



MID-AMERICA TRANSPORTATION CENTER

Report # MATC-KU: 463

Final Report
25-1121-0001-463



Evaluation of Large Truck Crashes at Horizontal Curves on Two-Lane Rural Highways in Kansas

Eric J. Fitzsimmons, Ph.D.

Postdoctoral Research Associate
Civil, Environmental, and Architectural Engineering
University of Kansas

Steven Schrock, Ph.D., P.E.

Associate Professor

Tomás E. Lindheimer

Graduate Research Assistant



2012

A Cooperative Research Project sponsored by the
U.S. Department of Transportation Research and
Innovative Technology Administration

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation University Transportation Centers Program, in the interest of information exchange.
The U.S. Government assumes no liability for the contents or use thereof.

MATC

**Evaluation of Large Truck Crashes at Horizontal Curves
on Two-Lane Rural Highways in Kansas**

Eric J. Fitzsimmons, Ph.D.
Postdoctoral Research Associate
Transportation Research Institute
University of Kansas

Steven D. Schrock, Ph.D., P.E.
Associate Professor
Department of Civil, Environmental, and Architectural Engineering
University of Kansas

Tomás E. Lindheimer
Graduate Research Assistant
Department of Civil, Environmental, and Architectural Engineering
University of Kansas

A Report on Research Sponsored by

Mid-America Transportation Center

University of Nebraska–Lincoln

August 2012

Technical Report Documentation Page

1. Report No. 25-1121-0001-463	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Evaluation of Large Truck Crashes at Horizontal Curves on Two-Lane Rural Highways in Kansas		5. Report Date August 2012	
		6. Performing Organization Code	
7. Author(s) Eric J. Fitzsimmons, Steven D. Schrock, and Tomás E. Lindheimer		8. Performing Organization Report No. 25-1121-0001-463	
9. Performing Organization Name and Address Mid-America Transportation Center 2200 Vine St. PO Box 830851 Lincoln, NE 68583-0851		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Organization Name and Address Research and Innovative Technology Administration 1200 New Jersey Ave., SE Washington, D.C. 20590		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code MATC TRB RiP No. 28685	
15. Supplementary Notes			
<p>16. Abstract</p> <p>The objective of this study was to investigate the relationship between roadway and environment-related factors and truck crash severity at horizontal curves located on rural, two-lane state highways in Kansas. Single vehicle truck crashes and multi-vehicle crashes involving at least one truck were extracted from the Kansas Department of Transportation's crash and roadway databases for the years 2006-2010, resulting in 452 crash records. Descriptive statistics and 95 percent confidence intervals were constructed for an odds ratio analysis comparing single-vehicle truck crashes to multi-vehicle crashes involving at least one truck for the variables that were included in both databases. Overall, the odds ratio analysis indicated that single vehicle truck crashes were less likely to occur on wet pavement with shoulder rumble strips present and during non-adverse weather conditions compared to multi-vehicle crashes involving at least one truck. Single-vehicle truck crashes were also more likely to result in an injury crash compared to multi-vehicle crashes involving at least one truck. The latter were more likely to result in a fatality or property damage only crash.</p>			
17. Key Words Rural Horizontal Curves, Large Trucks, Odds Ratio		18. Distribution Statement	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 23	22. Price

Table of Contents

Acknowledgements	viii
Disclaimer	viii
Abstract	ix
Chapter 1 Background	ix
Chapter 2 Literature Review	2
Chapter 3 Scope of Study	7
Chapter 4 Data Description	8
Chapter 5 Analysis	9
5.1 Descriptive Statistics	9
5.2 Simple Odds Ratio	14
Chapter 6 Discussion	19
References	21

List of Figures

Figure 5.1 Identified truck horizontal curve concentration areas in Kansas based on 1,000 ft. radius (2006-2010)	9
Figure 5.2 Single-vehicle fixed object collision type	11
Figure 5.3 Multi-vehicle collision type	12
Figure 5.4 (a) Road surface conditions at the time of crash for single-vehicle truck and (b) and multi-vehicle involving a truck (b)	13
Figure 5.5 (a) Lighting conditions at the time of crash for single-vehicle truck and (b) multi-vehicle involving a truck	14

List of Tables

Table 5.1 Summary of single-vehicle and multi-vehicle truck crashes and severity at rural horizontal curves in kansas	10
Table 5.2 Simple odds ratios and 95 percent confidence intervals	17

List of Abbreviations

Average Annual Daily Traffic (AADT)
Highway Safety Information System (HSIS)
Kansas Department of Transportation (KDOT)
Mid-America Transportation Center (MATC)
Point of Curvature (PC)
Point of Tangent (PT)

Acknowledgements

The authors wish to thank the Mid-America Transportation Center (MATC) for sponsorship of this research project. Additionally, the authors would like to thank Lanny Campbell, Rex McCommon, and Theresa Havenstein of the Kansas Department of Transportation's Bureau of Transportation Planning, for assistance with crash data.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Abstract

The objective of this study was to investigate the relationship between roadway and environment-related factors and truck crash severity at horizontal curves located on rural, two-lane state highways in Kansas. Single vehicle truck crashes and multi-vehicle crashes involving at least one truck were extracted from the Kansas Department of Transportation's crash and roadway databases for the years 2006-2010, resulting in 452 crash records. Descriptive statistics and 95 percent confidence intervals were constructed for an odds ratio analysis comparing single-vehicle truck crashes to multi-vehicle crashes involving at least one truck for the variables that were included in both databases. Overall, the odds ratio analysis indicated that single vehicle truck crashes were less likely to occur on wet pavement with shoulder rumble strips present and during non-adverse weather conditions compared to multi-vehicle crashes involving at least one truck. Single-vehicle truck crashes were also more likely to result in an injury crash compared to multi-vehicle crashes involving at least one truck. The latter were more likely to result in a fatality or property damage only crash.

Chapter 1 Background

Large truck crashes on rural two-lane highways result in a serious safety concern due to vehicle mass and size. In 2009, the U.S. Department of Transportation reported 3,215 fatal, 53,000 injury, and 239,000 property damage crashes involving large trucks. A total of 64 percent of rural fatal crashes in the United States were found to involve large trucks (1). The U.S. Government Accounting Office reports that although large trucks transport 60 percent of the country's total domestic tonnage, less than five percent of highway crashes involve a commercial motor carrier (2). Considering the high percentage of fatalities associated with crashes involving large trucks, it is implied that, though these crashes occur comparatively less frequently, they tend to be more severe than other crashes, especially in rural areas.

Chapter 2 Literature Review

Horizontal curves on two-lane roadways are a significant safety problem for drivers of both passenger cars and large trucks (3). Horizontal curve sites at rural locations often have smaller radii, a 55 mph posted speed limit, clear-zone fixed objects such as fences or trees, and limited sight distance. Campbell et al. stated the point of entry into a curve requires the most visual demand and control of the vehicle by the driver (4). Staplin et al. reported that crashes at horizontal curves stem from a combination of factors, including improper speed selection, the inability to negotiate curves with a superelevation greater than three degrees, and lack of awareness in sudden changes in roadway geometry (5). Drivers of large trucks face the additional challenge of negotiating rural horizontal curves to prevent cargo shift or rollover due to vehicle size, length, and engine performance when vertical curvature is present.

Understanding the causes and determining the differences between single-vehicle and multi-vehicle crash events involving large trucks can have a significant safety impact on rural highways. The selection of an appropriate rural curve countermeasure for both passenger cars and large trucks will significantly improve safety for state and local jurisdictions.

The causes of large truck crashes have been extensively investigated by researchers over the past 30 years. Most studies have focused on the development of statistical models of driver, vehicle, and roadway factors that are commonly reported at the crash scene by most state highway agencies. Chira-Chavel and Cleveland investigated historical crash data for factors related to truck drivers, and found statistically significantly lower crash rates for drivers with more than four years of experience as compared to one year of experience (6). Additionally, truck drivers under 30 and over 45 years of age showed higher crash rates in comparison to drivers that were between 30 and 45 years old. Gander et al. indicated that as truck driver route

familiarity decreased, the number of crashes increased (7). Researchers have also found that single drivers were more distracted than team drivers. Most studies indicated drowsiness as a common problem among truck drivers (8-10).

Various truck physical characteristics and roadway geometric features have also been investigated in relation to crashes. Increased truck gross weight has been found to increase the likelihood of a fatal crash (11), and worn or improperly secured truck equipment (e.g. brakes and load securement straps and chains) have also been shown to increase the risk of crashes among large trucks (12). Agent and Pigman evaluated roadway factors, finding that large trucks on interstates, as compared to other facilities, were more likely to be involved in crashes of all severity levels (12). Zeeger et al. reported that steeper side slopes had higher rates of single-vehicle truck crashes (13). Spainhour et al. reported that 30 percent of fatal truck crashes in Florida occurred on four- and five-lane highways (14). Finally, Stieff indicated that nighttime driving on non-limited access highways in rural areas, as compared to other facilities, displayed a higher rate of large truck crashes (15).

A limited body of literature has investigated factors that contribute to large truck crashes on rural two-lane highways at horizontal curves. The following literature was found to specifically address truck crashes at horizontal curves:

Spainhour et al. evaluated 600 truck crashes that occurred in Florida between 1998 and 2000. Crashes were evaluated using the state crash and roadway database, crash narratives with photos, and site visits, in order to determine fault for each crash. The researchers found that single-vehicle truck crashes accounted for 20 percent of all fatal crashes. For other crash types, such as run-off-road, rear-end, and intersection turning crashes, it was found that the driver of the large truck was more likely to be at fault. The researchers also evaluated large truck, head-on

crashes, and reported that the truck driver was at fault for only 23 percent of these crashes. Vehicle-related factors accounted for 30 percent of the factors contributing to crashes, and half of the fatal truck crashes resulted from vehicle rollover, in which 26 percent of trucks caught fire (14).

Khattak et al. investigated whether large truck crashes in North Carolina were more frequent due to this vehicle type being harder to maneuver, and whether rollover and injury crashes occurred more frequently on segments that included a horizontal or vertical curvature. The researchers used crash data extracted from the North Carolina Highway Safety Information System from 1996 to 1998. Rollover truck crashes were reported in 1,503 of the 5,163 single-vehicle crashes (approximately 30 percent). Common relationships between truck crashes were determined using simple statistics and cross-tabulated observations. The researchers noted that slippery road surfaces decreased the tendency for rollover crashes; they attributed this phenomenon to the possibility that truck drivers were more cautious under this type of roadway condition. The crash data were characterized by 65 percent non-injury crashes, 35 percent involving injuries, and 1 percent were fatal crashes. Of the total fatal crashes, 58 percent were rollover crashes, while 62 percent of all severe injury crashes were rollover crashes (16, 17).

A binary probit model was developed by Khattak et al. to analyze truck rollover tendencies in a crash. A second model was developed to analyze injury severity for truck crashes. When rollover model results were combined with injury severity model results, it was found that, when horizontal curves were present, higher injury severity crashes were expected to occur. The likelihood of injury to a truck occupant could be expected to increase by four percent when a crash occurred on a horizontal curve. Large truck rollover crashes were expected to

increase by nine percent on horizontal curves. Finally, it was concluded that 43 percent of truck crashes at curves involved a rollover (16, 17).

Reporting to the Federal Highway Administration (FHWA), Zeeger et al. (18, 19) investigated the effects of the presence of horizontal curves on truck-related crashes. The researchers focused their efforts on two-lane rural roads and cost-effective improvements. The study concluded that the first and last maneuver a truck made at a curve site could present significant problems when negotiating a horizontal curve. A roadside recovery distance of 3.05 meters (10 ft.) or less, smaller radii, curves greater than 0.161 kilometer (0.1 mile) in length, and narrow curve lane widths were some curve features found to be associated with higher crash rates.

Using the Federal Motor Carrier Safety Association's Large Truck Crash Causation Study (LTCCS), Hallmark et al. investigated factors related to large truck run-off-road crashes. The database was comprised of environmental, vehicle, and driver-related variables obtained from 24 data collection sites in 17 states. "Large truck run-off-road" was defined as the vehicle advertently or inadvertently leaving its travel lane during the crash sequence. Truck driver responsibility was assigned to each crash, based on the crash narratives. Single-vehicle and multiple vehicle crashes were also investigated (20). Narratives for 1,070 crashes were investigated, and an analysis of the data using odds ratios and logistic regressions was used to determine factors occurring in truck lane-departure crashes. Both the odds ratio and logistic regression showed the following variables to be significant or more likely to occur in single-vehicle and multi-vehicle run-off-road crashes (in no specified order): truck jackknife, driver fatigue, driver was upset, unfamiliarity with the roadway, horizontal curves, and vertical curvature (positive or negative grades). Additionally, the authors noted that approximately 65

percent of single-vehicle truck lane departure crashes had a horizontal curve present, and 20 percent occurred with the absence of paved shoulders (20).

Iragavapu investigated the relationship between large truck crashes and environmental factors, roadway geometry, and traffic conditions. The database included 204,848 crashes on freeways in Texas. Negative binomial models were developed, and it was found that the presence of horizontal curves, narrow shoulder widths, and posted speed limits affected the predicted number of crashes. Specifically, single-vehicle truck crashes decreased when right shoulder width increased. The researchers found that run-off-road and fixed-object crashes were the most common crash types (21).

Researchers in Ohio also developed a negative binomial model and a Bayesian model to evaluate truck crashes (22). Large truck data was comprised of 15,390 crashes that occurred from 2002 to 2006. The variables found to be significant in the models included the presence of a horizontal curve, roadway shoulder width, and average annual daily traffic (AADT). The study found that large truck crashes increased significantly at horizontal curves when the AADT was high and degree of curvature increased.

Chapter 3 Scope of Study

The state of Kansas has an extensive highway system, with over 9,500 centerline miles of two-lane roadway, most of which are located in rural agriculture areas where large trucks are common. In 2009, Kansas experienced a total of 1,422 vehicle fatalities (motorcycle, passenger car, and trucks), of which 90 percent occurred on rural roads (*1*). The objective of this study was to investigate factors that related to single-vehicle and multi-vehicle truck crashes at horizontal curves in the state system. The Kansas Department of Transportation (KDOT) database provided an excellent means through which to conduct an analysis of recorded crash information, specifically, information pertaining to the environment (weather, lighting condition, etc.), crash envelope, and roadway. This research focused on developing odds ratios for identified factors, and comparing them between single-vehicle and multi-vehicle truck crashes. The results of the investigation are aimed to provide critical information for a local jurisdiction to identify countermeasures to reduce truck crashes in rural Kansas.

Chapter 4 Data Description

Since KDOT is not included in the Highway Safety Information System (HSIS), multiple sources were used to collect the variables for the analysis. For roadway features (including shoulder type, shoulder width, the presence of rumble strips) and to identify horizontal curves on the state highway system, the roadway network database was used. Crash information was provided by the state crash database, which provides information taken from police reports and crash narratives. As stated previously, truck crashes were identified in the crash database as involving a single truck (typically, a single vehicle run-off-road) or a truck and multiple vehicles (motorcycle, passenger car, or truck). A horizontal curve-truck related crash was identified as a crash that occurred within a horizontal curve in either direction between the point of curvature (PC) and the point of tangent (PT). One limitation that was identified in the data extraction process was the inability to assign responsibility for a multi-vehicle crash that involved at least one truck. The crash data provided by KDOT, specifically the crash envelope sequence of events, was limited compared to a larger and more extensive database such as the LTCCS. For this study, a truck involved in a multi-vehicle crash was assumed to bear some, if not all of the responsibility, especially on a rural highway.

Rural horizontal curve segments on state two-lane highways were identified by the roadway system database by estimating the PC and PT from the given roadway network. Currently, the KDOT roadway network system database contains minimal information regarding curves within the state; therefore, geometric data such as radius, degree of curvature, or superelevation were not coded or used in the analysis. A rural area was defined as a two-lane state highway at least two miles outside of an incorporated area. Toll plazas and interchanges in which a state highway met one of the federal interstate systems were also not considered.

Chapter 5 Analysis

5.1 Descriptive Statistics

Crash and roadway data were extracted from the KDOT database for four years (2006-2010). When passenger cars were added to the dataset, a total of 2,546 crashes occurred at rural Kansas horizontal curves. Considering only truck crashes, a total of 452 crashes occurred during this time period. The truck database was first separated by the number of vehicles involved in each of the crash observations, which created separate databases for single-vehicle and multi-vehicle truck crashes. As part of the study, concentration areas were identified where a significant number of truck crashes occurred at rural horizontal curves on the state highway system as shown in figure 5.1.

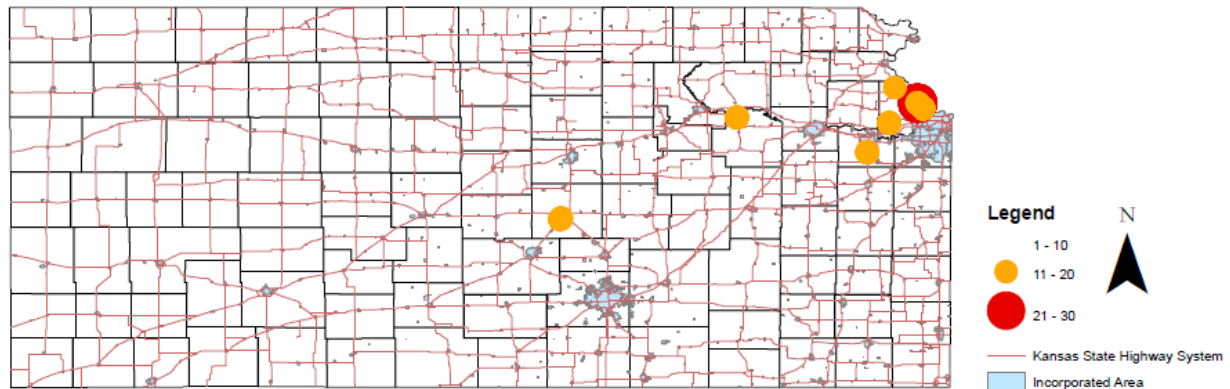


Figure 5.1 Identified truck horizontal curve concentration areas in Kansas based on 1,000 ft radius (2006-2010)

Concentrated areas, as shown in figure 5.1, were defined as spatially-joined areas with at least one horizontal curve present within a 1,000 ft radius which indicated more than 10 crashes in the four years of data. As shown, many of the concentrated areas were located in the northeastern part of Kansas near the Kansas City metropolitan area, in which a significant number of trucks and shipping operations occur daily. Many of the state highways around the

Kansas City metropolitan areas follow rivers and have steep elevation, requiring many horizontal curves compared to western Kansas, which has flatter elevation. These identified concentrated areas were created to help KDOT identify horizontal curves for future safety improvements, as well as to provide the research team an understanding of the magnitude and density of truck crashes in Kansas. Table 5.1 displays the total number of crashes per year for each crash type, and their respected severity count for each year.

Table 5.1 Summary of single-vehicle and multi-vehicle truck crashes and severity at rural horizontal curves in Kansas

Year	Total Truck Crashes at Horizontal Curves	Single-Vehicle Truck Crashes			Multi-Vehicle Crashes Involving One or More Trucks				
		Crash Count	Fatalities	Injuries	Property Damage Only	Crash Count	Fatalities	Injuries	Property Damage Only
2006	103	46	3	25	18	57	2	24	31
2007	106	38	1	16	21	68	3	28	37
2008	94	48	1	24	23	46	11	13	22
2009	72	42	0	14	28	30	0	8	22
2010	77	26	0	15	11	51	12	15	24
Total	452	200	5	94	101	252	28	88	136

As shown in table 5.1, the overall number of crashes at horizontal curves decreased from 103 in 2006 to 77 in 2010. Similarly, the number of single-vehicle truck crashes decreased from 46 to 26 in the same time period. However, the multi-vehicle crash count decreased from 2006 to 2009, then increased from 2009 to 2010 by 21 crashes. Overall, the number of property damage only and injury crashes exceeded the number of fatal crashes; however there continued to be a high number of fatal multi-vehicle crashes. As stated previously, the research team was unable to determine responsibility at the beginning of the crash envelope.

Investigating single-vehicle truck crashes further, it was found that three percent of these crashes resulted in trucks running off the road. Since these crashes were located at a horizontal curve, it was speculated that the truck drivers were unaware of the upcoming change in horizontal alignment, and therefore failed to properly adjust their speed prior to curve entry. In 2009, the KDOT vehicle crash report changed to allow officers to specify whether run-off-road crashes occurred to the left, right, or through. Since most of the data did not involve the use of the new crash report form, the direction of run-off-road was not taken into consideration. However, the crash report was able to provide detailed information on what the truck collided with once the vehicle left the road, which is shown in figure 5.2.

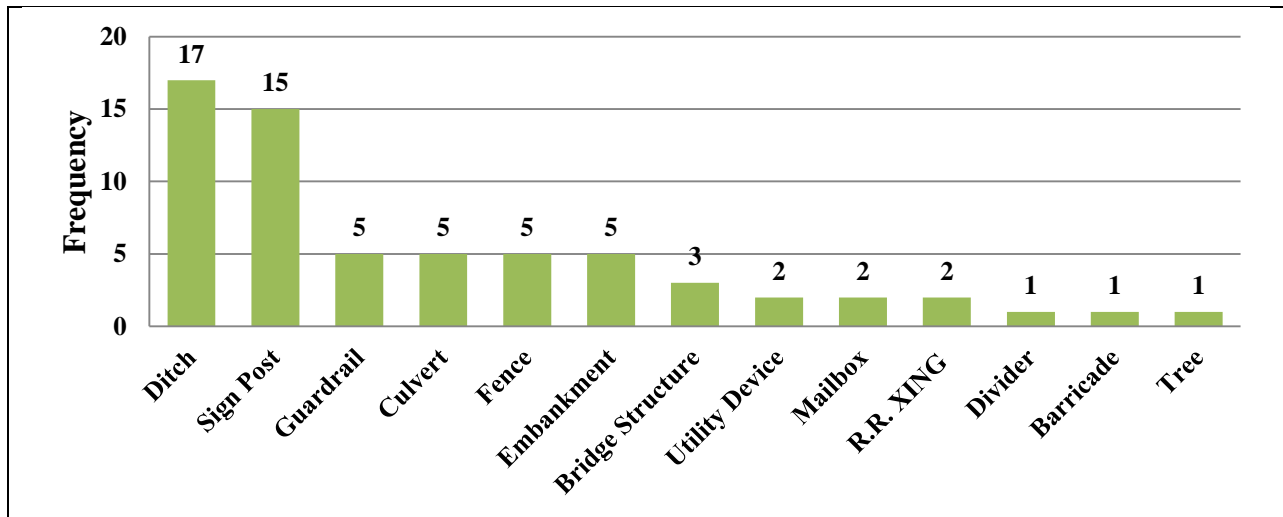


Figure 5.1 Single-vehicle fixed object collision type

As seen in figure 5.2, the most common single-vehicle truck fixed object crash collision type on the state highway system was with either a sign post or ditch. Typical of many rural two-lane highways, highway signs are located in narrow, clear zones and are typically unprotected. Results of the investigated collision types for multi-vehicle crashes involving at least one truck are shown in figure 5.3.

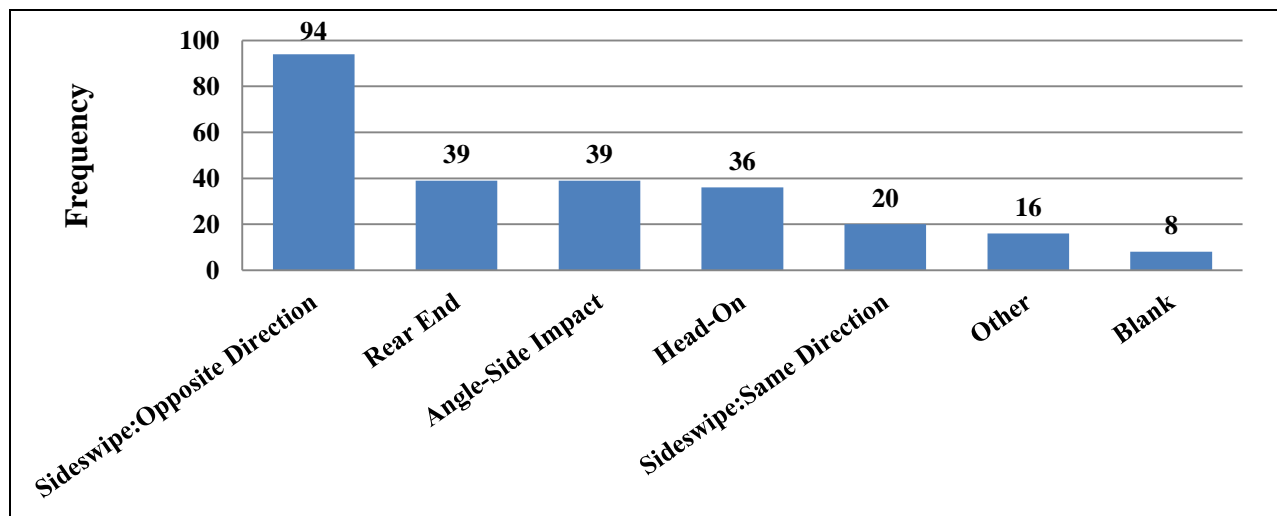


Figure 5.2 Multi-vehicle collision type

As shown in figure 5.3, the most common type of multi-vehicle crash involving at least one truck was sideswiping another vehicle in the opposing direction, with the second most common type of crash being an angle-side impact or rear-end crash. The high numbers of sideswipe opposing-vehicle crashes were expected at two-lane rural horizontal curves. It is speculated that these crashes involved the truck driver failing to maintain proper speed and lane position through the curve. The higher truck speed at the horizontal curve most likely resulted in centripetal force pushing the vehicle towards the outside of the curve. It is speculated that the truck driver either corrected this action by crossing the centerline, or the rear trailer carriage off-tracked through the curve, posing a dangerous situation for opposing vehicle. Consequently, the vehicle in the opposing direction may not have had enough lane width to maintain a safe distance from the opposing truck, resulting in an opposing side-swipe crash. The crash data were further reduced to investigate environmental factors related to single-vehicle truck and multi-vehicle crashes involving at least one truck. Shown in figure 5.4 are the surface conditions at the horizontal curve at the time of the crash.

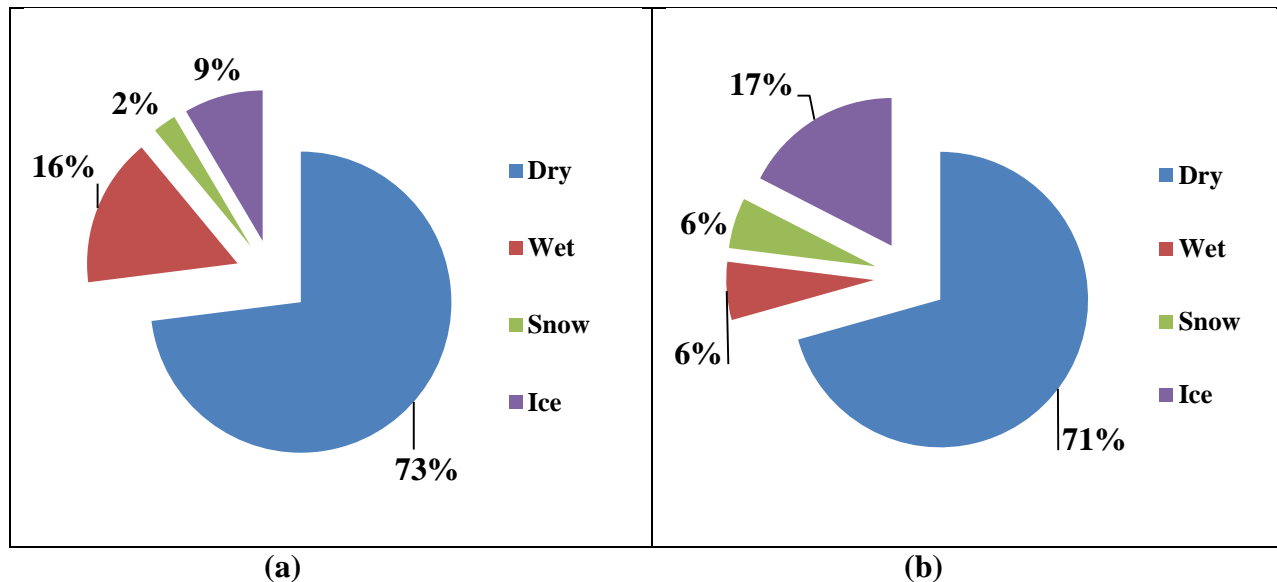


Figure 5.3 (a) Road surface conditions at the time of crash for single-vehicle truck and (b) multi-vehicle involving a truck

As shown in figure 5.4, over 70 percent of both types of truck crashes occurred on dry pavement, which indicates that surface conditions were not a significant factor in the occurrence of a crash. However, it was found that wet pavement conditions existed during more single-vehicle truck crashes than multi-vehicle crashes, indicating the possibility that truck drivers were more likely to slow or to maintain control at the curve site due to pavement conditions.

Figure 5.5 shows the time of the day the crashes occurred.

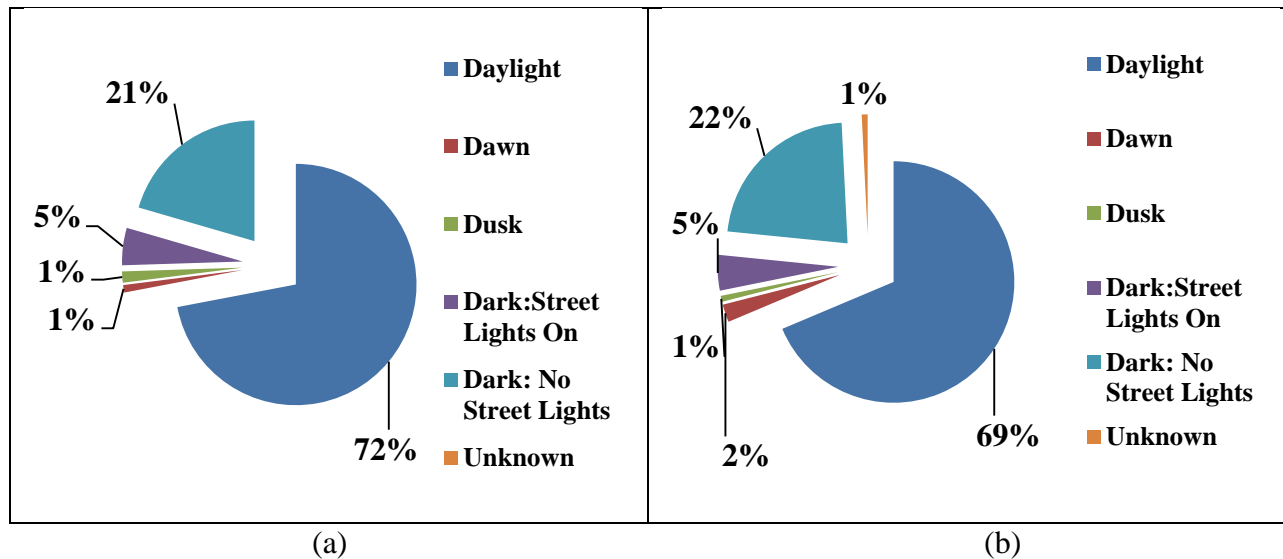


Figure 5.4 (a) Lighting conditions at the time of crash for single-vehicle truck and (b) multi-vehicle involving a truck

In figure 5.5, over 69 percent of single-vehicle truck and multi-vehicle crashes involving at least one truck occurred during daylight hours. The second highest time period was at dark without street lights. The results of both figures 5.4 and 5.5 indicate that a high percentage of crashes at horizontal curves involving trucks occurred during normal conditions of daytime and dry pavement. This indicates that other factors may have influenced the crash experience, including geometry, driver behavior, or other variables that could not be quantified in this study (e.g. driver training, experience, vehicle mechanical conditions).

5.2 Simple Odds Ratio

In addition to investigating the descriptive statistics of identified horizontal curve single-vehicle and multiple-vehicle truck crashes, a simple odds ratio analysis was performed to identify factors that related to these crashes. The odds ratio allows for only two responses respective to a variable, typically being “yes” or “no” (e.g. injury crash or not an injury crash). The crash and roadway data provided by the KDOT included several categorical variables that were of interest to the research team, which included several possible responses. If the responses

had a large number of crash observations, then an odds ratio was determined for each response. If a categorical variable had responses with few or no crash observations, then the responses were combined. For instance, “Light Conditions” included six responses (daylight, dawn, dusk, dark: street, dark: no street, unknown). Since there were a limited number of crash observations in “dawn,” it was combined with “daylight” to create the variable “day.” A similar procedure was utilized for the variable “shoulder width,” where there were four possible numerical responses. These four numerical responses were divided into two possible outcomes, including “less than or equal to 2 feet,” and “greater than 2 feet.”

Simple odds ratios were calculated for horizontal curve crashes for selected variables provided by the KDOT’s crash and roadway geometry database, using equation 5.1.

$$OR = \frac{\left(\frac{CrashI_j}{CrashI_k}\right)}{\left(\frac{CrashII_j}{CrashII_k}\right)} \quad (5.1)$$

where,

OR = odds ratio;

$CrashI_j$ = number of Type I crashes for response j ;

$CrashI_k$ = number of Type I crashes for response k ;

$CrashII_j$ = number of Type II crashes for response j ; and

$CrashII_k$ = number of Type II crashes for response k .

For this analysis, $CrashI$ and $CrashII$ represented either the number of single-vehicle or multi-vehicle crashes at horizontal curves in Kansas. A 95 percent confidence interval was developed for each variable in odds ratio equations 5.2 and 5.3.

$$\begin{aligned} & \text{Lower and Upper Limit of Confidence Interval} \\ & = OR \times e^{(\pm z \times VAR)} \end{aligned} \quad (5.2)$$

where,

$$VAR = \sqrt{\left(\frac{1}{CrashI_j}\right) + \left(\frac{1}{CrashI_k}\right) + \left(\frac{1}{CrashII_j}\right) + \left(\frac{1}{CrashII_k}\right)}; \text{ and} \quad (5.3)$$

z = z-statistic given in the selected confidence interval ($z=1.96$ for 95 percent confidence interval).

Odds ratios and their respective 95 percent confidence intervals were calculated separately for truck drivers involved in single-vehicle crashes and multiple-vehicle crashes at horizontal curves. An odds ratio greater than one for a single-vehicle crash indicated that the odds of a positive response were higher for single-vehicle crashes at a horizontal curves than that for multi-vehicle crashes at horizontal curves. The same could be implied in the case of an odds ratio greater than one for a multi-vehicle crash at a horizontal curve. In other words, the strength of association increases with deviation from one. The 95 percent confidence level indicates statistical significance where the “true” odds ratio is the determined minimum and maximum values. The results of the analysis are shown in table 5.2.

Table 5.1 Simple odds ratios and 95 percent confidence intervals

Variable	Description	Odds ratio, (95% Confidence Intervals)	
		Single-Vehicle	Multi-Vehicle
Wet Pavement	Crash occurred on a curve that was wet (rain, snow, ice)	0.88 (0.58, 1.34)	1.12 (0.74, 1.69)
Shoulder Width	Crash occurred on a curve with shoulder having width less than or equal to 2 feet	4.12 (2.74, 6.19)	0.24 (0.16, 0.36)
Rumble Strip	Crash occurred on a curve with right-side edge rumble strips	0.30 (0.19, 0.47)	3.25 (2.09, 5.04)
Day	Crash occurred during daylight hours	1.07 (0.71, 1.63)	0.92 (0.61, 1.40)
Weather	Crash occurred during adverse weather conditions	0.72 (0.21, 1.09)	1.37 (0.91, 2.06)
Posted Speed	Crash occurs on curve with posted speed limit under 55 mph	1.78 (1.06, 2.97)	0.56 (0.33, 0.93)
Fatal	crash resulted in a fatality	0.21 (0.07, 0.54)	4.87 (1.84, 12.86)
Injury	Crash resulted in an injury	1.65 (1.30, 2.41)	0.61 (0.41, 0.88)
PDO	Crash resulted in property damage	0.73 (0.50, 1.07)	1.36 (0.93, 1.99)

Note: Bold indicates odd ratio in which 1 is not included in the 95% confidence interval

As shown in table 5.2, truck drivers that were involved in single-vehicle crashes at horizontal curves were 4.12 times more likely than truck drivers involved in multi-vehicle crashes at horizontal curves to experience a crash at curve sites with a shoulder width of less than two feet. Truck drivers involved in single-vehicle crashes at horizontal curves were 1.78 times more likely to be involved in a crash at a curve site with a posted speed limit of less than 55 mph, and 1.65 times more likely to experience an injury as a result of the crash, than were truck drivers involved in multi-vehicle crashes.

As shown by the odds ratios for multiple-vehicle crashes involving at least one truck at horizontal curves, these types of crashes were 3.25 times more likely to occur with the presence

of rumble strips. Also, large truck multi-vehicle crashes were found more likely to be fatal (OR = 4.87) than single-vehicle truck crashes.

Chapter 6 Discussion

This research effort sought to investigate factors that contributed to large truck crashes at rural two-lane highways in Kansas. Large trucks intensify the crash experience with their size and weight, and, when involved in a multi-vehicle crash scenario, can result in dangerous crashes for all involved. Single-vehicle crashes at horizontal curves can often be attributed to driver error, including not identifying the change in horizontal alignment, improper lane keeping, and speed prior to and while negotiating the curve.

This study investigated single-vehicle truck crashes and multi-vehicle crashes involving at least one truck at horizontal curves in rural Kansas. Horizontal curves of interest were on the state highway system at least two miles outside of an incorporated area. A total of 425 truck-related crashes were extracted from the state crash database, and variables noted on the crash report were analyzed. The data were divided between single-vehicle truck crashes and multi-vehicle crashes that involved at least one truck. Severity was extracted, and it was found that overall, truck crashes at rural Kansas horizontal curves were decreasing, however a substantial number of crashes resulted in property damage and injuries. It was also found that crashes involving multiple vehicles incurred a higher number of fatalities, most likely due to the number of vehicles and drivers/occupants involved in the crash. Finally, it was found that single-vehicle truck crashes were more likely to result in injuries due to run-off-road crashes.

In investigating environmental factors, it was found that many of the crashes occurred during daylight hours and on dry pavement. This indicates that a high number of crashes may be due to factors that cannot be measured by a crash report. For example, from the data that the research team received, it was impossible to determine whether the truck had pre-existing

mechanical conditions (tire wear, suspension or air brake issues), if the driver was fatigued, or how much experience he/she had.

Simple odds ratios, along with the construction of 95 percent confidence levels were developed to further compare select factors with crash type. An odds ratio analysis was chosen due to the limited sample size of crashes at rural horizontal curves. The analysis provided the likelihood of an event occurring for a crash case as compared to a second crash case given a “yes” or “no” response. The 95 percent confidence level provided an interval where the true ratio was expected. It was found that four factors for both multi-vehicle crashes involving one truck and single vehicle truck crashes that the 95 percent confidence interval included 1. This indicated there was a chance that the identified factor may or may not have been as likely to occur when comparing the two types of truck crashes. Significant results of the analysis indicated that:

- A fatality (OR = 4.87) and the presence of shoulder rumble strips (OR = 3.25) were more likely to occur in a multi-vehicle crashes involving trucks at curves;
- A single-vehicle truck crash was 1.65 times more likely to result in an injury; and
- A single-vehicle truck crash was 4.12 times more likely to occur on narrow shoulders with a posted speed limit under 55 mph (OR = 1.78).

As stated previously, limited research is currently available that targets truck crashes at rural horizontal curves. Based on the initial analysis of truck crashes at horizontal curves in Kansas, the odds ratio and descriptive statistics indicated factors that were more likely to be present or contribute to the crash envelope. Knowing these factors, additional research could target the concentration areas by investigating low-cost countermeasures at these locations, and can also assist KDOT in evaluating these areas through programs such as road safety audits and targeted enforcement.

References

1. Federal Motor Carrier Safety Administration. 2011. "Large truck and bus crash facts 2009." *Report FMCSA-RRA-11-25*, Federal Motor Carrier Safety Administration, United States Department of Transportation, Washington, D.C.
2. United States Government Accountability Office. 2007. "Report to Congressional Requesters—Motor carrier safety: A statistical approach will better identify commercial carriers that pose high crash risks than does the current Federal approach." *Report GAO-07-585*, Government Accountability Office, Washington, D.C.
3. Torbic, D. J., D. W. Harwood, D. K. Gilmore, R. Pfefer, T. R. Neuman, K. L. Slack, and K. K. Hardy. 2004. "A guide for reducing collisions on horizontal curves." *NCHRP Report 500 Volume 7*, Transportation Research Board, National Research Council, Washington, D.C.
4. Campbell, J. L., C. M. Richard, and J. Graham. 2008. "Human factors guidelines for roadway systems." *NCHRP Report 600B*, Transportation Research Board, National Research Council, Washington, D.C.
5. Staplin, L., K. Lococo, S. Byington, and D. Harkey. 1977. "Field evaluation of selected delineation treatments on two-lane rural highways." *Report FHWA-RD-77-118*, Federal Highway Administration, United States Department of Transportation.
6. Chira-Chavala, T., and D. E. Cleveland. 1985. "Causal analysis of accident involvements for the nation's large truck and combination vehicles." *Transportation Research Record*, 1407: 56-64.
7. Gander, P. H., N. S. Marshall, I. James, and L. L. Quesne. 2006. "Investigating driver fatigue in truck crashes: Trial of a systematic methodology." *Transportation Research Part F: Traffic Psychology and Behavior*, 9, no. 1: 65-76.
8. Hanowski, R. J., M. A. Perez, and T. A. Dingus. 2005. "Driver distraction in long-haul truck drivers." *Transportation Research Part F: Traffic Psychology and Behavior*, 8, no. 6: 441-458.
9. TranSafety Reporter. 1998. "Trucker survey highlights causes of drowsy driving and suggests preventive measures." *U.S. Roads, Road Injury Prevention Litigation Journal*, 16, no. 3: 5-7.
10. McCartt, A. T., J. W. Rorbaugh, M. C. Hammer, and S. Z. Fuller. 2000. "Factors associated with falling asleep at the wheel among long distance truck drivers." *Accident Analysis and Prevention*, 32, no. 4: 493-504.

11. Polus, A. and D. Mahalel. 1985. "Truck impact on roadway safety." *Transportation Research Record*, 1047: 65-71.
12. Agent, K. R. and J. G. Pigman. 2002. "Investigation of the impact of large trucks on highway safety." Kentucky Transportation Center, University of Kentucky, Lexington, KY.
13. Zegeer, C. V., D. W. Reinfurt, W. W. Hunter, J. Hummer, R. Stewart, and L. Herf. 1988. "Accident effects of side slope and other roadside features on two-lane roads." *Transportation Research Record*, 1195: 33-47.
14. Spainhour, L. K., D. Brill, J. O. Sobanjo, J. Wekezer, and P. V. Mtenga. 2003. "Evaluation of traffic crash fatality causes and effects: A study of fatal traffic crashes in Florida from 1998-2000 focusing on heavy truck crashes." Florida A&M University / Florida State University, Tallahassee, FL.
15. Steiff, H. H. 1990. "Status report on large truck safety." *Transportation Quarterly*, 44: 37-50.
16. Khattak, A. J., R. J. Schneider, and F. Targa. 2002. "A comparison of rollovers with non-rollovers and analysis of injury severity in large truck crashes." Southeastern Transportation Center, University of Tennessee, Knoxville, TN.
17. Khattak, A. J., R. J. Schneider, and F. Targa. 2003. "Risk factors in large truck rollovers and injury severity: Analysis of single-vehicle collisions." Presented at the 82nd Annual Meeting of the Transportation Research Board, Washington, D.C.
18. Zegeer, C. V., D. Reinfurt, T. Neuman, R. Stewart, and F. Council. 1990. "Safety improvements on horizontal curves for two-lane rural roads - Information guide." *Report FHWA-RD-90.021*, Federal Highway Administration, United States Department of Transportation, Washington, D.C.
19. Zegeer, C. V., R. Stewart, D. Reinfurt, F. Council, T. Neuman, E. Hamilton, T. Miller, and W. Hunter. 1990. "Cost-effective geometric improvements for safety upgrading of horizontal curves." *Report FHWA-RD-90-021*, Federal Highway Administration, United States Department of Transportation, Washington, D.C.
20. Hallmark, S. L., Y.-Y. Hsu, T. H. Maze, T. McDonald, and E. Fitzsimmons. 2009. "Investigating factors contributing to large truck lane departure crashes using the Federal Motor Carrier Safety Administration's Large Truck Crash Causation Study (LTCCS) Database." Center for Transportation Research and Education, Iowa State University, Ames, IA.
21. Iragavarapu, V. 2007. "Examining potential factors affecting the safety performance and design of exclusive truck facilities." (Master's Thesis Texas A&M University, College Station, TX).

22. Schneider, W. H., K. H. Zimmerman, D. Van Boxel, and S. Vavilikolanu. 2009. "Bayesian analysis of the effect of horizontal curvature on truck crashes using training and validation data sets." *Transportation Research Record*, 2096: 41-46.