

Relationship between Speed and Lateral Position on Curves

Final Report
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16. Abstract Excessive speed is often cited as a primary driver factor in crashes, particularly rural two-lane crashes. It has also been suggested that speed plays a significant role in crashes on curves. However, the relationship between speed and crashes on curves is not well documented because it is difficult to determine driver speed after the fact when investigating a crash. One method to begin documenting this relationship is to explore the relationship between lateral position and speed as a crash surrogate. For this study, the researchers collected speed and lateral position data for three rural two-lane curves. The relationship between lateral position and speed was assessed by comparing the odds of a near-lane crossing for vehicles traveling 5 or more mph over the advisory speed to those for vehicles traveling below that threshold.					
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BACKGROUND

Lane departure crashes are a significant safety concern. The majority of lane departure crashes occur in rural areas, mostly on two-lane roadways. A disproportionate number of these crashes occur on horizontal curves.

The Federal Highway Administration (FHWA 2009) estimates that 58 percent of roadway fatalities are lane departures, the majority of which are single-vehicle run-off-road (SV ROR) crashes. Addressing lane departure crashes is therefore a priority for national, state, and local agencies.

Horizontal curves are of particular interest because they have been correlated with overall increased crash occurrence. Curves have approximately three times the crash rate of tangent sections (Glennon et al. 1985). Preston and Schoenecker (1999) reported that 25 to 50 percent of severe road departure crashes in Minnesota occurred on curves, even though curves only account for 10 percent of the system mileage.

Shankar et al. (1998) evaluated divided state highways without median barriers in Washington and found a relationship between the number of horizontal curves per kilometer and median crossover crashes.

Farmer and Lund (2002) evaluated single-vehicle fatal and injury rollover crashes using Fatality Analysis and Reporting System (FARS) data and data from Florida, Pennsylvania, and Texas. Using logistic regression, Farmer and Lund found that the odds of having a rollover on a curved section were 1.42 to 2.15 times that of having a rollover on a straight section.

A primary driver factor in crashes is excessive speed. The National Highway Traffic Safety Administration (NHTSA 2008) reports that approximately 31 percent of fatal crashes are speed related. Factors that contribute to excessive speed include driver workload and distraction, fatigue, sight distance, misperception of degree of roadway curvature, and situational complexity.

Driver errors on horizontal curves are often due to the inappropriate selection of speed and the inability to maintain lane position. Driver speed selection at curves depends on both explicit attentional cues and implicit perceptual cues (Charlton 2007).

Driver speed prior to entering a curve has a significant effect on ability to negotiate the curve successfully (Preston and Schoenecker 1999).

Inappropriate speed selection and lane positioning can be a result of a driver failing to notice an upcoming curve or misperceiving the roadway curvature. Driver workload plays important role in driver speed maintenance.

Distracting tasks, such as radio tuning or cell phone conversations, can draw driver attention away from speed monitoring, detection of headway changes, lane keeping, and detection of potential hazards (Charlton 2007). Other factors include sight distance issues, fatigue, or complexity of the driving situation (Charlton 2007, Charlton and DePont 2007).

The amount of speed reduction needed to traverse a curve has an impact on frequency and severity of crashes on curves (Farmer and Lund 2002, Preston and Schoenecker 1999, Anderson and Krammes 2000). Inappropriate speed selection and lane positioning can be a result of the driver failing to notice an upcoming curve or misperceiving the roadway curvature.

Driver workload, distraction, sight distance, fatigue, and complexity of the driving situation all affect driver speed selection and ability to negotiate a horizontal curve successfully (Charlton 2007, Charlton and DePont 2007).

Summary of Information on the Relationship between Speed and Lateral Position

Although the relationship between speed and lateral position is important in understanding curve negotiation, the relationship is not well understood. A few studies have addressed the topic, including one by Stodart and Donnell (2008) that collected driver speed and lateral vehicle position along a closed course two-lane rural highway at night.

Speed, lateral position, and other data were collected in an instrumented vehicle using 16 naïve drivers. The authors used several statistical methods to determine whether there is an endogenous relationship between speed and lateral position.

In another study, Preston and Shoenecker (1999) evaluated vehicle paths through a curve on a two-lane rural roadway with a speed limit of 55 mph and annual average daily traffic (AADT) of 3,250 vehicles per day (vpd).

The researchers collected data over a four-day period and evaluated 589 vehicles, which were selected randomly. A total of 340 of the vehicles were traveling over 55 mph and the rest were traveling at or below the speed limit.

The authors evaluated whether each vehicle successfully negotiated the curve, defined as a vehicle remaining within the lane lines as it traverses the curve. Vehicles that crossed a left or right lane line on one or more occasions were defined as not navigating the curve successfully.

Preston and Shoenecker conducted a logistic regression to model the relationship between initial speed and the probability of a vehicle unsuccessfully navigating the curve. The authors found a 20 percent better chance for vehicles traveling at or below the speed limit than those traveling over the speed limit, with the difference being statistically significant at 99 percent.

The authors found that 45 percent of vehicles traveling at or above 65 mph were unable to negotiate the curve compared to 30 percent for vehicles traveling under 65 mph, with the difference being statistically significant at the 90 percent confidence level.

Project Objectives

Curve-related crashes involve a number of roadway and driver causative factors. Understanding how drivers negotiate curves can assist in application of countermeasures such as use of road departure curve-warning systems.

One aspect of curve negotiation that is not well documented is the relationship between lateral position and speed. For this study, the researchers assessed the relationship between lateral position and speed by comparing the odds of a near-lane crossing for vehicles traveling 5 or more mph over the advisory speed to those for vehicles traveling below that threshold.

DATA COLLECTION

Data were collected using a Z configuration of road tubes at three rural two-lane curves. Data were collected at various locations within those curves including the point of curvature (PC) and center of curve.

Data were compared for daytime and nighttime periods separately, given driver behavior can vary between these time periods.

Longitudinal speed and lateral position were collected during a related study to evaluate the effectiveness of roadway-based curve countermeasures. Data for the period before the countermeasures were applied were used to assess the relationship between speed and lateral position.

Three sites were available where both speed and lateral position were collected. All sites were rural two-lane paved roadways with no paved shoulders in Iowa. Gravel or earth shoulders were present of varying widths.

All roadways had both a centerline and edge lines. Roadway width for all three sites was approximately 23 ft from edge line to edge line.

The posted speed limit on the tangent section was 55 mph for all sites and all sites had an advisory speed posted for the curve. Table 1 provides the details about each of the sites.

Table 1. Site information

Curve	Advisory Speed (mph)	Radius (ft)	Volume (vpd)
221st Street	50	957	2,410
IA 141	35	514	830
US 52	40	617	2,280

To collect lateral position, the team followed a methodology used by Finley et al. (2009) and Porter et al. (1995) that uses pneumatic road tubes set up in a Z configuration, as shown in Figure 1.

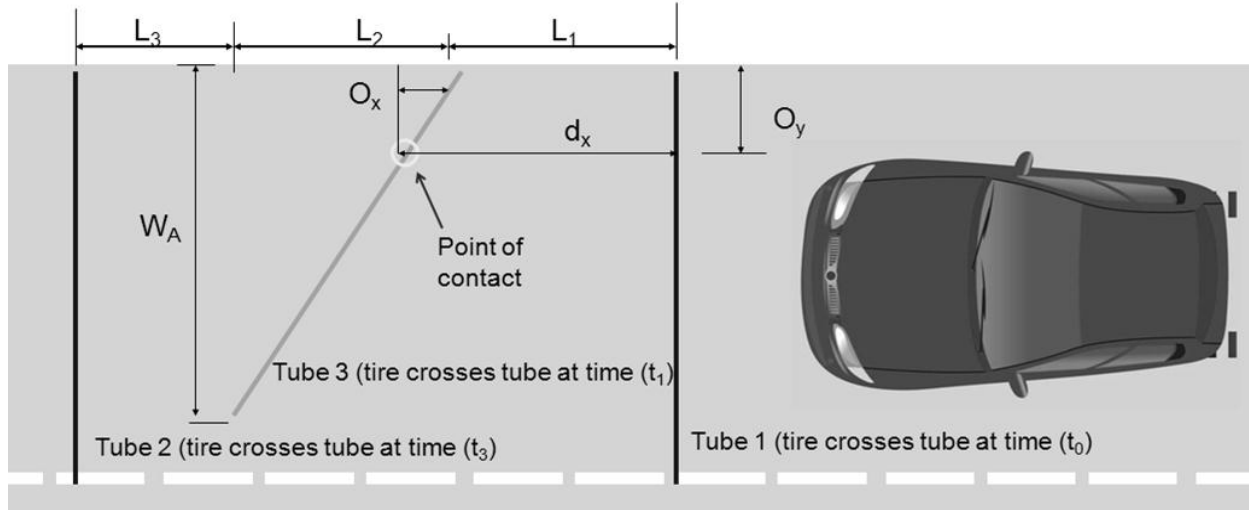


Figure 1. Layout configuration of road tubes to measure lateral displacement

Using the timestamp of when each tire strikes a particular road tube and geometric relationships, the distance that the vehicle is from the edge of the roadway (O_x) can be determined. The tube configuration is set up so that the right edge of the right lane line for tube 1 is the reference point (0,0).

Data were collected at two or more locations through each of the three curves. Data from the counters was output as raw data into a spreadsheet with date, time (to the millisecond), and sensor (tube) number. Each row represented one tire strike on a particular sensor and data were ordered sequentially.

Ideally, tubes 1 and 2 receive one strike for each vehicle axle, while tube 3 could receive one or two strikes depending on whether the outside tire crosses tube 3. As a result, a particular tube order indicates number of axles and direction.

Other scenarios, such as a vehicle crossing the centerline from the other direction, vehicle crossing the tubes at an unusual angle, and air backwash, result in tube configurations that are illogical. This information was used to remove erroneous data from the datasets.

Vehicle speed was calculated using time from when the first axle of tires strikes tube 1 and tube 2 using equation 1.

$$v = \frac{(L_1 + L_2 + L_3)}{(t_2 - t_1)} \quad (1)$$

When speed is known and the time the first tire strikes tube 3, the distance from tube 1 to tube 3 can be calculated using equation 2.

$$d_x = v (t_3 - t_1) \quad (2)$$

The variable dx is different for each vehicle given the vehicle strikes tube 3 at a different location depending on its distance from the edge line.

Using properties of similar triangles, the lateral distance the wheel is from the edge of the right lane (O_y) is calculated. A 6 ft track width and known lane width were used to convert lateral position to reflect distance of vehicle center in relationship to lane center.

Data were collected for several days at each site. Given it was difficult to account for the large number of unusual configurations that could occur, it was determined in this case that it was more feasible to reduce the data manually than to attempt to write a computer program to reduce the data.

The manual data reduction was quite time consuming, so an attempt was made to reduce only 500 passenger vehicles for the daytime period for each location and 300 passenger vehicles for the nighttime period.

Given data reduction was mostly a manual process and large trucks made up only a small percentage of the traffic stream, only passenger cars were included in the analysis.

METHODOLOGY

The researchers disaggregated data into daytime and nighttime periods. They evaluated data by time period given curve negotiation may be different during the daytime as compared to nighttime.

Daytime was defined as sunrise until one half hour before sunset. Nighttime was determined to be sunset until one half hour before sunrise. Data for the remaining half hours at sunrise and sunset were discarded, given light conditions were transitioning between light and dark then.

The relationship between speed and lateral position was assessed using an odds ratio. The odds of a near lane crossing for vehicles traveling 5 or more mph over the advisory speed were compared to those traveling within 5 mph of the advisory speed. A near lane crossing was defined as a vehicle tire coming within 6 in. of the edge line or centerline.

RESULTS

Results are presented in Table 2.

Table 2. Relationship between near lane crossings and speed

	Day				Night			
	Near Edge/center	Total Observations	Fraction	Odds Ratio	Near Edge/center	Total Observations	Fraction	Odds Ratio
221st St at PC								
< 55 mph	19	309	0.061	1.43	2	56	0.036	0.43
≥ 55 mph	30	320	0.086	(0.87, 2.36)	1	64	0.016	(0.06, 3.29)
221st St at Center of Curve								
< 55 mph	12	251	0.048	0.92	7	107	0.065	2.38
≥ 55 mph	19	431	0.044	(0.49, 1.71)	13	91	0.143	(1.06, 6.25)
221st St at Curve Exit								
< 55 mph	25	289	0.087	0.84	14	86	0.163	2.37
≥ 55 mph	54	729	0.074	(0.56, 1.28)	35	111	0.315	(1.32, 4.26)
IA 141 at South PC								
< 40 mph	5	73	0.064	4.47	Low numbers			
≥ 40 mph	83	271	0.234	(2.03, 9.83)				
IA 141 at Center of Curve								
< 40 mph	12	70	0.146	0.32	Low numbers			
≥ 40 mph	26	467	0.053	(0.18, 0.6)				
IA 141 at North PC								
< 40 mph	8	23	0.258	0.30	Low numbers			
≥ 40 mph	25	240	0.094	(0.14, 0.64)				
US 52 at PC								
< 45 mph	14	74	0.159	0.37	3	36	0.077	1.66
≥ 45 mph	33	471	0.065	(0.21, 0.65)	9	65	0.122	(0.53, 5.24)
US 52 at Center of Curve								
< 45 mph	54	122	0.31	1.03	15	44	0.254	0.89
≥ 45 mph	129	282	0.31	(0.75, 1.42)	31	102	0.322	(0.49, 1.62)

For the daytime period, seven locations had odds ratio that were not statistically different at the 90 percent level of significance. At one location (221st Street at the south PC), vehicles traveling 5 or more mph over the advisory speed were 4.47 times more likely to cross near the centerline or edge line as vehicles traveling below that threshold.

Three locations during the nighttime period had too few observations to evaluate. In addition, three locations had odds ratios that were not statistically different at the 90 percent level of significance.

At two locations, the odds of crossing near the centerline or edge line were higher for vehicles traveling 5 or more mph over the advisory speed than for vehicles traveling below that threshold. At one location, the odds were 2.38 times greater and, at the other, the odds were 2.37 times greater for vehicles traveling 5 or more mph over the curve advisory speed.

CONCLUSIONS

This Tech Brief summarizes research to assess the relationship between speed and lateral position. Longitudinal speed and lateral position were collected at three curve sites on rural two-lane roadways. Data were only collected at three sites due to the significant amount of manual effort required to reduce the data.

The odds of a near lane crossing for vehicles traveling 5 or more mph over the advisory speed were compared to vehicles traveling under the speed threshold. Results were not statistically significant at the majority of the locations evaluated.

However, the researchers found some evidence of a relationship at one location during the daytime and two locations during the nighttime. In those cases, the odds of a near lane crossing were 2.37 to 4.47 times greater at higher speeds. When results were statistically significant, vehicles at higher speeds had greater odds of near lane crossings.

Although there were some limitations with this approach, the results provide evidence of the relationship between lateral position and speed. This finding is useful in evaluating roadway-based countermeasures, given metrics that reduce speeds may result in better lane positioning and less likelihood of a lane departure.

REFERENCES

- Anderson, I. B. and R. A. Krammes. "Speed Reduction as a Surrogate for Accident Experience at Horizontal Curves on Rural Two-Lane Highways." *Transportation Research Record: Journal of the Transportation Research Transportation Research Board*. No. 1701. 2000. pp. 86-94.
- Charlton, S. G. "The Role of Attention in Horizontal Curves: A Comparison of Advance Warning, Delineation, and Road Marking Treatments." *Accident Analysis and Prevention*. Vol. 39. 2007. pp. 873-885.
- Charlton, S. G. and J. J. DePont. *Curve Speed Management*. Land Transport New Zealand Research Report 323. July 2007.
- Farmer, C. M., and A. K. Lund. "Rollover Risk of Cars and Light Trucks after Accounting for Driver and Environmental Factors." *Accident Analysis and Prevention*. Vol. 34. 2002. pp. 163-173.
- Felipe, E. and F. Navin. "Automobiles on Horizontal Curves: Experiments and Observations." *Transportation Research Record: Journal of the Transportation Research Transportation Research Board*. No. 1628. 1998. pp. 50-56.
- FHWA. FHWA's Road Departure Program. http://www.t2.unh.edu/nltapa/Pubs/fhwa's_roadway_departure_program.pdf. Accessed Federal Highway Administration. December 2009.
- Finley, M. D., Dillon S. Funkhouser, and Marcus A. Brewer. *Studies to Determine the Operational Effects of Shoulder and Centerline Rumble Strips on Two-Lane Undivided Roadways*. Texas Transportation Institute. August 2009.
- Glaser, S., S. Mammari, and C. Sentouh. "Integrated Driver-Vehicle-Infrastructure Road Department Warning Unit." *IEEE Transactions on Vehicular Technology*. Vol. 59, No. 6. July 2010.. pp. 2757-2771.
- Glennon, J. C., T. Neuman, and J. Leisch. *Safety and Operational Considerations for Design of Rural Highway Curves*. FHWA. FHWA/RD-86-035. December 1985.
- McGehee, D., J. Lee, M. Rakauskas, N. Ward, and B. Wilson. The effect of lateral drift and curve speed warnings on driver response. Proceedings of the Human Factors and Ergonomics Society annual meeting. 2007.
- Meuter, M., S. Muller-Schneiders, A. Mika, S. Hold, C. Nunn, and A. Kummert. A Novel Approach to Lane Detection and Tracking. Proceedings of the 12th International IEEE Conference on Intelligent Transportation Systems. St. Louis, MO. Oct. 2009.
- NHTSA. *Traffic Safety Facts 2008 Data: Speeding*. National Highway Traffic Safety Administration. 2008. DOT HS 811 166.
- Porter, R. J., E. T. Donnel, and K. M. Mahoney. "Evaluation of the Effects of Centerline Rumble Stripes on Lateral Vehicle Placement and Speed." *Transportation Research Record: Journal of the Transportation Research Transportation Research Board*. No. 1862. 1995. pp. 10-16.
- Preston, H., and T. Schoenecker. *Potential Safety Effects of Dynamic Signing at Rural Horizontal Curves*. Minnesota Local Road Research Board. December 1999.
- Redmill, K. A., S. Upadhyaya, A. Krishnamurthy, and U. Ozguner. A Lane Tracking System for Intelligent Vehicle Applications. 2001 IEEE Intelligent Transportation Systems Conference Proceedings. Oakland, CA. August 2001.

- Shankar, V., 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. 1998. pp. 44-57.
- Stodart, B. P. and E. T. Donnell. "Speed and Lateral Vehicle Position Models from Controlled Nighttime Driving Experiment." *ASCE Journal of Transportation Engineering*. Vol. 134, No 11. 2008. pp. 439-449.