) | <.01 |
| Road surface, n (%) | | | | | | | |
| Dry | 92 (38.5) | 84 (56.8) | 8 (8.8) | .04 | 36 (70.6) | 56 (29.8) | <.01 |
| Ice | 32 (13.4) | 32 (21.6) | 0 (0) | — | 9 (17.6) | 23 (12.2) | <.01 |
| Slush | 1 (0.4) | 1 (0.6) | 0 (0) | — | — | 1 (0.5) | — |
| Snow | 14 (5.9) | 14 (9.5) | 0 (0) | — | 1 (2.0) | 13 (6.9) | <.01 |
| Wet | 14 (5.9) | 14 (9.5) | 0 (0) | — | 5 (9.8) | 9 (4.8) | <.01 |
| Weather condition, n (%) | | | | | | | |
| Clear | 72 (30.1) | 65 (43.9) | 7 (7.7) | .04 | 26 (51.0) | 46 (24.5) | .88 |
| Cloudy | 46 (19.2) | 45 (30.4) | 1 (1.1) | .47 | 18 (35.3) | 28 (14.9) | .03 |
| Fog | 4 (1.7) | 4 (2.7) | 0 (0) | — | 1 (2.0) | 3 (1.6) | <.01 |
| Rain | 8 (3.3) | 8 (5.4) | 0 (0) | — | 3 (5.8) | 5 (2.7) | <.01 |
| Severe winds | 2 (0.8) | 2 (1.3) | 0 (0) | — | — | 2 (1.1) | — |
| Snow | 19 (7.9) | 19 (12.8) | 0 (0) | — | 2 (3.9) | 17 (9.0) | <.01 |
| Direction of travel, n (%) | | | | | | | |
| Eastbound | 86 (36.0) | 48 (32.4) | 38 (41.8) | .23 | 18 (35.3) | 68 (36.2) | .03 |
| Northbound | 29 (12.1) | 23 (15.5) | 6 (6.6) | .05 | 9 (17.6) | 20 (10.6) | <.01 |
| Southbound | 25 (10.5) | 24 (16.2) | 1 (1.1) | <.01 | 7 (13.7) | 18 (9.6) | <.01 |
| Westbound | 93 (38.9) | 48 (32.4) | 45 (49.4) | .01 | 17 (33.3) | 76 (40.4) | .01 |
| License status , n (%) | | | | | | | |
| Expired | 1 (0.4) | 1 (0.7) | 0 (0) | — | — | 1 (0.5) | — |
| Not Licensed | 4 (1.7) | 4 (2.7) | 0 (0) | — | 1 (2.0) | 3 (1.6) | .56 |
| Revoked | 2 (0.8) | 2 (1.3) | 0 (0) | — | 1 (2.0) | 1 (0.5) | .56 |
| Suspended | 4 (1.7) | 3 (2.0) | 1 (1.1) | .76 | 1 (2.0) | 3 (1.6) | .56 |
| Alcohol test (N = 1 result, 0.17% BAC), n (%) | 6 (2.5) | 6 (4.1) | 0 (0) | — | 4 (7.8) | 2 (1.1) | .12 |
| Drug Test, n (%) | 5 (2.1) | 5 (3.4) | 0 (0) | — | 4 (7.8) | 1 (0.5) | .18 |

Abbreviations: SD, standard deviation; IQR, interquartile range; BAC, blood alcohol count.

ately represented among injury/fatality crashes (70.5% vs 29.7%, $P < .01$). Similar patterns were observed for weather conditions: cloudy conditions and snow were more frequently associated with injury/fatality events (35.2% and 3.9%, respectively), although clear weather remained the most common condition overall. Direction of travel was also associated with injury outcomes, with most crashes occurring in the westbound direction (38.9%) and a greater proportion of injury/fatality events occurring among westbound vehicles (33.3%, $P = .01$).

Although alcohol and drug involvement were documented more frequently in injury/fatality crashes, these variables were recorded infrequently and did not reach statistical significance.

### Second Analysis, Logistic Regression Model; Injury and Fatalities

A multivariable logistic regression model was developed to assess the relationship between crash characteristics and the risk of injury or death in MVCs on US Highway 10 during 2019-2024. The model included 7 potential predictors: EMS elapsed time to crash, roadway location, angle of impact, daylight conditions, dry road surface, clear weather, and westbound travel direction (Table 2).

Of these variables, only angle of impact was independently associated with increased odds of injury or death. Crashes involving an angle impact had 2.52 times greater odds of resulting in injury or fatality than other collision types of (OR, 2.52; 95% CI, 1.04–6.09; $P = .04$).

None of the environmental factors, including daylight conditions (OR, 1.22; 95% CI, 0.56–2.65; $P = .60$), dry road surface (OR, 1.41; 95% CI, 0.55–3.61; $P = .46$), or clear weather (OR, 1.10; 95% CI, 0.47–2.56; $P = .81$), were significantly associated with injury outcomes. Likewise, westbound travel direction (OR, 1.00; 95% CI, 0.46–2.16; $P = .99$) and roadway location (OR, 1.26; 95% CI, 0.47–3.34; $P = 63$) were not associated with increased injury risk.

EMS elapsed time, treated as a continuous variable, was not a significant predictor (OR, 1.00; $P = 87$), indicating that differences in response timing did not significantly affect injury outcomes in the study population.

### Geospatial Analysis

Geospatial mapping revealed distinct crash clustering patterns along the Highway 10 corridor (Figure 1). Non-deer-related and angle collisions were tightly clustered around major intersections, particularly County Roads 80, A, and 186. Directional stratification showed that westbound non-deer-related crashes were concentrated in the western half of the corridor, whereas eastbound crashes occurred more frequently between County Roads 80 and 186. In contrast, deer-related crashes were more evenly distributed and occurred primarily in the rural eastern segment near the towns of Milladore and Sherry.

**Table 2.** Logistic Regression Among the Injuries and Fatalities by Motor Vehicle Crashes on US Highway 10, 2019 – 2024

| | Standard Error | Odds Ratio (95% CI) | *P* value |
|---|---|---|---|
| Elapsed time to crash | 0.00 | 1.00 (1.00–1.00) | .87 |
| Event location on roadway | 0.49 | 1.26 (0.47–3.34) | .63 |
| Angle collision | 0.45 | 2.52 (1.04–6.09) | .04 |
| Daylight condition | 0.39 | 1.22 (0.56–2.65) | .60 |
| Dry road surface | 0.47 | 1.41 (0.55–3.61) | .46 |
| Clear weather condition | 0.43 | 1.10 (0.47–2.56) | .81 |
| Westbound direction | 0.39 | 1.00 (0.46–2.16) | .99 |

## DISCUSSION

This study provides a focused geospatial and mechanistic analyses of MVCs along a rural 4-lane corridor in central Wisconsin. Despite the high frequency of deer-related crashes, our findings suggest that collision mechanism and vehicle dynamics, rather than environmental conditions, are the most significant predictors of injury and fatality risk. Specifically, angle collisions were associated with more than a 2-fold increase in the odds of injury risk, consistent with national reports indicating that side-impact collisions are disproportionately fatal because of reduced structural protection and a higher likelihood of passenger-compartment intrusion.

Wrong-way driving events, although infrequent, were disproportionately represented among injury/fatality crashes in the univariate analysis. This finding is consistent with national data showing that wrong-way crashes are often head-on collisions and frequently involve older drivers or impaired driving, resulting in high-impact velocities and high lethality.[10,14] These findings underscore the need for improved detection and prevention infrastructure in rural settings, where long, uninterrupted roadways may increase the risk of driver disorientation or deliberate misuse of access points.

Environmental variables, including dry roads, daylight conditions, and clear weather, were not statistically significant predictors of injury or death in the multivariable model, despite being most common in the descriptive data. This finding supports previous research suggesting that crash severity is more strongly associated with crash type and vehicle interaction dynamics than with roadway surface or visibility conditions alone.[15] Although lighting and weather conditions are often linked to crash causation, their independent effects on injury severity appear limited after accounting for collision mechanism and vehicle count.[16]

A notable finding was the low severity of deer-related collisions, which accounted for more than one-third of all crashes but rarely resulted in injury (4.3%). Although deer-related crashes are often highlighted in rural road-safety campaigns, our findings suggest they pose a greater risk of vehicle damage than serious injury. These results are consistent with prior studies demonstrating that most deer-related MVCs involve single vehicles traveling at moderate speeds and rarely cause severe injury.[17]

Geospatial analysis identified clustering of injury-producing crashes--although not detailed in this regression model--near rural transition zones and at key intersections along Highway 10. Previous geospatial analyses similarly have demonstrated that high-speed rural corridors have concentrated patterns of crash risk that can be addressed with engineering interventions, including rumble strips, enhanced signage, or lane separation.[9,18] Although westbound crashes occurred more frequently and were more often associated with injury, geospatial mapping also suggested clusters of fatal events in eastbound travel segments; however, this trend did not reach statistical significance.

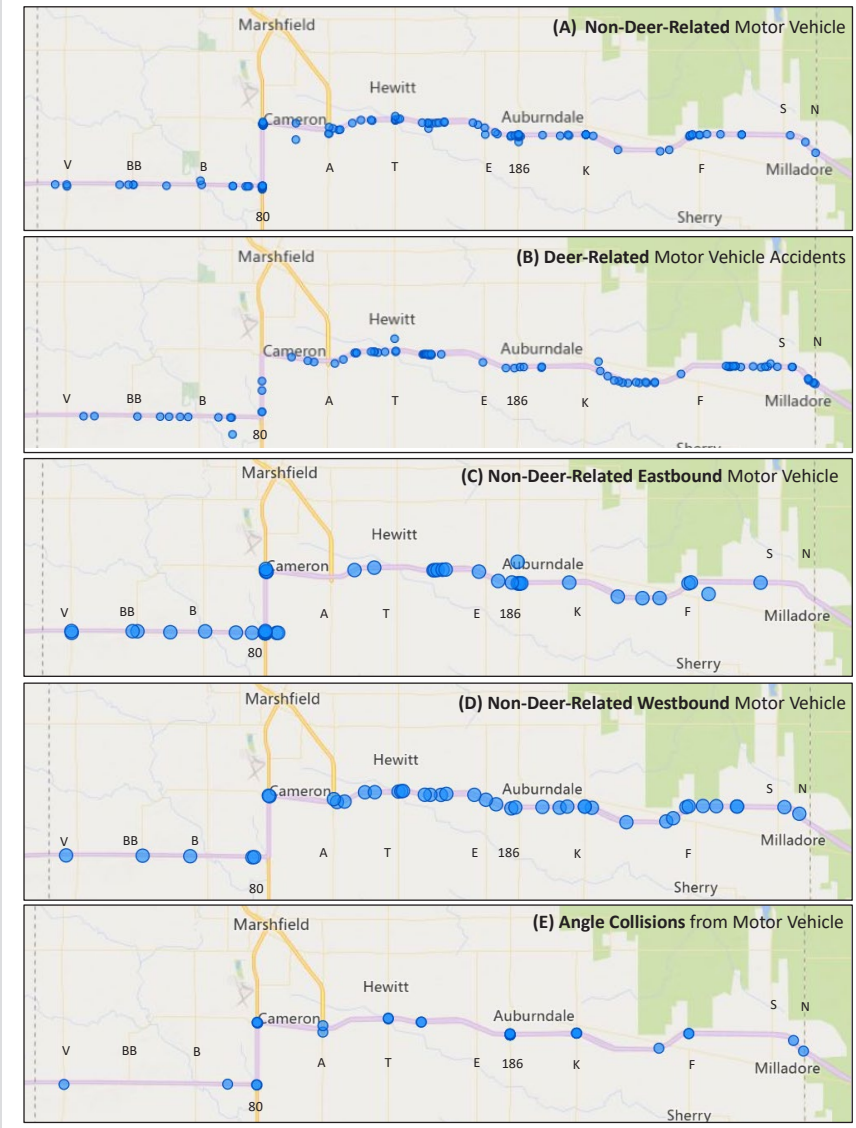
One possible explanation for the higher incidence of westbound crashes is increased commuter traffic entering Marshfield from the south, resulting in greater vehicle density and turning conflicts at key intersections. Further investigation using larger datasets is warranted to better clarify directional risk patterns along rural corridors.

In response to these findings, the study team shared results with transportation planners, local traffic engineers, and representatives from the Wisconsin Department of Transportation (WisDOT) to support corridor-specific safety interventions. Proposed countermeasures currently under consideration include J-turn intersection redesigns, enhanced signage at crossover points, high-reflectivity pavement markings, and rumble-strip installation along high-frequency crash segments. These measures align with Federal Highway Administration (FHWA) guidance on rural road safety improvements, particularly for divided highways with multiple uncontrolled access points.[19,20]

In addition to roadway design, behavioral strategies such as public education campaigns, dynamic warning signs, and targeted enforcement in identified injury hotspots may complement infrastructure improvements. These approaches may be particularly relevant for addressing the wrong-way driving and angle-impact risks observed in this study. The geospatial crash maps developed for this analysis have already been used during stakeholder meetings to support site-specific planning efforts. Future research could further integrate crash-clusters data with EMS response metrics and traffic-flow modeling to enhance rural road safety across Wisconsin.

Overall, this study highlights the need for prevention strategies tailored to specific collision mechanisms, with a particular focus on angle collisions and less common but potentially severe wrong-way driving events. Investments in passive infrastructure, such as median barriers and improved signage, as well as active technologies, including vehicle-based detection and warning systems, may help significantly reduce injuries along high-speed rural corridors.

**Figure.** Geospatial Distribution of Motor Vehicle Accidents Along Highway 10, Wisconsin, 2018-2023




## Limitations

This study has several limitations. First, the data were obtained exclusively from Wood County Sheriff's Office dispatch face sheets and therefore may be affected by reporting inconsistencies, incomplete documentation, or classification errors, particularly for environmental variables such as lighting and weather. Injury status was recorded at the scene or during transport, and outcomes could not be verified using hospital records or trauma registry data, potentially resulting in underestimation of the true injury burden.

Second, the dataset lacked detailed clinical information regarding injury severity, medical interventions, and long-term outcomes, limiting the ability to categorize injuries by severity or health care resource utilization. In addition, toxicology testing was documented inconsistently and was not performed in all cases, limiting assessment of the effects of alcohol or drug impairment on crash outcomes.

Third, although the analysis intentionally focused on a rural segment art of US Highway 10, the findings may not be generalizable to other highway types, urban roads, or regions with different traffic patterns and enforcement practices.

Finally, although the multivariable model adjusted for key confounders, the limited sample size restricted the number of variables that could be included, potentially excluding other relevant predictors such as driver behavior, seat belt use, or vehicle type.

## CONCLUSIONS

This analysis of MVs along a rural 4-lane corridor of US Highway 10 found that collision mechanism, particularly angle impacts, was the strongest predictor of injury or fatality, independent of environmental or time-related factors. Although deer-related crashes were common, they rarely resulted in injury, indicating a need to shift rural safety priorities towards high-severity but less frequent events such as angle and wrong-way collisions. These findings support targeted, mechanism-specific interventions, including roadway design changes, improved signage, and driver warning technologies, to reduce injuries on high-speed rural highways. Integration of dispatch-based data with clinical and geospatial analyses may provide a valuable framework for localized traffic-safety planning and injury prevention in rural areas.

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**Appendix:** Supplemental Table available at www.wmjonline.org

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