An Examination of Horizontal Curve Collisions Characteristics and Corresponding Countermeasures

By

Joseph E. Hummer, Ph.D., P.E.
Professor, North Carolina State University
423 Mann Hall
Raleigh, NC 27695-7908
Tel.: 919-515-7733
Fax: 919-515-7908
Email: hummer@ncsu.edu

William Rasdorf, Ph.D., P.E., F.ASCE
Professor, North Carolina State University
200 Mann Hall
Raleigh, NC 27695-7908
Tel.: 919-515-7637
Fax: 919-515-7908
Email: rasdorf@ncsu.edu

Daniel J. Findley*
Research Associate, Institute of Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8564
Fax: (919) 515-8898
Email: Daniel_Findley@ncsu.edu

Charles V. Zegeer, P.E.
Associate Director, Engineering and Planning
UNC Highway Safety Research Center
730 Martin Luther King, Jr. Blvd.
Chapel Hill, NC 27599-3430
Tel.: 919-962-7801
Fax: 919-962-8710
Email: Charlie_Zegeer@unc.edu

Carl A. Sundstrom
Research Associate, UNC Highway Safety Research Center
730 Martin Luther King, Jr. Blvd.
Chapel Hill, NC 27599-3430
Tel.: 919-843-4963
Fax: 919-962-8710
Email: sundstrom@hsrc.unc.edu

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* Corresponding Author

ABSTRACT

Horizontal curves are relatively dangerous portions of the roadway network. Agencies optimizing the use of their safety funds on curves should have an idea of the characteristics of the collisions that occur on those segments. However, few previous published papers had attempted to characterize the crashes on horizontal curves. This paper describes an effort that characterized crashes reported to be on curves in North Carolina using the Highway Safety Information System. Over 51,000 crashes on two-lane road curves were compared to crashes on all two-lane roads and to crashes on all roads. Since NC has wide varieties of terrain, climate, and development, the findings should be generally representative of the US.

The analysis revealed that over-represented two-lane curve crash types included:

- Crashes on grades;
- Rural;
- Severe injury or fatal;
- Fixed object (particularly tree, ditch, and embankment);
- Overturn;
- Off peak hours (particularly during darkness on unlighted roads);
- Weekend;
- Holiday periods; and
- Wet, icy or snowy pavement.

In addition, the analysis showed that there were few short roadway segments (of 0.1- to 1-mile length) with more than 10 reported curve crashes in 3 years.

This paper provides a summary of recommendations from the national literature to treat the over-represented crash types on horizontal curves. Based on the findings, agencies should target countermeasures for the most common and over-represented crash types. Agencies should also consider horizontal curves when locating hazardous locations.

INTRODUCTION

Horizontal curves provide a transition from one tangent section of roadway to the next. These curves exert forces on a vehicle that vary significantly from a tangent section. Drivers must react appropriately to horizontal curves to safely traverse them. A clear understanding of the scope and characteristics of horizontal curve collisions is critical for the informed design of roadways and implementation of traffic control devices to provide warning to drivers.

Prioritizing collision countermeasures on two-lane roadways can benefit from an advanced knowledge of curve collisions primarily through a better understanding of prior collision experience. The type of collisions, particularly with fixed roadside objects, play a significant role in collision severity. The same elements can assist the deployment of traffic control devices along with an understanding of the impact of the time of day, lighting, and roadway surface conditions. These elements can also help design effective enforcement, education, and other countermeasures. Which countermeasures have the most promise? What types of crashes should agencies target? Numerous other research efforts have examined specific curve crash countermeasures. However, to this point, no one has published a characterization of curve collisions on a statewide scale.

The objective of this research is to characterize when, where, and how horizontal curve collisions occur on two-lane roads. Many states do not have a systematic, statewide method to identify horizontal curves which have high crash experience and/or a high potential for crashes. Understanding curve collision characteristics is important for developing a methodology to find and treat hazardous curve locations. This paper also focused on identifying countermeasures which can potentially reduce curve crashes associated with various crash factors. This requires a good understanding of the human, roadway, and environmental factors which contribute to the cause and the resulting severity of the crash. It also requires a thorough understanding of the different types of geometric and traffic control countermeasures which are available to address specific crash causes, as determined by available guidelines, research, and agency experiences. In conjunction with this analysis of curve crashes, this paper matched specific countermeasures to various crash characteristics.

The crash data analysis in this study was focused on NC roads. NC experiences a broad range of topographic conditions, climates, and rural/urban settings. This diversity in conditions makes NC an appealing location for determining representative horizontal curve collision characteristics. The reporting threshold in NC is a collision that resulted in a fatality, non-fatal personal injury, property damage of $1,000 or more, or property damage of any amount to a vehicle seized (*1*). The NCDOT controls almost 80,000 miles of roadways, which creates consistency across the state with roadway design, construction, and maintenance. These factors make findings based on NC collision data useful to many other jurisdictions.

LITERATURE REVIEW

There are many studies identifying crash characteristics and geometric design features that have an effect on crashes. The following studies all identify horizontal curves as causal factors in highway crashes with a significantly higher crash rate than tangent sections or study specifically horizontal curve crashes.

Garber and Kassebaum (*2*) studied nearly 10,000 crashes on urban and rural two-lane highways in Virginia finding the predominate type of crash to be run-off-the-road crashes. The significant causal factors of these run-off-the-road crashes included roadway curvature and traffic volume as determined through a fault tree analysis. The countermeasures identified to mitigate run-off-the-road crashes include widening the roadway, adding advisory signs or chevrons to sharp curves, and adding or improving shoulders.

Another study that investigated the relationship between roadway design attributes and crash activity was performed by Strathman et al (*3*). This study investigated the statistical relationship between crash activity and roadway design attributes on Oregon highways. Using crash data from a two-year period (1997-1998), the highways were divided into variable length homogenous highway segments, yielding a set of over 11,000 segments. For non-freeway segments, maximum curve length and right shoulder width were found to be among the design attributes related to curves that were statistically related to crash activity. Maximum curve angle was not found to be related to crash activity.

Souleyrette et al.(*4*) evaluated roadway and crash characteristics for all highways in Iowa through integrating databases with digital imagery, roadway characteristics, and crash data. This project studied five crash types including crashes on horizontal curves and made use of the GIS data to collect roadway characteristics that were not identified by crash records. The analysis of high crash locations on horizontal curves found that the degree of curvature had a direct impact on the crash rate. The model also indicated that the degree of curvature had a direct impact on horizontal curves and that the crash rate on shorter curve lengths was significantly higher than on longer curves. In addition, this study produced a curve database for Iowa with radii and length attributes and a procedure for identifying horizontal curves with high crash occurrences statewide.

Zegeer et al. (*5*) analyzed over 13,000 horizontal curves, primarily in Washington, to evaluate the relationship between curve features and crashes. To meet the study objective, the horizontal curve features which affected traffic safety and operation were first identified. A collision prediction model consisting of six variables relating to collisions and curve features was developed through a variety of statistical methods. These six variables were: curve length, vehicles volume, degree of curve, presence of spiral transitions, and roadway width. From these identified features, existing countermeasures for enhancing safety and operations at particular curve sections were determined and the model developed an effectiveness of crash reduction for each of these treatments. This study also provided general safety guidelines for curve design including signing, marking, and delineation as recommended cost-effective countermeasures.

McGee and Hanscom (*6*) provide a publication on low-cost treatments that can be applied to horizontal curves to address identified or potential safety problems. These treatments included: basic traffic signs and markings from the MUTCD, enhanced TCDs, other TCDs not mentioned in the

MUTCD, rumble strips, minor roadway improvements, and innovative and experimental treatments. For every treatment, the authors concisely identified a description of the treatment, and application guideline, design elements, the effectiveness, cost, maintenance, and additional sources.

In Volume 7 of NCHRP Report 500, Torbic et al. (*7*) provided strategies to improve the safety of horizontal curves. This study had two primary purposes. The first was to reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve. The other purpose was to minimize the adverse consequences of leaving the roadway at a horizontal curve. To accomplish these research objectives, twenty detailed strategies were described as countermeasures for reducing curve-related crashes. Each strategy included a general description, an estimate of the effectiveness of treatments, and special issues pertaining to horizontal curves. These treatments addressed traffic control devices, markings, sight distances, and horizontal alignments.

Many other research efforts have examined specific curve crash countermeasures. However, to this point, as mentioned previously, no past study has characterized curve collisions on a large scale and matched the results with countermeasures directed at specific crash causes. Also, this paper provides recommendations on how an agency can conduct a comprehensive analysis of horizontal curve safety problems and deal with these problems in a systematic manner.

METHODOLOGY

The Highway Safety Information System (HSIS) collects and reports statewide collision data for participating states, which includes seven states with recent collision data (*8*). North Carolina was preselected as a data source by the Federal Highway Administration (FHWA) for inclusion in the HSIS program for its high quality crash, roadway inventory, and traffic volume databases. The NC database that the FHWA receives is derived from an Oracle database on the North Carolina Division of Motor Vehicles System. NC provides collision characteristics, data on vehicles and occupants in the collisions, and a roadway inventory (*9*). To achieve the objective of characterizing curve collisions, the research team requested horizontal curve collision data from the HSIS. While NC does not have an individual curve database, a high number of curve crashes and corresponding roadway data are still available, making the database suitable for the curve crash analysis. The analysis was conducted on the dataset of curve crashes received from the HSIS and included curve and non-curve collisions on two-lane roads and on all road types. The two-lane road and all roads datasets were obtained from an internet application which contains crash data from 2001 to 2006 from the North Carolina Department of Transportation crash database (*10*).

For our study NC collision data from 2003 to 2005 were analyzed in each database. The statewide data for all roads were useful for comparisons to rural and urban settings in which we had the greatest interest. The collision data on all two-lane roads were an effective comparison because two-lane curve collisions are a subset of the all two-lane roads database with which the curves share some roadway feature similarities.

COLLISION DATA ANALYSIS

The three-year analysis period of collision data (2003 to 2005) resulted in 51,238 reported collisions on curves on two-lane roads in NC and 95,552 reported collisions on curves on all roads in North Carolina. These crashes were identified based on their coding as “curve-related” by the reporting police officer on the crash report form.

In the following tables, some column totals might not sum to 100% because of rounding. The data are presented as percentages, not frequencies, for easier comparison. In the tables, “2-lane curve collisions” represent the collisions reported on two-lane curves, “all 2-lane collisions” represent the collisions reported on all two-lane roadways throughout North Carolina, and “all roads collisions” represent the collisions reported on all roads throughout North Carolina.

Road Characteristics

Aspects of the roadway itself significantly affect collisions. TABLE 1 shows that 21% of all two-lane road reported collisions occur on horizontal curves, compared to 14% among all roads statewide. Curve collisions occur more often on roadways sections with a grade (37% for all two-lane roads, 38% for all roads) rather than on tangent sections on a grade (18% for all two-lane roads, 17% for all roads). The reported curve collisions primarily occur in rural locations (70%), compared to 62% of all two-lane collisions and 45% of all statewide collisions (TABLE 2). It appears that rural, horizontal curves are particularly susceptible to collisions.

TABLE 1 Horizontal Curve Collision Roadway Characteristics

Road Characteristic	Grade	All 2-Lane Collisions		All Roads Collisions	
Tangent	Level	68%	77%	80%	78%
	Hillcrest		4%		4%
	Grade		18%		17%
	Bottom		1%		1%
Curve	Level	21%	56%	14%	53%
	Hillcrest		4%		6%
	Grade		37%		38%
	Bottom		3%		3%
Other	N/A	10%	0%	6%	1%
Uncoded	N/A		100%		99%

TABLE 2 Horizontal Curve Collision Setting Characteristics

Setting	Grade	2-Lane Curve Collisions		All 2-Lane Collisions	All Roads Collisions
Urban	Level	30%	54%	38%	55%
	Hillcrest		6%		
	Grade		37%		
	Bottom		3%		
Rural	Level	70%	57%	62%	45%
	Hillcrest		3%		
	Grade		37%		
	Bottom		2%		

Collision Characteristics

This section discusses how severity, frequency, type, alcohol involvement, time of day, day of week, month of year, lighting, and surface conditions affect collisions.

Severity

Collision severity is an important component of collision analysis and countermeasure initiatives. Severity is measured on a five-point scale in North Carolina: fatality (K), disabling injury (type A), evident injury (type B), possible injury (type C), and property damage only (PDO) (NCDMV, 2006). Two-lane curves typically have narrower lanes and shoulders, more sight distance concerns, and less frequent maintenance than other segments and roadway types. Table 3 shows that these factors indicate that two-lane curve collisions have twice the percentage of fatal and type A injury collisions when compared to collisions on all two-lane roads and all roads statewide. Fatal collisions compose 1.9% of total reported two-lane curve collisions, compared to 0.9% of all two-lane road collisions and 0.6% of all statewide collisions. Type A collisions have a similar trend, with 3.5% of total reported two-lane curve collisions compared to 1.9% of all two-lane road collisions and 1.4% of all statewide collisions. Two-lane curve collisions are much more severe in urban areas than all road collisions.

TABLE 3 Horizontal Curve Collision Severity Characteristics

Severity	2-Lane Curve Collisions			All 2-Lane Collisions	All Roads Collisions		
	Setting		Total	Total	Setting		Total
	Urban	Rural			Urban	Rural	
K	1.5%	2.1%	1.9%	0.9%	0.3%	1.0%	0.6%
A	3.0%	3.7%	3.5%	1.9%	0.8%	2.1%	1.4%
B	16.1%	18.3%	17.6%	11.9%	7.4%	11.7%	9.4%
C	24.4%	24.6%	24.5%	25.5%	26.2%	23.7%	25.1%
PDO	49.1%	44.1%	45.6%	54.7%	62.1%	58.0%	60.2%
Unknown	5.9%	7.2%	6.8%	5.1%	3.3%	3.5%	3.4%

Frequency

The frequency of collisions on curves on rural two-lane curved roads were examined with a sliding scale analysis using 0.1-, 0.2-, 0.3-, 0.5- and 1-mile segment lengths. A sliding scale analysis is useful for identifying concentrations of collisions without arbitrarily defining segments to analyze. The sliding scale of predetermined length moves along a roadway to determine the number of collisions within the segment. The results, presented in Table 4 show that only four segments experienced 10 or more collisions in 0.1-mile segment lengths during the three-year period of analysis. Figure 1 shows a graph of the 0.1-mile segment length collision frequency versus a theoretical Poisson distribution. Using a chi-square goodness of fit test, which is a stringent test to meet, the data do not fit a Poisson distribution function at the 95% confidence level, but a visual inspection showed a decent match.

The key question related to this analysis is what is the most appropriate roadway segment length for use in identifying high-crash curves in a spot safety improvement analysis. The answer to this question must consider the accuracy of crash location reporting by the reporting police agency, the characteristics of horizontal curves (e.g., spacing between curves, length of curves, etc.), and the nature of the crash file (e.g. relative number and distribution of curve crashes along routes). For purposes of their spot safety improvement program, many states use a floating fixed segment length, such as a 0.1 or 0.3-mile segment, and may also include a longer section (e.g., 1-mile section) for “flagging” roadway sections for further analysis.

One way to approach determining an optimal segment length, for the purpose of a curve safety analysis, is to test different segment lengths for a sample of roadways and determine the segment length that yields the most useful results. For example, if roadway sections are in rolling areas and have long gradual curves, a floating segment length of 0.3 to 0.5 miles may be appropriate. In mountainous areas with many sharp, short curves, a floating segment length of shorter (e.g., 0.1 mile) might be more meaningful to identify individual high-crash curves. Longer floating segment lengths (e.g., 1-mile) can be used to identify roadway sections which have more than their share of curve-related crashes, so the entire section can be addressed (and not each curve individually).

TABLE 4 Rural Horizontal Curve Collision Frequency Characteristics

Total Collisions	Frequency by Segment Length 0.1 Mile	0.2 Mile	0.3 Mile	0.5 Mile	1.0 Mile
0	282,960	129,260	78,966	40,206	13,755
1	22,767	18,721	16,176	12,497	7,496
2	3,037	3,690	3,857	3,910	3,327
3	668	959	1,175	1,467	1,563
4	224	353	455	601	786
5	67	144	181	285	435
6	23	60	101	122	247
7	17	25	39	77	129
8	11	18	26	48	100
9	4	7	19	33	50
10	2	6	8	7	26
11	1	2	2	8	17
12	-	3	3	6	19
13	-	-	1	4	13
14	-	-	1	-	4
15	-	-	1	1	2
16	-	-	-	-	1
17	-	1	-	-	3
18	-	-	-	-	1
19	1	-	-	-	-
20	-	1	1	1	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	1
24	-	-	-	-	2
25	-	-	-	-	-
26	-	-	-	-	-
27	-	-	-	1	-
28	-	-	-	-	-
29	-	-	-	-	1
Total	309,782	153,250	101,012	59,274	27,978

Note: "-" represents 0 collisions

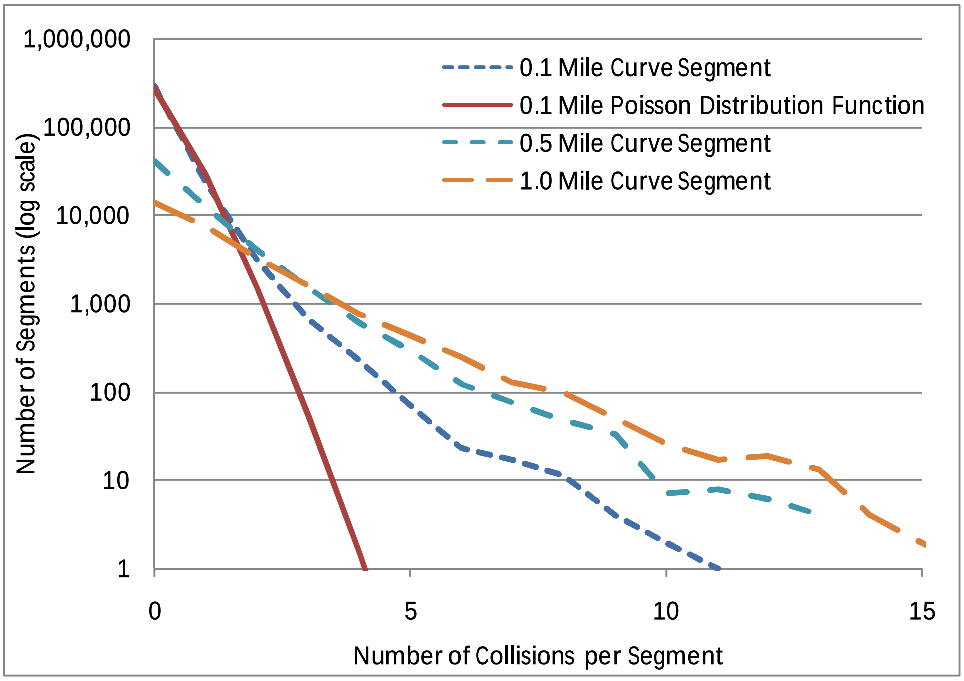

FIGURE 1 Horizontal curve collision frequency distribution.

Type

Table 5 shows that collisions with fixed objects make up the majority of total reported two-lane curve collisions (52%), compared to 23% of all two-lane road collisions and 15% of all statewide collisions. The differences are more pronounced on urban two-lane curves, where collisions with fixed objects make up 43% of reported collisions, compared to 4% of all urban statewide collisions. Two-lane curve collisions experience a lower percentage of reported rear-end-stopped, angle, and animal collisions than all two-lane road and all road collisions.

Table 6 shows the most harmful events and objects in single vehicle collisions. This table provides insight into which objects were struck by the vehicle. Overturn/rollover collisions (31%), collisions with trees (20%), and ditches (16%) constitute the majority of most harmful events in single vehicle collisions on two-lane curves. For all two-lane roads and all roads, the most harmful events are collisions with animals at 30% and 24%, respectively.

TABLE 5 Horizontal Curve Collision Type Characteristics

Collision Type	2-Lane Curve Collisions			All 2-Lane Collisions	All Roads Collisions		
	Setting		Total		Setting		Total
	Urban	Rural			Urban	Rural	
Fixed Object	43%	56%	52%	23%	4%	28%	15%
Overturn/Roll	6%	10%	9%	3%	0%	4%	2%
Run Off Road - Right	8%	7%	7%	5%	4%	3%	4%
Rear End - Stopped	11%	4%	6%	20%	33%	17%	26%
Side Swipe - Opposite Direction	5%	5%	5%	3%	1%	2%	2%
Angle	5%	2%	3%	12%	21%	7%	15%
Left Turn - Different Road	4%	2%	3%	5%	4%	5%	5%
Run Off Road - Left	3%	3%	3%	2%	2%	2%	2%
Head On	2%	2%	2%	2%	1%	1%	1%
Left Turn - Same Road	3%	2%	2%	5%	6%	5%	5%
Animal	2%	2%	2%	4%	1%	13%	7%
Moveable Object	1%	1%	1%	1%	1%	1%	1%
Side Swipe - Same Direction	1%	1%	1%	3%	8%	3%	6%
Parked Motor Vehicle	1%	1%	1%	2%	2%	1%	1%
Other Non-Collision	1%	1%	1%	1%	1%	1%	1%
Rear End - Turning	1%	1%	1%	2%	1%	1%	1%
Other Collision	1%	0%	0%	1%	1%	1%	1%
Backing Up	1%	0%	0%	3%	3%	1%	2%
Right Turn - Different Road	1%	0%	0%	1%	1%	1%	1%
Right Turn - Same Road	0%	0%	0%	1%	1%	1%	1%
Pedestrian	0%	0%	0%	1%	1%	0%	1%

TABLE 6 Horizontal Curve Collision Most Harmful Event Characteristics

Event Type	2-Lane Curve Collisions			All 2-Lane Collisions	All Roads Collisions		
	Setting		Total	Total	Setting		Total
	Urban	Rural			Urban	Rural	
Overturn/Rollover	16%	32%	31%	18%	8%	18%	16%
Tree	14%	20%	20%	12%	6%	12%	11%
Ditch	7%	16%	16%	12%	3%	11%	10%
Embankment	3%	6%	5%	3%	1%	3%	3%
Utility Pole	8%	5%	5%	4%	7%	3%	3%
Other Fixed Object	5%	4%	4%	3%	5%	3%	3%
Fence or Fence Post	2%	3%	3%	2%	1%	2%	2%
Catch Basin or Culvert on Shoulder	2%	3%	3%	2%	1%	2%	2%
Animal	5%	2%	2%	30%	11%	27%	24%
Mailbox	1%	2%	2%	1%	0%	1%	1%
Guardrail Face on Shoulder	5%	1%	1%	1%	5%	2%	3%
Movable Object	4%	1%	1%	1%	6%	2%	2%
Official Highway Sign Non-Breakaway	1%	1%	1%	1%	1%	1%	1%
Ran Off Road Right	7%	0%	1%	1%	5%	0%	1%
Pedestrian	1%	1%	1%	2%	8%	2%	3%
Bridge Rail End	0%	1%	1%	0%	0%	0%	0%
Guardrail End on Shoulder	1%	0%	0%	0%	1%	1%	1%
Official Highway Sign Breakaway	1%	0%	0%	0%	1%	0%	1%
Bridge Rail Face	1%	0%	0%	0%	1%	1%	1%
Other Non-Collision	1%	0%	0%	1%	2%	1%	1%
Pedalcyclist	1%	0%	0%	1%	3%	1%	1%
Ran Off Road Left	4%	0%	0%	0%	2%	0%	1%
Fire/Explosion	0%	0%	0%	0%	0%	1%	1%
Other Collision With Vehicle	1%	0%	0%	0%	1%	0%	0%
Angle	1%	0%	0%	0%	2%	0%	0%
Shoulder Barrier Face	1%	0%	0%	0%	1%	0%	0%
Head On	1%	0%	0%	0%	1%	0%	0%
Sideswipe, Same Direction	0%	0%	0%	0%	1%	0%	0%
Read End, Slow or Stop	0%	0%	0%	0%	1%	0%	0%
Traffic Island Curb or Median	1%	0%	0%	0%	1%	0%	0%
Guardrail Face in Median	1%	0%	0%	0%	3%	2%	3%
Median Barrier Face	1%	0%	0%	0%	6%	2%	3%

Alcohol Involvement

Alcohol is involved in 11% of reported two-lane curve collisions, compared to 7% of all two-lane road collisions and 5% of all statewide collisions. Impaired drivers likely have a more difficult time keeping their vehicles on the road in curves than they do on tangents.

Time of Day

Two-lane road curve collisions tend to be more evenly dispersed throughout the day than do statewide road total collisions and two-lane roads total collisions (Figure 2). During almost all hours, the point representing two-lane curve collisions is closer to the average percentage of 4.2 per hour than the other points. Two-lane road curve collisions are more likely to be single vehicle collisions, primarily with fixed objects. Other roads experience more multi-vehicle collisions which are more likely a function of traffic volume fluctuations occurring during morning and afternoon peak periods. Also, visibility at night is a more serious problem on curves than other road segments.

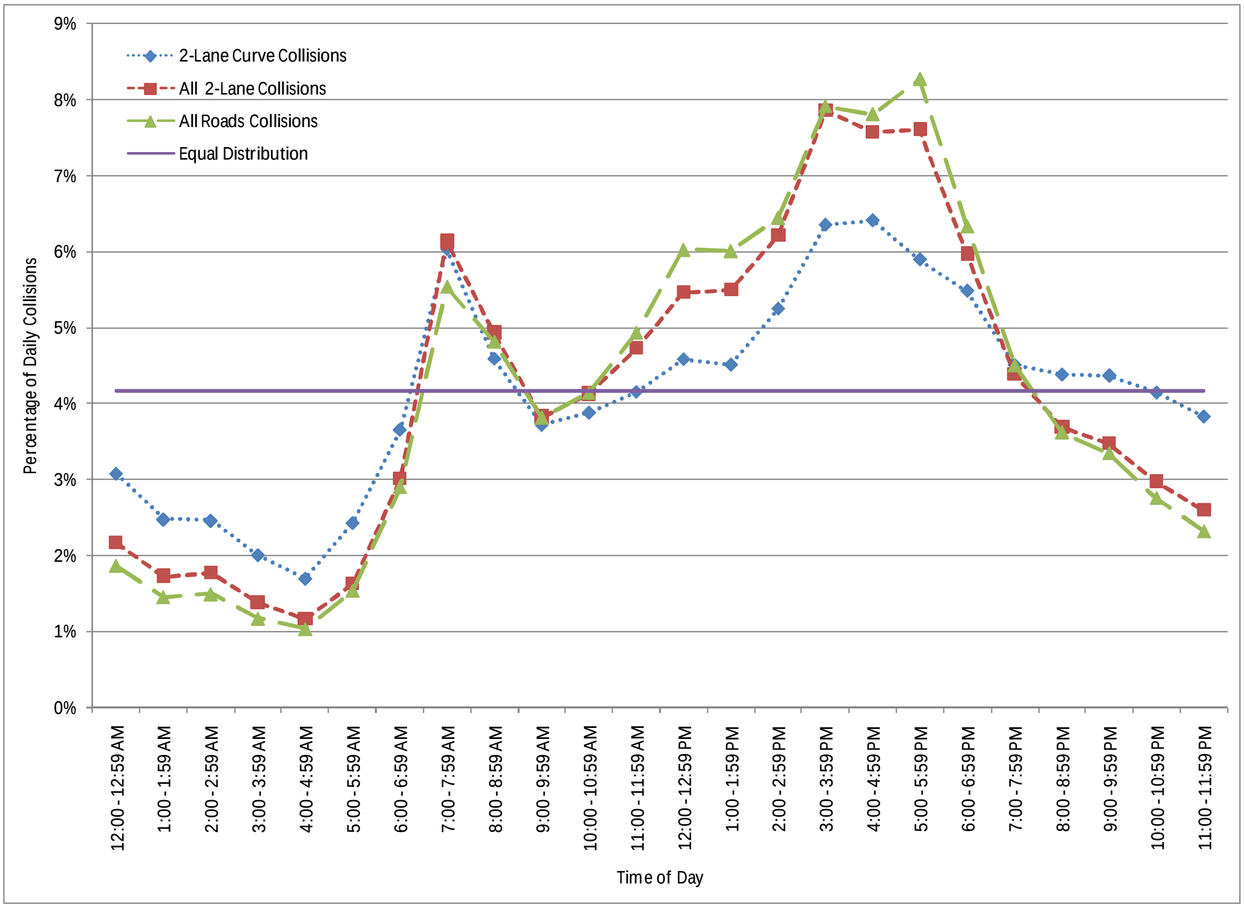

FIGURE 2 Horizontal curve collision time of day characteristics.

Day of Week

Two-lane road curve collisions tend to be more evenly dispersed throughout the week –and thus are more prominent during weekends– than statewide road total collisions and two-lane roads total collisions (Figure 3). This dispersion could again be because curve collisions are a function of a permanent roadway feature while the two-lane and all statewide road categories are subject to more pronounced traffic volume peaks. Two-lane statewide total collisions and statewide total collisions experience two peaks during the week: at the beginning of the work week (Monday) and at the end of the work week (Friday). Two-lane curve collisions experience a more gradual peak centered on the weekend. Two-lane road curve collisions are also more likely to involve a single vehicle, while other roads experience more multi-vehicle collisions which are more possible during heavy traffic conditions. Alcohol could also play a role in increasing the weekend peak of two-lane curve collisions. Hourly volumes would be a useful addition to the crash data to present the crashes in relation to crashes per million vehicle miles travelled. However, hourly volume data was not readily available for integration with the crash database.

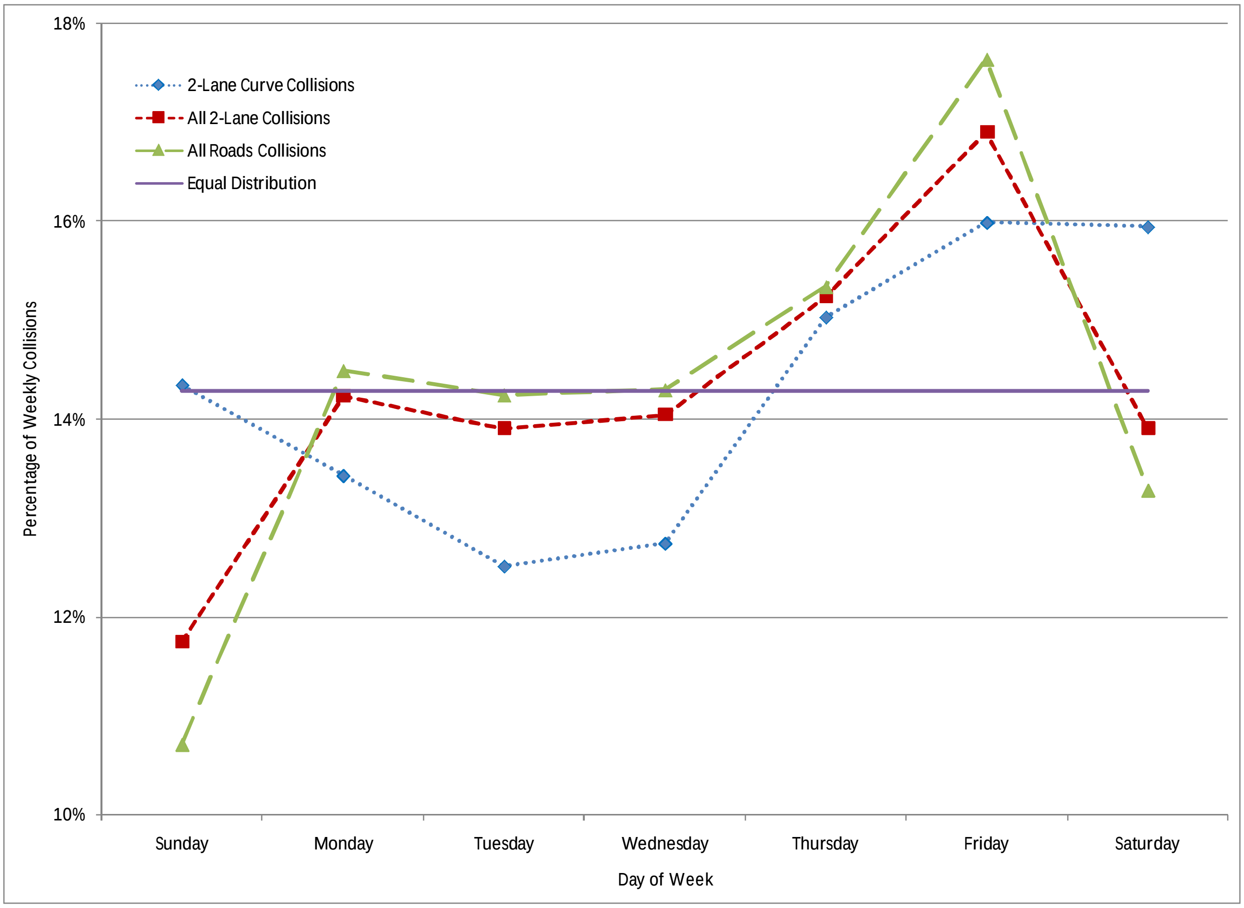

FIGURE 3 Horizontal curve collision day of week characteristics.

Month of Year

Two-lane road curve collisions tend to be less evenly dispersed by month throughout the year than statewide road total collisions and two-lane roads collisions (Figure 4). This dispersion could be because curve collisions are impacted more heavily by more pronounced seasonal variations in volume. Each of the roadway types experience peaks in percentage of collisions during the winter holiday months and at the beginning and ending of the summer months. The peak in the winter is likely due to weather conditions and a lower maintenance standard (e.g., ice and snow removal priorities) for two-lane curves than other roads. Higher volumes in recreation areas on rural roads during the summer months could cause the increase in collisions for two-lane curves.

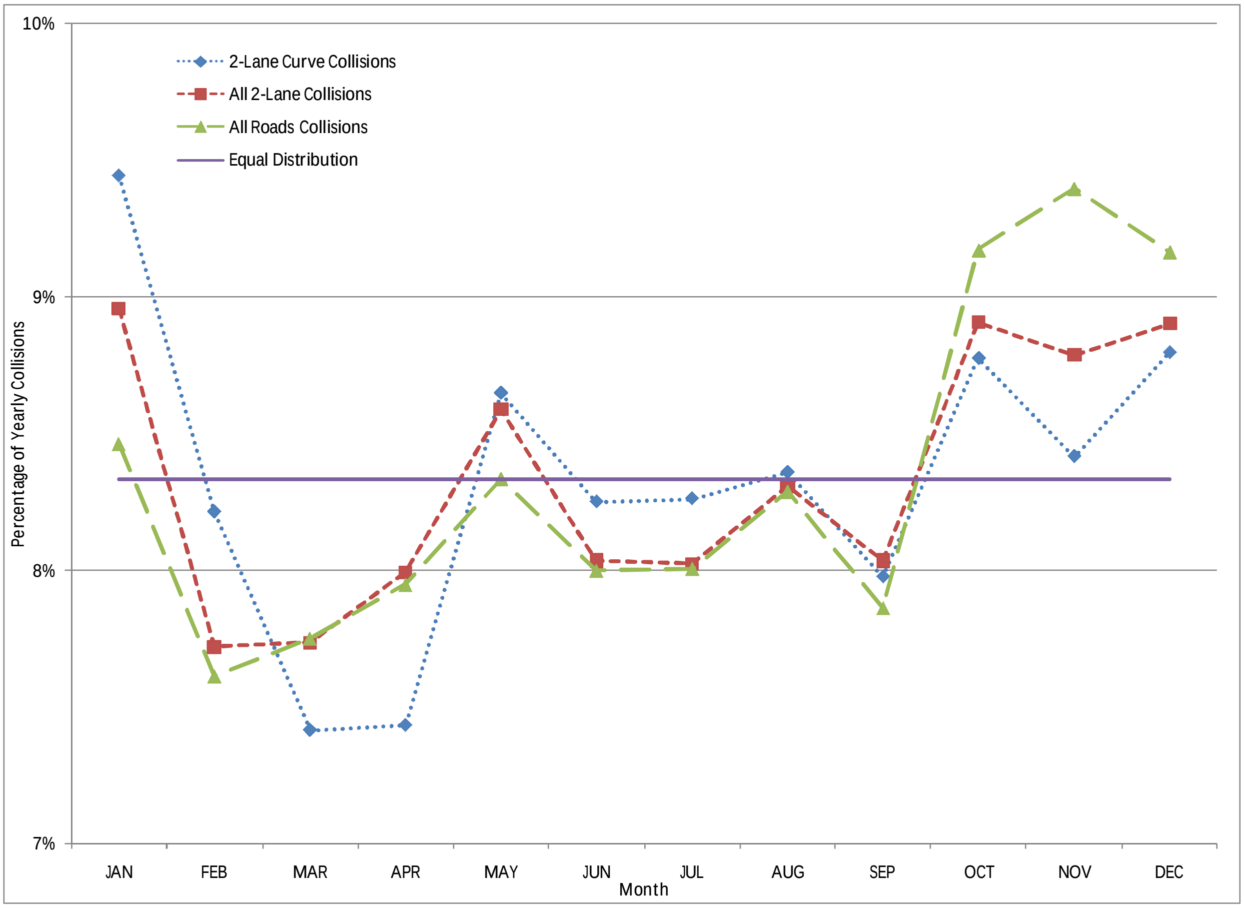

FIGURE 4 Horizontal curve collision month of year characteristics.

Lighting

Collisions during the daylight make up the majority of the total reported two-lane curve collisions (59%), compared to 67% of all two-lane road collisions and 68% of all statewide collisions. Collisions during the dark in unlighted conditions make up 31% of urban reported two-lane curve collisions, compared to 5% of all urban statewide collisions. Two-lane curve collisions experience a lower percentage of reported collisions during the dark in lighted conditions than all two-lane collisions or all road collisions. The collisions during the dark in lighted and unlighted conditions are likely influenced by the percentage of statewide roads that have roadway lighting compared to 2-lane curve segments (particularly in urban locations).

Surface

Collisions on a dry roadway surface make up 70% of total reported two-lane curve collisions, compared to 77% of all two-lane road collisions and 77% of all statewide collisions (Table 7). Collisions on non-ideal roadway surface conditions (the combination of all conditions except dry) constitute a greater portion of total reported two-lane curve collisions (30%) than on all two-lane road collisions (23%) and all statewide collisions (23%). These findings tend to indicate that surface condition doesn't significantly influence collisions on curves.

TABLE 7 Horizontal Curve Collision Roadway Surface Characteristics

Roadway Surface Condition	2-Lane Curve Collisions			All 2-Lane Collisions	All Roads Collisions		
	Setting		Total	Total	Setting		Total
	Urban	Rural			Urban	Rural	
Dry	71%	70%	70%	77%	79%	76%	77%
Wet	21%	21%	21%	17%	18%	18%	18%
Water	1%	1%	1%	1%	1%	1%	1%
Ice	4%	4%	4%	3%	2%	3%	2%
Snow	2%	2%	2%	2%	1%	2%	1%
Slush	1%	1%	1%	0%	0%	0%	0%

RESULTS

The collision analysis and characterization led to the creation of a table which presents potential countermeasures to reduce the frequency and/or severity of horizontal curve crashes. Table 8 shows a total of 37 different countermeasures which may be useful for reducing curve crashes, particularly on 2-lane roads. For each of the countermeasures in the table, the check marks in the matrix indicate the type of collision factor the countermeasure is most likely to address. These collision factors were identified from the data analysis described earlier. For example, crashes involving inadequate lighting are most likely to be reduced by such measures as countermeasure number 1 (provide advanced warning prior to curve), 2 (enhanced curve delineation), 3 (provide adequate sight distance, 9 (provide lighting on curve), 10 (provide dynamic curve warning signs), etc., as indicated by the check marks in the corresponding matrix cells.

CONCLUSIONS

The purpose of this study was to conduct a detailed multi-year analysis of horizontal curve collisions on a statewide basis to identify key contributing factors associated with curve crashes. These results were used to match major crash causes to potential countermeasures. The primary factors found to be associated with curve crashes on rural, 2-lane roads include fixed objects (particularly trees and poles), overturn/ditch related factors, alcohol-related, adverse light conditions (i.e., nighttime), adverse roadway surface conditions, curve/grade geometric issues, and time-related factors (weekends), among others. However, two-lane curve collisions most often involve only a collision with roadway or roadside features, which means countermeasures can have a disproportionately positive impact on collisions.

In all of North Carolina over a three-year period, only 4 segments out of almost 310,000 statewide (one tenth of a mile in length) experienced 10 or more curve collisions (see Table 4 and Figure 1). Thus, the frequency of curve collisions per site are low compared to intersections, which could lead transportation agencies to overlook curves during hazard site identification processes. The selection of roadway segment length for identifying hazardous curve locations is critical. Length of segment to use in the analysis should depend on the available budget for further inspection and investigation of the curves.

TABLE 8 Summary of Potential Countermeasures to Reduce the Frequency and/or Severity of Horizontal Curve Crashes

Potential Countermeasures	Collision Characteristics							References
	Overturn/ Rollover/ Ditch Related	Adverse Surface Conditions	Inadequate Lighting	Tree	Utility Pole	Other Fixed Object	Curve/Grade Geometric	
1. Provide advance warning prior to curve	ü	ü	ü	ü	ü	ü	ü	7
2. Enhance curve delineation or pavement markings	ü		ü	ü	ü	ü		7,11
3. Provide adequate sight distance			ü				ü	7
4. Install shoulder rumble strips	ü			ü	ü	ü	ü	7,11
5. Install centerline rumble strips	ü			ü	ü	ü	ü	7
6. Prevent edge dropoffs	ü			ü	ü	ü		7,11
7. Provide skid-resistant pavement surfaces	ü	ü		ü	ü	ü		7,11
8. Provide grooved pavement	ü	ü		ü	ü	ü		7
9. Provide lighting of the curve			ü					7
10. Provide dynamic curve warning system	ü		ü	ü	ü	ü		7
11. Widen the roadway and/or shoulder	ü			ü	ü	ü	ü	7,11
12. Improve or restore superelevation	ü			ü	ü	ü	ü	7
13. Modify curve alignment/geometry	ü			ü	ü	ü	ü	7,11
14. Install automated anti-icing systems	ü	ü		ü	ü	ü		7
15. Prohibit/restrict long semi-trailers				ü	ü	ü	ü	7
16. Design safer slopes and ditches to prevent rollovers	ü						ü	7,11
17. Remove/relocate objects in hazardous locations				ü	ü	ü		7,11,12,13
18. Delineate roadside objects (trees, utility poles)			ü	ü	ü	ü		7,11,12,13
19. Add/improve roadside hardware	ü			ü	ü	ü	ü	7,11,13
20. Improve design/application of barrier systems	ü					ü	ü	7,13
21. Install edgeline profile marking or rumble strips	ü		ü	ü	ü	ü		11
22. Install midlane rumble strips	ü			ü	ü	ü	ü	11
23. Provide enhanced shoulder or in-lane delineation	ü		ü	ü	ü	ü		11
24. Develop and implement tree planting guidelines				ü				12
25. Develop mowing and vegetation control guidelines				ü				12
26. Remove trees in hazardous locations				ü				12
27. Shield motorists from striking trees/poles				ü	ü	ü		12,13
28. Modify roadside clear zone near trees				ü		ü		12
29. Remove utility poles in hazardous locations					ü			13
30. Relocate poles further from the roadway					ü			13
31. Use breakaway poles					ü			13
32. Shield drivers from poles in hazardous locations					ü			13
33. Improve driver's ability to see poles			ü		ü			13
34. Apply traffic calming measures					ü			13
35. Revise pole placement policies					ü			13
36. Place utilities underground					ü			13
37. Decrease number of utility poles along a corridor					ü			13

RECOMMENDATIONS

The research team recommends several actions to help transportation agencies to better understand and identify problems involving horizontal curve collisions and identifying horizontal curves collisions. A similar statewide curve analysis can help identify any unique circumstances that create an overrepresentation of certain types or characteristics of collisions. The severity of two-lane curves, particularly in rural areas, should be considered as part of a hazardous site identification program. The curve collision analysis can identify specific hazardous locations as well as systematic deficiencies among regions, routes, geometric design factors, traffic control device consistency, shoulder width or type, maintenance practices, etc. A comprehensive horizontal curve process would help guide agencies through horizontal curve identification, investigation, analysis, evaluation, countermeasure selection and evaluation, assessment of funding sources, and recommendation of countermeasures. The team also recommends the use of Table 8 as an initial guide to select potential countermeasures for horizontal curve collisions.

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