Relationship between Lane Departure Events and Roadway Characteristics

Final Report
September 2012

MIDWEST TRANSPORTATION CONSORTIUM

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This study will provide better information about the effectiveness of rural roadway safety countermeasures with a focus on lane departures. The main emphasis of the research is to conduct a crash surrogate analysis for common road departure events and develop a model that can be used to predict and mitigate road departures.

The purpose of the study covered in this report was to explore use of naturalistic driving study (NDS) data to assess the relationship between roadway and other characteristics and lane departures on rural two-lane roads.

Road departure events from an NDS dataset from the University of Michigan Transportation Research Institute (UMTRI) were used to predict the likelihood of a lane departure as influenced by driver, roadway, and environmental factors.</td></tr>
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RELATIONSHIP BETWEEN LANE DEPARTURE EVENTS AND ROADWAY CHARACTERISTICS

Final Report
September 2012

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The team would also like to thank the University of Michigan Transportation Research Institute (UMTRI) for providing naturalistic driving study data and for their assistance in working with the data and the Michigan DOT (MDOT) for providing roadway and crash data.

BACKGROUND

The Federal Highway Administration (FHWA) (2011) estimates that 58 percent of roadway fatalities are lane departures, while 40 percent of fatalities are single-vehicle run-off-road (SV ROR) crashes.

Addressing lane-departure crashes is therefore a priority for national, state, and local agencies. Frequency and severity of crashes are commonly used to assess factors contributing to lane departure crashes and to evaluate whether a countermeasure is effective.

Several issues with crash-based safety analyses have been identified (Songchitruksa and Tarko 2006). Events with similar traffic, weather, and roadway conditions are quite rare and, as a result, safety analyses must depend on small sample sizes.

In addition, crash reporting can be inconsistent, which makes comparisons across sites difficult. Another problem is the timeliness of crash data.

Once a countermeasure is implemented, agencies like to evaluate the immediate effectiveness to assess whether more resources should be invested. However, before and after crash studies often cannot be completed until several years after treatment installation, because a representative sample is not available immediately to assess significant differences with sufficient power.

Some researchers have addressed limitations in crash data by utilizing crash surrogates as a measure of risk.

Lane deviation is one measure used as a crash surrogate to assess the likelihood of ROR crashes (LeBlanc et al. 2006) and the likelihood of crashes due to distraction (Donmez et al. 2006).

Several studies have used lateral placement to assess countermeasures so that more immediate measures of safety than reduction in crashes can be obtained. Porter et al. (2004) used lateral placement and speed to evaluate centerline rumble strips. Pratt et al. (2006) used vehicle lateral position and change in vehicle separation to evaluate the impact of centerline and edge-line rumble strips.

Miaou (2001) developed a method to estimate roadside encroachment frequency and the probability distribution for the lateral extent of encroachments using an accident-based prediction model.

Miles et al. (2006) recorded the number of erratic and avoidance maneuvers that occur with placement of advance stop-line rumble strips to determine how drivers respond to the devices. Taylor et al. (2005) observed vehicle placement relative to the edge line using single versus double paint lines to delineate presence of shoulder rumble strips.

Finally, Hallmark et al. (2010) used lateral position to evaluate the effectiveness of edge-line rumble stripes.

Project Scope

The purpose of this study was to explore use of naturalistic driving study (NDS) data to assess the relationship between roadway and other characteristics and lane departures on rural two-lane roads.

Road departure events from an NDS dataset from the University of Michigan Transportation Research Institute (UMTRI) were used to predict the likelihood of a lane departure as influenced by driver, roadway, and environmental factors.

DATA

Data were extracted from a field operational test conducted by UMTRI. Eleven vehicles (same make and model) in the study included an instrumentation package that encompassed a variety of sensing systems, including a forward video and driver face video, forward and side radar, and global positioning system (GPS).

The road departure curve warning (RDCW) system also utilized a lane-tracking system that calculated lane position, based on vehicle position relative to lane lines or roadway edge (LeBlanc et al. 2006).

Naïve driving data were available for a one-week period prior to activation of the RDCW system. UMTRI provided a set of both lane-departure and normal driving events on rural two-lane curves for 44 different drivers.

The database contained a number of fields with data from the instrumentation system, such as lateral acceleration, forward speed, and so forth. GPS data provided vehicle position that can be overlaid with aerial imagery or roadway data.

Data Reduction

The researchers reduced the data for each event. A lane departure was defined as a vehicle wheel path crossing over the right (right-side lane departure) or left (left-side lane departure) lane line and encroaching on either the shoulder or the adjacent lane by 3.28 ft (1 m) or more.

The data reduction resulted in 22 right-side lane departure and 51 left-side lane departure events for two-lane rural roads. Some of the left-side lane departures for either curve direction may have been drivers crossing the centerline intentionally (as in “cutting the curve”).

The reduction also resulted in more than 113,000 observations (0.1 sec data frames) of normal driving with an observation created for each event.

The start point for each lane departure was defined as the point at which the vehicle began deviating from its path toward the edge of the lane and the end point being the point after the vehicle returned to the roadway and corrected its path.

Data for which no lane departure had occurred were used to represent normal driving data.

The length of time varied for each event and a variable was included in the model to account for length of time.

Driver variables, such as age and gender, were reported with the dataset. Roadway variables (lane width, radius, shoulder width, speed limit, advisory speed, average annual daily traffic/AADT, etc.) were either included with the dataset, extracted from aerial imagery, or available in a roadway database from the Michigan Department of Transportation (MDOT).

The researchers used the forward view to tabulate the number of on-coming vehicles that passed the subject vehicle during the segment.

The team calculated the fraction of time a driver spent traveling over the posted or advisory speed limit for each driver using all of the observations of data that were available for that driver. The researchers used the time spent traveling over the posted or advisory speed as a measure of driver aggressiveness.

The study identified time of day as nighttime or daytime based on time and the forward view. The research plan was to assess environmental conditions, but only dry roads were present for the data obtained, and no overhead street lighting was present on any of the roadways.

The researchers calculated lane-departure crash density by overlaying segments with the Michigan crash database (for 2000 through 2006). The research summed the number of lane-departure crashes and divided that by the total segment length, resulting in the variable, lane-departure crash density (crashes per meter).

METHODOLOGY

The researchers developed separate logistic regression models for right- and left-side lane departures. For each model, the team used recorded data for lane departures as cases, with the records that included no lane departures as controls (or normal driving). Each lane departure event or normal driving epoch was modeled as one observation and length of event (time) was included as a variable.

A list of the explanatory variables considered for the analysis is shown in Table 1. Both models were created using the LOGISTIC procedure in the SAS/STAT 9.2 software package.

The response variable for lane departure (Z) was coded as 0 if there is no lane departure (normal driving) and 1 if a lane departure occurred (either right- or left-side departure).

The researchers used stepwise selection to determine which variables were relevant and should be included in the model. The study used Akaike Information Criteria (AIC) and Schwarz criterion (SC) to compare models and determine which variables to include in the final model.

Only a small sample of left- and right-side lane departures was available (51 and 22, respectively). As a result, it was not possible to evaluate the significance of all variables and test correlations between variables.

To build a model that best represented the data, the decision to remove variables from the model was based on whether it was expected that there would be correlation among input variables. The maximum likelihood (ML) method was used to calculate the coefficient estimates, and the Wald statistic was used to test the significance of each explanatory variable.

Odds ratios were used to assess whether a specific condition was more or less likely to result in a lane departure. An odds ratio greater than 1 indicated that the odds of a lane departure occurring are higher, and an odds ratio less than 1 revealed lower odds. Hosmer and Lemeshow Goodness-of-Fit Test is used and Large Chi-Square values (and small p -values) indicate a lack of fit of the model.

Table 1. Explanatory variables used in analysis

Variable	Description	Type	Values
driver	Driver ID, included to account for repeated measurements		NA
Age	driver age category	categorical	0: 20 to 30 years old 1: 31 to 59 years old 2: 60 to 70 years old
Gender	driver gender	categorical	1: male 2: female
Curve	type and direction of curve	categorical	0: tangent 1: right curve 2: left curve
Radius	curve radius (meters)	continuous	98 to 1,717 tangent indicated as 9999
LaneWidth	lane width (meters)	continuous	3.0 to 4.7
AADT	volume (vpd)	continuous	11 to 57410
ShldWidth	shoulder width (meters)	continuous	0.8 to 5.0
Density	on-coming vehicles per meter	continuous	0.0 to 0.5
PvmMarking	pavement marking condition	categorical	0: highly visible 1: visible 2: obscure
TimeOfDay	time period	categorical	0: day 1: dusk/night
CrashDensity	lane departure crashes per meter	continuous	0.0 to 0.029
DwyDensity	driveways per meter	continuous	0.0 to 0.027
OvrSpd5	Fraction of time driver traveled 5 mph over the speed limit	continuous	0.0 to 0.90
OvrSpd10	Fraction of time driver traveled 10 mph over the speed limit	continuous	0.0 to 1.0
ShldType	shoulder type	categorical	1: paved 3: gravel 4: earth 6: no shoulder 7: partially paved

RESULTS

Left-Side Lane Departures

The final model for the left-side lane departure is as follows:

$$\log\left(\frac{P(LD)}{1-P(LD)}\right) = -0.3097 + 0.5746 * I_{\text{Age}}(0) + 0.4118 * I_{\text{Age}}(1) +$$

$$0.5197 * I_{Gender}(1) - 0.00025 * Radius - 0.7282 * LaneWidth +$$

$$0.3193 * ShoulderWidth - 0.9096 * I_{PvmMarking}(0) + 0.2320 * I_{PvmMarking}(1) -$$

$$0.6147 * I_{TimeOfDay} - 1.4494 * OvrSpd10$$

where P(LD) indicates the probability that a left-side lane departure occurs.

The odds ratio (OR) estimates are shown in Table 2.

Table 2. Results for the left-side lane departure model

Variable	Condition	Estimate	Std Error	p-value	OR 95 percent lower	OR estimate	OR 95 percent upper
Intercept		-0.3097	0.3013	0.3040			
Age	0 vs 2	0.5746	0.0529	<.0001	1.602	1.776	1.970
Age	1 vs 2	0.4118	0.0528	0.0360	1.361	1.510	1.674
Gender	1 vs 2	0.5197	0.0423	<.0001	1.548	1.682	1.827
Radius		-0.00025	3.662E-6	<.0001	1.00	1.00	1.00
LaneWidth		-0.7282	0.0726	<.0001	0.419	0.483	0.557
ShldWidth		0.3193	0.0229	<.0001	1.316	1.376	1.439
PvmMarking	0 vs 2	-0.9096	0.1180	<.0001	0.32	0.403	0.507
PvmMarking	1 vs 2	0.2320	0.0876	.0081	1.062	1.261	1.497
TimeOfDay	0 vs 1	-0.6147	0.0373	<.0001	0.503	0.541	0.582
OvrSpd10		-1.4494	0.1052	<.0001	0.191	0.235	0.288

Given the exponential function is an increasing function, the positive sign of $\hat{\beta}_i$ means an increase in the odds of a left-side lane departure occurring and a negative sign of $\hat{\beta}_i$ means a decrease in the odds of a left-side lane departure.

The coefficient estimates for agegroups 0 (20 through 30 year olds) and 1 (31 through 59 year olds) are reported in comparison to agegroup 2 (60 through 70 year olds). Hence, the odds of a left-side lane departure for drivers aged 20 through 30 years old compared to drivers aged 60 through 70 is given by the following equation:

$$\exp(\text{age} = 0 \text{ vs } 2) = \exp(0.5746) = 1.78$$

Consequently, drivers aged 20 through 30 are 1.78 times more likely to be involved in a left-lane departure than older drivers. Similarly, the odds of a left-side lane departure for middle aged drivers (age = 1) compared to older drivers (age = 2) is 1.51.

These results indicate that middle-aged drivers 31 through 59 years old are 1.51 times more likely to be involved in a lane departure than older drivers. Middle-aged drivers have 0.85 times the odds of being involved in a lane departure compared to their counterparts aged 20 through 30 years old. Conversely, the odds for a younger driver compared to a middle-aged driver are 1/0.85 = 1.18.

Based on similar calculations, males are 1.68 times more likely to be involved in a left-lane departure than females. The negative coefficient for "Radius" indicates that the odds of a left-side lane departure decrease as radius increases.

A very large radius value of "9999" was used for tangent sections and the variable was modeled as a continuous variable. For each 100 ft (30.48 meter) increase in radius, the odds of having a left-side lane departure decreases by 0.99. Therefore, a 100 ft increase in radius results in an approximate 1 percent decrease in the odds of a lane departure.

The positive coefficient for shoulder width indicates that as shoulder width increases, the odds of a left-lane departure also increase. This result was unexpected given increased shoulder width has generally been correlated to a decrease in lane-departure crashes.

Highly visible lane markings (*PvmMarking* = 0) had much lower odds (0.403) of a left-lane departure than lane markings indicated as obscure (*PvmMarking* = 2), while moderate visible lane markings (*PvmMarking* = 1) had higher odds (1.062) of having a lane departure than obscure markings (*PvmMarking* = 2).

As noted in Table 2, daytime crashes have 0.54 times the likelihood of a left-lane departure than nighttime crashes or nighttime crashes have 1/0.54 = 1.85 times the odds than during daytime hours.

The negative coefficient for the explanatory variable (*OvrSpd10*) indicates that drivers who spend a greater fraction of their time traveling at 10 or more mph over the posted or advisory speed have lower odds of a left-lane departure.

However, this result is somewhat counter-intuitive. The opposite effect was found for right-side lane departures, so drivers who regularly speed may be more likely to stay toward the right side of their lane.

Right-Side Lane Departures

The final model for a right-side lane departure is given by the following equation:

$$\log\left(\frac{P(RD)}{1-P(RD)}\right) = 8.1914 - 1.7341 * I_{\text{Age}}(0) - 1.1016 * I_{\text{Age}}(1) - 0.0003 * \mathit{Radius} -$$

$$0.0001 * \mathit{AADT} - 2.1367 * \mathit{LaneWidth} - 5.3996 * \mathit{Density} + 0.2273 * I_{PvmMarking}(0)$$

$$- 1.9341 * I_{PvmMarking}(1) + 2.4446 * \mathit{OvrSpd10} + 2.4232 * I_{ShldType}(1) - 1.2771 *$$

$$I_{ShldType}(3) - 3.2313 * I_{ShldType}(4) + 2.4946 * I_{ShldType}(6)$$

where *P(RD)* indicates the probability that a right-side lane departure occurs.

The odds ratio estimates are shown in Table 3.

Table 3. Results for the right-side lane departure model

Variable	Condition	Estimate	Std Error	p-value	OR 95 percent lower	OR estimate	OR 95 percent upper
Intercept		8.1914	0.4943	<.0001			
Age	0 vs 2	-1.7341	0.1337	<.0001	0.136	0.18	0.229
Age	1 vs 2	-1.1016	0.0891	<.0001	0.279	0.33	0.396
Radius		-0.0003	6.768E-6	<.0001	1.00	1.00	1.00
AADT		-0.0001	7.115E-6	<.0001	1.00	1.00	1.00
LaneWidth		-2.1367	0.1321	<.0001	0.091	0.12	0.153
Density		-5.3996	1.4526	0.0002	<0.001	0.01	0.078
PvmMarking	0 vs 2	0.2273	0.1086	0.0364	1.015	1.26	1.553
PvmMarking	1 vs 2	-1.9341	0.0959	<.0001	0.120	0.15	0.174
OvrSpd10		2.4446	0.1151	<.0001	9.198	11.53	14.441
ShldType	1 vs 7	2.4232	0.0914	<.0001	9.431	11.28	13.496
ShldType	3 vs 7	-1. 2771	0.0786	<.0001	0.239	0.28	0.325
ShldType	4 vs 7	-3.2313	0.1219	<.0001	0.031	0.04	0.050
ShldType	6 vs 7	2.4946	0.1646	<.0001	8.775	12.12	16.731

Results are interpreted similarly to that of the left-side lane departure model. The negative coefficient for "*LaneWidth*" indicates that for each meter increase in lane width, the odds of a right-lane departure decreases 0.882 times. Similarly, as on-coming traffic density and volume (*AADT*) increase, the odds of a right-side lane departure decrease, which may be due to improved lane keeping.

The negative coefficient for *Radius* indicates that the odds of a right-side lane departure decrease as radius increases. A very large radius value of "9999" was used for tangent sections and the variable was modeled as a continuous variable.

For each 100 ft (30.48 m increase) in radius, the odds of having a right-side lane departure decrease by 0.99. Therefore, a 100 ft increase in radius results in an approximate 1 percent decrease in the odds of a right-lane departure.

The odds of a right-side lane departure for drivers aged 20 through 30 years old compared to drivers aged 60 through 70 is 0.18 times the odds of being involved in a right-lane departure than for older drivers.

Similarly, the odds of a right-side lane departure for middle aged drivers (age = 1) compared to older drivers (age = 2) is 0.33, indicating that middle-aged drivers 31 through 59 years old are are less likely to be involved in a lane departure than older drivers. And, the odds of a left-side lane departure for middle-aged drivers compared to younger drivers is 1.88.

The impact of highly visible pavement markings (*PvmMarking* = 0) versus obscure pavement markings (*PvmMarking* = 2) is given by 1.25, indicating that right-lane departures were more likely to occur when highly-visible pavement markings were present, although this result is not consistent with the concept that better lane delineation will result in fewer lane departures.

Alternatively, the impact of visible pavement markings (*PvmMarking* = 1) compared to obscure pavement markings (*PvmMarking* = 2) is 0.15, so right-side lane departures are much less likely with visible pavement markings.

The model also indicates a strong positive relationship exists between the amount of time a driver spent driving 10 or more mph over the posted speed limit and the likelihood of a right-lane departure.

Shoulder type was also relevant in the model. The coefficients indicate that paved shoulders (*Shldtype* = 1) are more likely to have a right-lane departure than partially paved (*ShldType* = 7), while gravel and earth shoulders are more likely to have a lane departure than partially paved.

A positive coefficient for no shoulders (*ShldType* = 6) versus partially paved indicates that a right-side lane departure was much more likely when no shoulder was present than when shoulders were partially paved.

Other relationships between shoulder types are provided in Table 4.

Table 4. Comparison of lane departure likelihood by shoulder type

	Gravel	Earth	No shoulder	Partially paved
Paved	40.44	282.05	0.931	11.28
Gravel	—	6.98	0.023	0.28
Earth	—	—	0.003	0.04
No shoulder	—	—	—	12.12

As indicated, all shoulder types had less likelihood of a right-lane departure than no shoulder. Paved shoulders were more likely to result in a right-lane departure than gravel, earth, or partially-paved shoulders. Although this might seem counter-intuitive, it may be due to the fact that drivers are less likely to lane keep with a paved shoulder given there is less risk of a severe outcome if the tire leaves the travel way.

Paved shoulders have been shown to reduce number of crashes (Hallmark et al. 2010), so the impact of a paved shoulder may be a less severe outcome to a lane departure.

CONCLUSIONS AND DISCUSSION

This study demonstrated that, in addition to age and gender, the radius of curvature had an impact on the likelihood of a lane departure.

Although studies on age and gender have been documented clearly, this study also brings to light the impact of the road. Although it may seem obvious that greater radii would result in increased lane departures, studies have not actually captured the degree to which radius, lane and shoulder width, and even pavement marking may influence lane departures.

This study also brings to light the differences between right and left lane departures.

Left-side lane departures were less likely as lane width and curve radius increase. These departures were also less likely in daytime compared to nighttime (OR = 0.54) and were more likely for males compared to females (OR = 1.68).

Younger drivers (aged 20 through 30) were more likely to have a left-side lane departure than older drivers (aged 60 through 70) (OR = 1.776) and were slightly more likely to be involved in a left-lane departure (OR = 1.18) than their middle-aged counterparts (ages 31 through 59). However, middle-aged drivers were more likely to be involved than their older counterparts were (OR = 1.51).

Results indicate that an increase in shoulder width increases the odds of a left-side lane departure, although shoulder width has generally been correlated to a decrease in crash rate.

Pavement marking condition was also relevant. The amount of time a driver spends at 10 or more mph over the speed limit decreased the odds of a left-lane departure. Given the opposite result was found for right-side lane departures, the researchers speculate that drivers who speed may tend to stay toward the right side of their lane.

The right-side lane departure model indicated that, with an increase in lane width, radius, on-coming vehicle density, and traffic volume, the odds of a right-side lane departure decrease, which may be due to improved lane keeping.

The amount of time a driver spent traveling at 10 or more mph over the posted or advisory speed increased the odds of a right-side lane departure. Pavement marking condition and shoulder type were also relevant variables.

Results of the study indicated several relationships, which are not intuitive. These results may be due sample size.

The researchers examined correlation between variables, but correlation with variables that were not considered may have been present. In addition, the impact of some variables may be different from what was expected.

For instance, an increase in shoulder width resulted in an increase in left-side lane departures. While a wider shoulder may decrease crash risk or severity if a driver leaves the roadway, a driver may be less likely to lane keep when a wide shoulder is present than with a narrow shoulder.

The left-lane departure model also indicated that drivers who spend more time traveling over the speed limit are less likely to have a lane departure. Aggressive drivers may be more likely to lane keep, given the consequences of leaving their lane are more likely to be severe.

The opposite effect was found in right-side lane departures, where an increased amount of time traveling over the speed limit resulted in increased odds of having a right-side lane departure.

Results that might be counterintuitive in the right-side lane departure model include an increase in the odds of a lane departure as lane width increases and that presence of a paved shoulder had higher odds of a right-lane departure than any other type of shoulder. These results may be due to drivers paying more attention and doing better lane keeping when lanes are narrow or no shoulders are present.

Study Limitations

The study provided useful information that can be used to better understand why lane departures occur. The outcomes demonstrate the value of using naturalistic data that could not have been observed otherwise.

However, the researchers acknowledge several limitations. First, the sample size was limited due to the available data, which may have some consequences for the statistical models.

For example, the coefficients for several covariates were not as intuitive as expected and the small sample size may not been sufficient to develop a robust model.

In addition, results may have been affected by correlations that were not noted in the model. A larger dataset, such as the one being collected as part of the Strategic Highway Research Program 2 (SHRP 2), can solidify the results more concretely.

REFERENCES

Archer, J. Traffic Conflict Technique: Historical to Current State-of-the-Art. Institutionen for Infrastruktur. 2001.

Bonneson, J., and K. Zimmerman. *Red-Light-Running Handbook: An Engineer's Guide to Reducing Red-Light-Related Crashes.* Texas Transportation Institute, Texas A&M University, College Station. 2004.

Burgett, A., and R. J. Miller, Jr. *A New Paradigm for Rear-end Crash Prevention Driving Performance.* National Highway Traffic Safety Administration. 2001.

Corkle, J., M. Marti, and D. Montebello. *Synthesis on the effectiveness of rumble strips*. Report no. MN/RC-2002-07. Minnesota Department of Transportation. 2001.

Council, F. M. "Safety Benefits of Spiral Transitions on Horizontal Curves on Two-Lane Rural Roads." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1635. pp. 10-17. 1993.

Deng, Z., J. N. Ivan, and P. Garder. "Analysis of Factors Affecting the Severity of Head-On Crashes: Two-Lane Rural Highways in Connecticut." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1953. pp. 137-146. 2006.

Donmez, B., L. Boyle, and J. Lee. "The Impact of Driver Distraction Mitigation Strategies on Driving Performance." *Human Factors.* Vol. 48, No. 4. pp. 785-804. 2006.

Donnell, E. T., and J. M. Mason. "Predicting the Frequency of Median Barrier Crashes on Pennsylvania Interstate Highways." *Accident Analysis and Prevention*. Vol. 38. pp. 590-599. 2006.

FHWA. Roadway Departure Safety. Federal Highway Administration. http://safety.fhwa.dot.gov/roadway_dept. Accessed April 2011.

FHWA. *Stop Red Light Running Facts and Statistics*. U.S. Department of Transportation. Federal Highway Administration. August 3, 2006. http://safety.fhwa.dot.gov/intersections/redl_facts.htm. Accessed April 2011.

Fitzsimmons, E. J., S. L. Hallmark, M. Orellana, T. McDonald, and D. Matulac. "Investigation of Violation Reduction at Intersection Approaches with Automated Red Light Running Enforcement Cameras in Clive, Iowa Using a Cross-Sectional Analysis." *ASCE Journal of Transportation Engineering*. Vol. 135, Issue 12. pp. 984-989. December 2009.

Garber N. J, J. S. Miller, S. Eslambolchi, R. Khandelwal, K. M. Mattingly, K. M. Sprinkle, and P. L. Wachendorf. *An Evaluation of Red Light Camera (Photo-Red) Enforcement Programs in Virginia: A Report in Response to a Request by Virginia's Secretary of Transportation*. Virginia Transportation Research Council, Charlottesville, Virginia. January 2005.

Garder, P. and M. Davies. Safety Effect of Continuous Shoulder Rumble Strips on Rural Interstates in Maine. Proceedings, 85th Annual Meeting of the Transportation Research Board, Washington, DC. 2006.

Hallmark, S. L., T. McDonald, Y. Tian, and D. J. Andersen. *Safety Benefits of Paved Shoulders In Iowa*. August 2010. http://www.intrans.iastate.edu/research/detail.cfm?projectID=832537926

Hauer, E., F. M. Council, and Y. Mohammedshah. "Safety Models for Urban Four-Lane Undivided Road Segments." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1897. pp. 96-105. 2004.

Hayward, J. "Near-Miss Determination Through Use of a Scale of Danger." *Highway Research Record*. No. 384. pp. 24-34. 1972.

Khattak, A. J., and J. E. Hummer. "Analysis of Run-off-the-Road Collisions on Two-Lane Rural Highways in North Carolina." *ITE Journal*. Vol. 68, No. 10. p. 18. 1998.

LeBlanc, D., J. Sayer, C. Winkler, R. Ervin, S. Bogard, J. Mefford Devonshire, M. Hagan, Z. Bareket, R. Goodsell, and T. Gordon. *Road Departure Crash Warning System Field Operational Test: Methodology and Results*. University of Michigan Transportation Research Institute, Ann Arbor, Michigan. 2006.

Lamm, R., E. M. Choueiri, J. C. Hayward, and A. Paluri. "Possible Design Procedure to Promote Design Consistency in Highway Geometric Design on Two-Lane Rural Roads." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1195. pp. 111-122. 1988.

McGinnis, R. G., M. J. Davis, and E. A. Hathaway. "Longitudinal Analysis of Fatal Run-off-Road Crashes, 1975 to 1997." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1746. pp. 47-58. 2001.

McLaughlin, S. B., J. M. Hankey, S. G. Klauer, and T. A. Dingus. *Contributing Factors to Run-Off-Road Crashes and Near-Crashes*. National Highway Traffic Safety Administration. DOT HS 811 079. January 2009.

Miaou, S. *Estimating Roadside Encroachment Rates with the Combined Strengths of Accident and Encroachment-Based Approaches*. FHWA-RD-01-124. 2001.

Miaou, S. P. and H. Lum. "Statistical Evaluation of the Effects of Highway Geometric Design on Truck Accident Involvements." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1407. pp. 11-24. 1993.

Miles, J., M. Pratt, and P. Carlson. "Evaluation of Erratic Maneuvers Associated with Installation of Rumble Strips." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1973. pp. 73-79. 2006.

Miles, J. D., P. J. Carlson, M. P. Pratt, and T. D. Thompson. *Traffic Operational Impacts of Transverse, Centerline, and Edgeline Rumble Strips*. (0-4472-2). TxDOT. http://tti.tamu.edu/documents/0-4472-2.pdf . 2005.

Porter, R., E. Donnel, and K. Mahoney. "Evaluation of Effects of Centerline Rumble Strips on Lateral Vehicle Placement and Speed." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1862. pp. 10-16. 2004.

Pratt, M., J. Miles, and P. Carlson. "Evaluation of Operational Impacts of Installation of Centerline and Edge Line Rumble Strips." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1973. pp. 80-88. 2006.

Retting, R. A., S. A. Ferguson, and C. M. Farmer. *Reducing Red Light Running Through Longer Yellow Signal Timing and Red Light Camera Enforcement: Results of a Field Investigation*. Insurance Institute for Highway Safety. 2007.

Shankar, V. N., R. B. Albin, , J. C. Milton, and F. L. Mannering. "Evaluating Median Crossover Likelihoods with Clustered Accident Counts: An Empirical Inquiry Using the Random Effects Negative Binomial Model." *Transportation Research Record: Journal of the Transportation Research Board*. No. 1635. pp. 44-57. 1998.

Songchitruksa, P. and A. Tarko. "The Extreme Value Theory Approach to Safety Estimation." *Accident Analysis and Prevention*. 38. pp. 811-822. 2006.

Sun, X., J. Park, V. O. Tekell Jr., and N. S. Ludington. “Evaluation of Pavement Edge Lines on Narrow Highways with Low Traffic Volume in Louisiana.” *Transportation Research Record: Journal of the Transportation Research Board*. No. 1989. pp. 115-122. 2007.

Taylor, W., G. Abu-Lebdeh, and S. Rai. “Effect of Continuous Shoulder Rumble Strips and Pavement marking on Lateral Placement of Vehicles.” *Transportation Research Record: Journal of the Transportation Research Board*. No. 1911. pp. 105-112. 2005.

Ulmer, R. G., A. F. Williams, and D. F. Preusser. “Crash Involvements of 16-year-old Drivers.” *Journal of Safety Research.* Vol. 28 No. 2. pp. 97-103. 1997.

Williams A. F., A. K. Lund, D. F. Preusser, and R. D. Bloomberg. “Results of a seat belt use law enforcement and publicity campaign in Elmira, New York.” *Accident Analysis and Prevention.* **19**, pp. 243-249. 1997.

Zegeer, C. V., R. Stewart, F. M. Council, D. W. Reinfurt, and E. Hamilton. “Safety Effects of Geometric Improvements on Horizontal Curves.” *Transportation Research Record: Journal of the Transportation Research Board*. No. 1356. pp. 11-19. 1992.