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Evaluation of Large-Truck Fixed-Object Crashes at Bridge Structures in Kansas

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16. Abstract

The aim of this study was to investigate any possible relationships between roadway geometry, pavement conditions, and large-truck, fixed object crashes at bridge sites. Data on single-vehicle and multiple-vehicle large-truck crashes were extracted from the Kansas Department of Transportation's crash and roadway database for a five year study period (2006-2010). This analysis was limited to bridge sites located on state and federal roadways in both rural and urban environments. A total of 77 crashes were extracted, in which 73 were single-vehicle run-off-the-road crashes where a large-truck struck a fixed object at or very close to the bridge site. Due to the limited sample size, a simple odds ratio analysis was used to evaluate the crash data. Because no fatalities were reported, the likelihood of an injury crash or a property damage only crash were tested. The results of the simple odds ratio analysis showed that the odds of an injury resulting from a fixed-object crash were 4.93 times higher on a limited access facility. This finding was statistically significant at the 95% level of confidence, while all other tested variables were found to be non-significant.

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List of Abbreviations

American Association of State Highway and Transportation Officials (AASHTO)
Highway Safety Information System (HSIS)
Kansas Department of Transportation (KDOT)
Maryland Automated Accident Reporting System (MAARS)
Mid-America Transportation Center (MATC)
National Bridge Inventory database (NBI)
Property Damage Only (PDO)

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Disclaimer

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Abstract

The aim of this study was to investigate any possible relationships between roadway geometry, pavement conditions, and large-truck, fixed object crashes at bridge sites. Data on single-vehicle and multiple-vehicle large-truck crashes were extracted from the Kansas Department of Transportation's crash and roadway database for a five year study period (2006-2010). This analysis was limited to bridge sites located on state and federal roadways in both rural and urban environments. A total of 77 crashes were extracted, in which 73 were single-vehicle run-off-road crashes where a large-truck struck a fixed object at or very close to the bridge site. Due to the limited sample size, a simple odds ratio analysis was used to evaluate the crash data. Because no fatalities were reported, the likelihood of an injury crash or property damage only crash were tested. The results of the simple odds ratio analysis showed that the odds of an injury resulting from a fixed-object crash were 4.93 times higher on a limited access facility. This finding was statistically significant at the 95 percent level of confidence, while all other tested variables were found to be non-significant.

Chapter 1 Introduction

1.1 Background

Large-truck crashes on high-speed roadway facilities pose a serious safety concern due to the mass and high center of gravity of large-trucks. The United States Department of Transportation estimated that 3,215 fatal crashes and 53,000 injury crashes involved large trucks in 2009. Crashes involving large trucks are of particular concern to state highway agencies when the tractor and/or trailer departs the travel lane and strikes a fixed object. To minimize the chances of a fixed object strike by a large truck or any other vehicle, roadway clear zone guidelines are in place by the American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide*. This publication provides guidance on clear zone distances for fixed and breakaway objects, and also provides recommendations on countermeasures to prevent errant vehicles from departing the roadway.

1.2 Literature Review

Critical bridge components are often located in the roadway clear zone, and constitute a hazard, especially for large trucks, since lateral clearance may be limited depending on the type and location of the bridge. Fixed-object features for bridges typically found in the clear zone include bridge rails, guardrails, headwalls, abutments, or piers located in the median and on the edge of the roadway. Fixed objects in proximity of the bridge, such as medians, piers, or the ends of bridge rails and guardrails, are often protected by a crash attenuator. Figure 1.1 shows an example of a set of bridge piers protected by a rigid longitudinal barrier that can withstand the impact of a large truck or an errant vehicle of any other size.

Figure 1.1 Box beak longitudinal barrier (AASHTO 2004)

Limited research has directly investigated large-truck, fixed-object crashes at bridge sites. In terms of fixed object strikes by large trucks, Chen (1996) indicated through an investigation of the FARS database from 1975 to 1989 that 20 percent of fatal large truck crashes on highways involved striking a fixed object. Krishnaswami and Blower (2003) further investigated aspects of truck-related crashes, finding that larger fixed objects, including buildings and bridge structures (abutments, piers, and embankments), were associated with serious injury to drivers.

Holdridge et al. (2005) developed multivariate nested logit models to identify significant variables that effected vehicle crash severity when roadside fixed objects were struck. Crash data from the state of Washington were obtained for the years 1993 to 1996, comprising all vehicle types, for vehicles that were involved in single vehicle crashes characterized by run-off-road or collision with a fixed object. The crash data included in the study indicated that 8.2 percent of vehicle crashes occurred in urban areas in the presence of a bridge structure. Models indicated that vehicle crashes involving bridge abutments, columns, and piers were expected to have a higher crash severity than crashes involving other roadside fixed objects. When the authors further investigated vehicle type in the models, they found that crash severity

decreased when a light truck was involved in a crash, and property damage increased only when a large truck was involved in the crash.

Using data from Minnesota and Texas, Buth et al. (2010) investigated 32,934 large-truck, run-off-road crashes that involved striking a bridge structure. Two statistical models were developed to evaluate the risk of large-truck crashes characterized by striking either a bridge pier or abutment. The developed models assumed the crash risk involving a single bridge that crossed a highway. Crash risk was estimated using a negative binomial regression as a function of large-truck exposure and roadway geometry variables. The results of both analyses indicated that large trucks were more likely to strike a bridge if the structure was located on a horizontal curve. Additionally, the developed models indicated that lane width, shoulder width, and bridge density were statistically significant variables.

Fixed-object collisions at bridge sites occur not only when the vehicle departs the roadway into the clear zone, but they also sometimes occur when vehicle dimensions may pose a risk for fixed-object collisions with a bridge structure. Fu et al. (2004) investigated large-truck crashes in Maryland in cases where the involved truck and/or trailer was found to be over-height. The researchers compiled six years of crash data (1995 to 2000) using the Maryland Automated Accident Reporting System (MAARS) and bridge inspection reports. During the study period, it was found that most over-height vehicles detected by sensors did not have a permit. The number of bridge strikes increased over the study period. It was also found that approximately one out of every five overpasses in Maryland had been struck at some point, with one-half showing scrapes, one- third showing minor damage, and one-sixth needing repairs. Based on the identified literature, limited information is available that specifically identifies large-truck, fixed-object

crashes at bridge sites. This research is of great importance to Kansas, a state which provides multiple vital routes for the transcontinental trucking of goods across the United States.

1.3 Scope of Project

The state of Kansas includes an extensive state and federal highway system with over 9,500 miles of centerline miles, including 5,047 functional bridges in rural and urban environments on both roadway systems. In particular, large trucks are frequently found on these two roadway networks, and provide critical movements of goods within and through Kansas. Many of the large truck trips occurring in Kansas will pass through, terminate, or end in the Kansas City metropolitan area, which is a port city. This exploratory investigation was designed to target large-truck, fixed-object crashes that have occurred at bridges located on the state and federal highway roadway networks. Using the extrapolated data, secondary objectives included determining the quality and quantity of the crash type data available through the Kansas Department of Transportation (KDOT), and determining whether statistical analyses could be performed. The results of the investigation are expected to provide critical information as to any locations, types, or variables common to the extracted large-truck crashes.

Chapter 2 Data Description

Because the state of Kansas is not included in the Highway Safety Information System (HSIS), multiple data sources within KDOT were utilized for the current study. The roadway network database included roadway features (shoulder type and width, presence of rumble strips, roadway classification, traffic volumes, and geometric features such as curves and intersections). Large truck crash data were mined from the KDOT crash database. As stated previously, crashes considered for this study included those that involved at least one large truck as a vehicle within the crash envelope (with the understanding that a multiple-vehicle crash could include passenger cars or other types of vehicles). Primary causes for multiple-vehicle crashes were unknown for this study, and it was assumed that this would not affect the results of the investigation. Large-truck, fixed-object bridge crashes were extrapolated for both rural and urban environments, which included incorporated areas in Kansas. The crash query was limited to roads in Kansas which the research team believed most of the large truck traffic would occur; this included only the federal interstate and state highway road networks.

To identify crashes specifically occurring at bridge sites, the KDOT crash database included a field that identified whether the crash occurred within a 50 meter radius of a bridge structure. A 50 meter radius was assumed to include any bridge structure, guardrail, bridge rail, cable barrier, or earth embankment that may have been present. Crashes at bridge structures on state highways are generally identified both in the field by the reporting police officer and/or by KDOT crash coding officials who compare latitude/longitude values and the roadway milepost with known bridges in the state. Bridges that were considered and identified for this study are currently inspected regularly (every four years for culverts, two years for bridges, and annually

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for bridges with known deficiencies), and are listed in the National Bridge Inventory database (NBI).

To further refine the database query, crashes were considered only if the most harmful event in the crash envelope included a large-truck striking a fixed-object at the bridge site. A fixed object was defined as one, or a combination of, the following: striking the bridge rail, striking the guardrail (prior to the bridge rail, pier, or embankment) or striking the bridge embankment or structure.

Once the final dataset was determined, key variables were extracted for further analysis, including latitude and longitude, environmental conditions, roadway geometry, and sequence of events. These variables were targets for analysis by the research team using descriptive and statistical tests. One significant limiting factor that was identified by the research team early in the data processing stage was the fact that KDOT database does not include an indicator variable defining where at the bridge a crash occurred. For example, if a state highway tangent crossed over a federal interstate tangent via a bridge, and a large-truck crash was identified, there would be limited knowledge of whether the crash occurred on the crossing state highway or on the federal interstate system. Although this limitation was noted by the research team, it was determined that useful information could be produced by the analysis without taking this variable into account.

Chapter 3 Data Analysis

3.1 Descriptive Statistics

Using the parameters stated in the previous section, five years of Kansas data were investigated (2006-2010). A total of 77 large-truck, fixed-object crashes at bridge sites were found in which the officer or KDOT crash coder stated that the crash occurred at or very near a bridge. Using the latitude and longitude of each crash observation, a map (figure 3.1) was developed to illustrate where these crashes occurred around the state of Kansas.
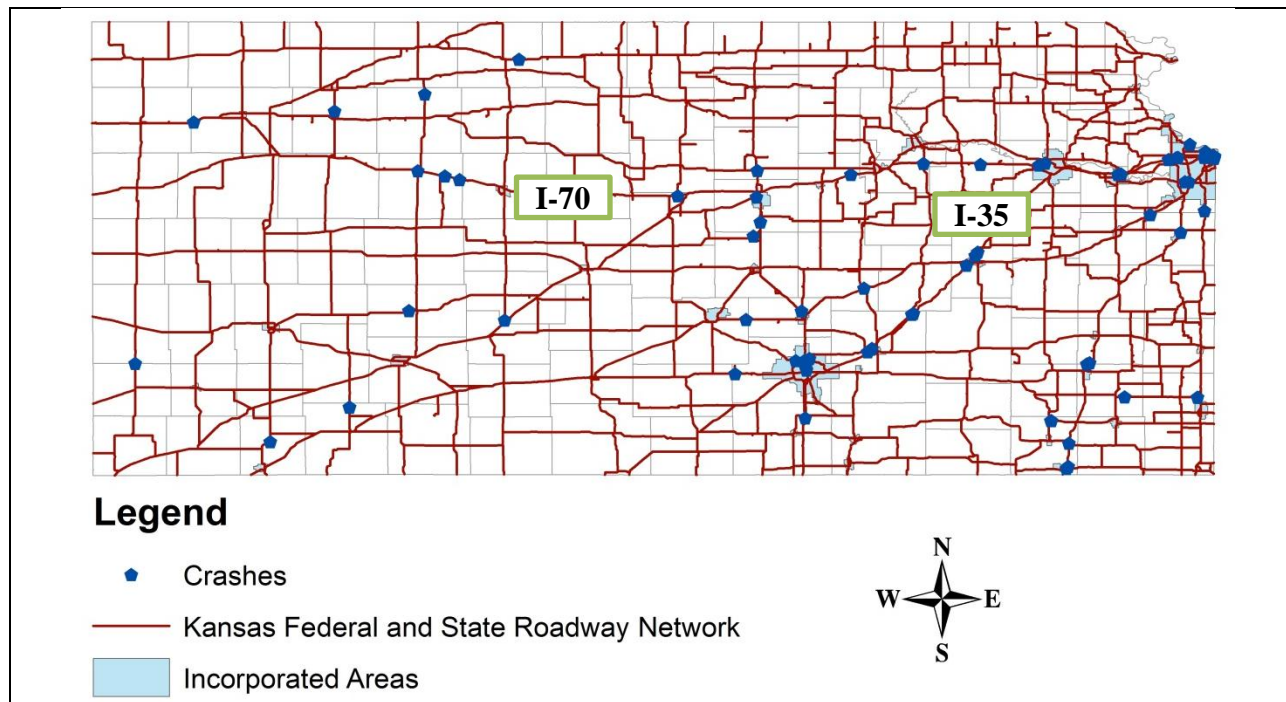

Figure 3.1 Large-truck crashes at bridges on the Kansas state highway and federal interstate network (2006 to 2010)

As illustrated in figure 3.1, a significant number of crashes occurred within incorporated areas (the Kansas City metropolitan area, Topeka, and Wichita). This was expected, as these cities have a large number of bridges adjacent to natural features (rivers) and convergences of highway systems and local roads. However, many of the identified crashes occurred in rural Kansas along Interstate 70 and Interstate 35, which are routes between major cities or state borders. Of the 77 total crashes identified for this investigation, 73 were identified as single-vehicle crashes where the large truck departed the roadway and the most harmful event was striking a fixed object. Four crashes were identified as multiple-vehicle crashes in which at least one of the vehicles was a large truck. The large truck in the multiple-vehicle crashes was identified as the primary vehicle to hit a fixed object. Table 3.1 summarizes single-vehicle and multiple-vehicle crash severity for the five years that were studied.

Table 3.1 Summary of total truck-bridge fixed-object crashes per year and severity

Year	Total Number of Crashes	Fatality	Injury	Property Damage Only
2006	14	0	6	8
2007	19	0	8	11
2008	14	0	5	9
2009	9	0	1	8
2010	21	0	5	16
Total	77	0	25	52

As shown in table 3.1, the highest number of crashes (21) occurred in 2010, and the lowest number of crashes (9) occurred in 2009. Also shown in table 3.1, these types of large-truck crashes resulted in 0 fatalities, 25 injuries, and 52 property damage only crashes. This indicates that when a large truck departed the roadway and struck a fixed-object, either the vehicle was moving at a low velocity or the safety devices (e.g., guardrail, bridge rail, or cable barrier) performed correctly. One important aspect of this study was to determine whether other factors, including roadway surface conditions or roadway geometry, contributed to the severity of the crashes. Figure 3.2 summarizes these variables for the 77 identified crashes.

(a)   (b)
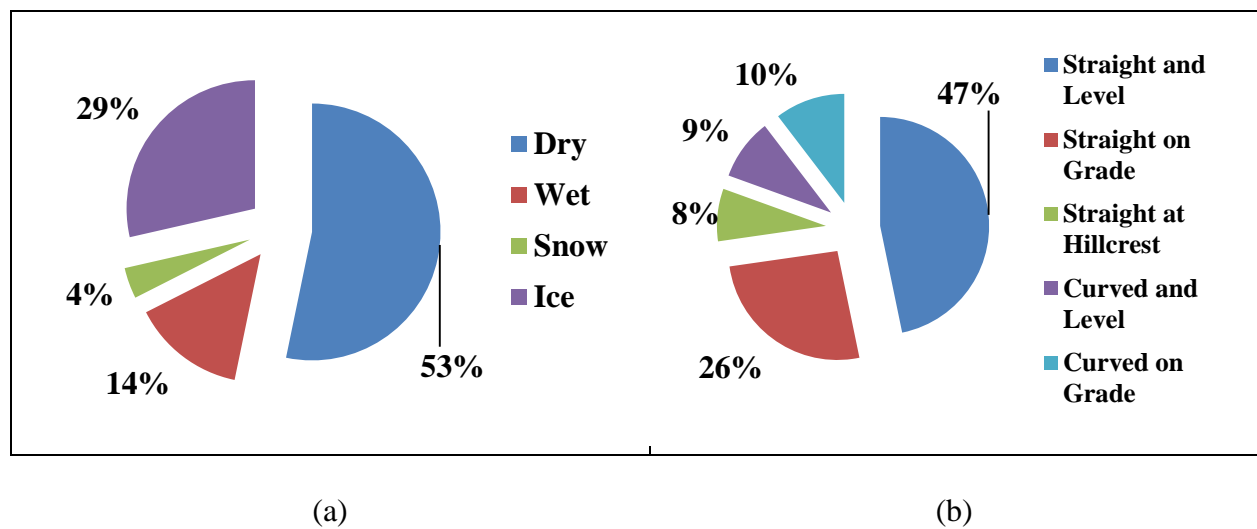
Figure 3.2 (a) Road surface conditions at the time of crash and (b) road alignment characteristics

As shown in figure 3.2(a), approximately 53 percent of crashes occurred during dry roadway surface conditions, with the second highest percentage (29 percent) occurring on icy roadway surface conditions. This indicates that many of the crashes occurred under normal driving conditions. However, over half of the crashes occurred during non-normal roadway surface conditions. Figure 3.2(b) indicates that 81 percent of all identified crashes occurred on

straight roadways, with the highest percentage (47 percent) occurring on a level grade. This high percentage was expected, since many of the federal interstate bridges in Kansas are located on straight alignments or very large horizontal curves (that may appear to be straight tangents in the field). It should be noted that 19 percent of the identified crashes occurred at horizontal curves that included level or non-level grades.

The research team was also interested in determining what type of fixed objects the large trucks struck. This information was included in the crash narratives, and is summarized in figure 3.3.
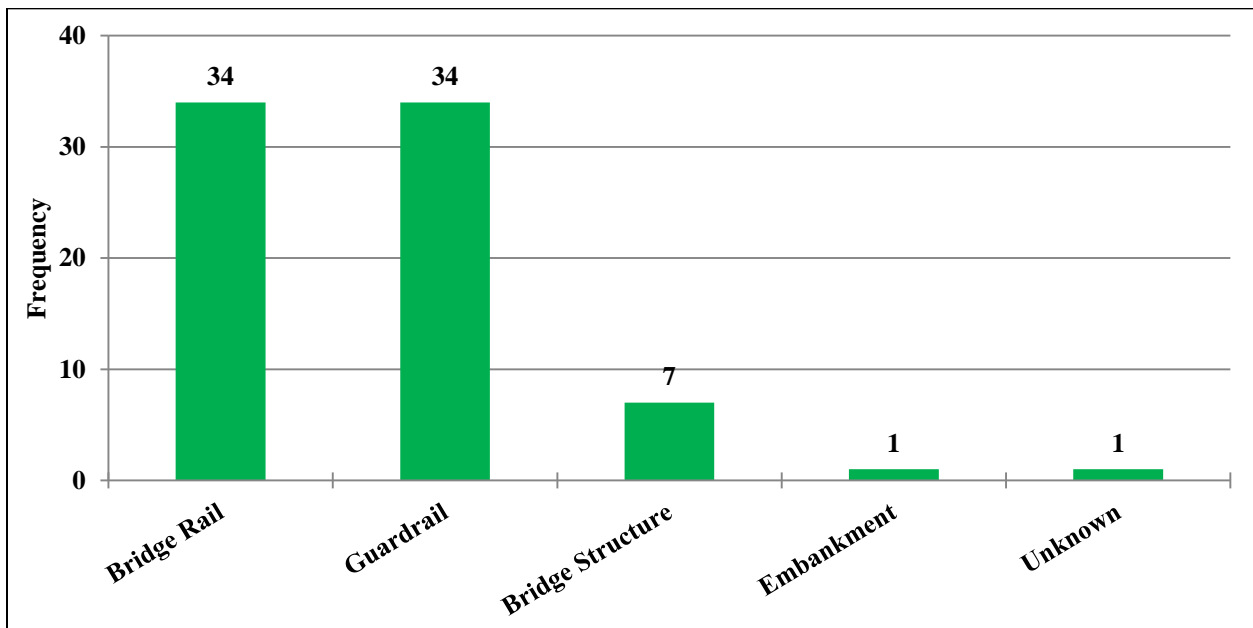
Figure 3.3 Truck crash bridge fixed-object type by most harmful event

As shown in figure 3.3, longitudinal safety barriers (bridge rail and guardrail) were found to be the most common fixed object struck by large vehicles at bridge sites. These safety devices are designed to withstand impact and redirect a vehicle, reducing the chances of a fatal crash. The second most common objects struck by large trucks were various elements of the bridge structure, which included columns, decks, and beams. One crash was observed in which a large truck struck the bridge embankment.

Aside from the type of object struck by the large truck, the research team investigated each crash sequence of events to determine which factor began the crash envelope. Illustrated in figure 3.4 is a summary of the first events of the crash sequences as determined by the reporting police officer. These do not represent the most harmful events, which are summarized in figure 3.4.
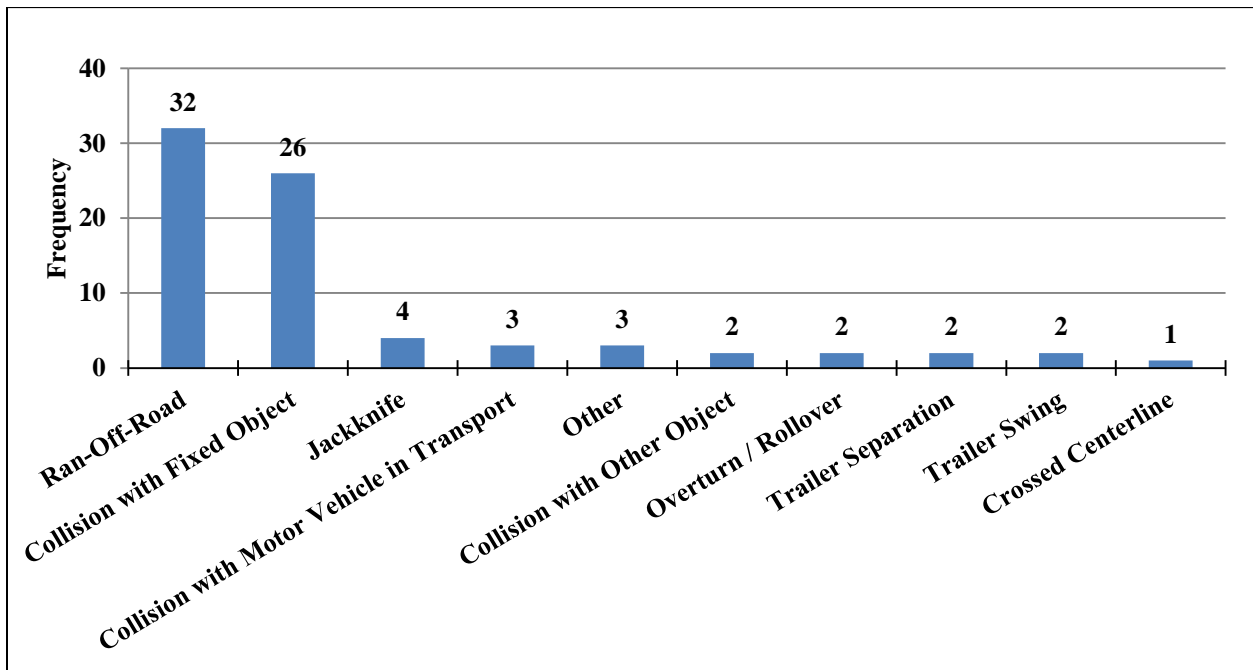
Figure 3.4 First coded entry in the sequence of events for large-truck fixed-object bridge crashes

As shown in figure 3.4, many different causes determined the beginning of a crash sequence. One important aspect to note is that, as reported by the crash narrative, 26 crashes indicated that a collision with a fixed object was the first sequence of events. A vehicle departing the roadway (i.e., running-off-road) is very common among fixed-object crashes, so this higher number was expected by the research team. In support of this expectation, the most frequent initial event reported was a vehicle running-off-road, representing 32 reported crashes. Other events reporting multiple crashes included the large truck jackknifing, or a collision with another motor vehicle.

3.2 Simple Odds Ratio

In addition to investigating trends in the crash data as described in the previous section, a simple odds ratio analysis was performed to determine which factors significantly contributed to large-truck, fixed-object crashes at bridge sites. Because only 77 crashes were observed in the five-year time period, limited statistical methods could be used to analyze the data. To overcome this identified limitation, an odds ratio analysis was utilized. An odds ratio analysis allows for two responses to a specific variable, such as "yes" or "no" (e.g., did the crash occur on dry pavement?) for a limited sample data set. As described in pervious sections, each crash observation comprised roadway and environmental conditions in which an officer had the choice of multiple conditions (or categorical variables) such as dawn, day, dusk, and night. In the cases where multiple choices were available, the research team combined the categorical variable into a binary variable. For example, a crash occurred either during nighttime or daytime conditions. Simple odds ratios were calculated for fixed-object bridge crashes for selected variables, provided by the KDOT's crash and roadway geometry database, using equation 3.1.

$$OR = \frac{\left(\frac{CrashA_j}{CrashA_k}\right)}{\left(\frac{CrashB_j}{CrashB_k}\right)} \tag{3.1}$$

where,

OR = odds ratio;

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

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

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

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

For this analysis, *CrashA* and *CrashB* represented either a fixed-object injury crash (minor, major, or incapacitating) at a bridge site, or a fixed-object property damage only (PDO) crash at a bridge site in Kansas, respectively. A 95 percent confidence interval was developed for each variable using odds ratio equations 3.2 through 3.3.

$$Lower\ and\ Upper\ Limit\ of\ Confidence\ Interval \tag{3.2}$$
$$= OR \times e^{(\pm z \times VAR)}$$

where,

$$VAR = \sqrt{\left(\frac{1}{CrashA_j}\right) + \left(\frac{1}{CrashA_k}\right) + \left(\frac{1}{CrashB_j}\right) + \left(\frac{1}{CrashB_k}\right)}\ ;\ and \tag{3.3}$$

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

Odds ratios and their associated 95 percent confidence intervals were calculated separately, then compared for fixed-object truck crashes at bridges which resulted in either an injury or PDO crash. A calculated odds ratio greater than 1 for either an injury crash or PDO crash indicated that the likelihood, or, "odds," of that type of crash were greater than those for the other type of crash being compared. Similarly, an odds ratio of less than 1 indicated that there was a lower likelihood, or odds, that the specific type or crash would occur. The strength of association of the calculated odds ratio value increases as it deviates in either direction from 1. Statistical significance is determined by the calculated 95 percent confidence intervals, which indicates where the "true" odds ratio value may be located. The results of the analysis are shown in table 3.2 (below).

Table 3.2 Simple odds ratios and 95 percent confidence intervals

Variable	Description	Odds ratio, (95% Confidence Interval)	
		Injury Crash	**PDO Crash**
Time of Day	Fixed-object bridge crash occurred during daylight hours (including dawn)	2.83 (0.72, 11.10)	0.35 (0.09, 1.38)
Weather	Fixed-object bridge crash occurred under adverse weather	0.66 (0.22, 1.98)	1.50 (0.50, 4.45)
Pavement	Fixed-object bridge crash occurred on dry roadway pavement	0.87 (0.29, 2.55)	1.14 (0.39, 3.37)
Alignment	Fixed-object bridge crash occurred on a straight alignment (includes hillcrest, grade and level)	1.36 (0.33, 5.63)	0.73 (0.17, 3.01)
Posted Speed	Fixed-object bridge crash occurred on a roadway with a posted speed limit equal to or greater than 55 mph	1.65 (0.31, 8.63)	0.60 (0.11, 3.13)
Right Shoulder	Fixed-object bridge crash occurred on a roadway where the right shoulder was equal to or greater than 2 feet	5.21 (0.62, 43.52)	0.19 (0.02, 1.60)
Access	Fixed-object bridge crash occurred on a full access controlled facility (highway with limited access)	**4.93 (1.09, 23.86)**	**0.20 (0.04, 0.97)**

Note: Bold indicates the odds ratio was found to be significant at the 95 percent level of confidence

As shown in table 3.2, as a result of the limited sample size, it was found that all but one of the variables selected to be analyzed were not significant at the 95 percent level of confidence, due to the constructed confidence level including the value of 1. The sole variable that was found to be significant at the 95 percent level of confidence was "Access," or, whether the fixed-object crash occurred on a full access controlled facility or a highway. The analysis indicated that an injury crash was 4.93 times more likely to occur on a full access controlled

facility. Consequently, a less serious crash (i.e., PDO) would be less likely to occur at this type

of facility.

Chapter 4 Discussion

This project investigated large-truck, fixed object crashes at bridge sites in Kansas.
These crashes were located in both rural and urban environments, including incorporated areas.
Bridges were located on both the federal interstate network in Kansas and the state highway
network. Data from a total of 77 crashes were gathered, including both single-vehicle and
multiple-vehicle crashes. In cases of multiple-vehicle crashes, at least one of the vehicles in the
crash was required to be a large truck that struck a fixed object. Additionally, roadway and
environmental factors were determined for each extracted crash. Such variables included
lighting, surface conditions, alignment type, access control, and posted speed limit. Other
variables were provided; however, they were not included in the analysis if a large number of
blanks were found in the data. Crash severity was also analyzed. It was found that zero fatalities
occurred during the five-year study period, and that PDO crashes were the most common crash
severity type. This finding alone is an excellent indicator that truck crashes at bridge sites in
Kansas are typically not severe, and that existing safety devices are protecting truck drivers and
other motorists.

Upon investigating specific roadway and environmental factors using descriptive
statistics, it was found that 53 percent of crashes occurred on dry pavement surfaces, indicating
that the driver lost control of the truck and struck a fixed object. It should be noted that a large
percentage of the crashes occurred when the pavement surface was non-normal, indicating that
weather conditions may have a significant role in the occurrence of crashes. It was also found
that many of the crashes occurred on straight tangents, with only 19 percent of the crashes
occurring on horizontal curves. This was expected by the research team since most bridges in
Kansas exist on straight tangent sections of roadway. In investigating which specific fixed

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objects were struck by large trucks at the bridge sites, bridge rail and guardrail were found to be the most prevalent. Seven crashes were specifically coded as striking the bridge structure, including the embankment. The research team believes these crashes would have been serious had these safety devices not been installed at the bridge sites. The crash envelope first sequence of events for each crash was also investigated. Although this variable was derived from information recorded by the officer at the scene and/or by crash coding staff, most of the crashes indicated that run-off-road occurrences and collisions with fixed objects were the two most common first sequences of event entries. A large vehicle running off the roadway indicates that improper speed, position within the lane, distraction, or cargo shift may have contributed to the crash, as these are common variables found in other research studies when examining roadway departure crashes.

Because only 77 crashes were found that were met the study extraction criteria, limited statistical analyses could be performed to further investigate the crash data or predict a crash based on the given variables. A simple odds ratio analysis was used to determine the likelihood of an injury or PDO crash occurring as the result of a fixed-object crash by a large truck. Seven variables were investigated during the analysis, in which a "yes" or "no" answer was used to describe the variable. Additionally, the variables selected for investigation had a response from the officer or crash coder, and no blanks or unknown entries were observed. An odds ratio was determined for each variable and crash severity, along with a 95 percent confidence interval. The only variable found to be statistically significant was "Access," indicating that an injury crash was more likely to result on a limited access facility or highway.

Although a simple odds ratio test was found to be appropriate for the amount and quality of the data, limited conclusions for large-truck, fixed-object crashes in Kansas can be drawn

from this study. The research team found that this specific type of crash was rare in Kansas, even on routes that were determined to be significant corridors for truck traffic. Also, based on the investigation, it appeared that among the crashes that did occur, roadside safety devices that were struck by large trucks reduced the severity of crashes. One significant limitation noted by the research team was that KDOT was unable to provide information on exactly where the large truck struck the fixed object. For example, if a state highway tangent crossed a federal highway tangent via a bridge and a crash occurred at the bridge site, the data was incapable of explaining whether the crash occurred on the state highway or the federal system. Additionally, the data did not reveal whether the crash occurred prior to the bridge, under the bridge, on a bridge on top of another roadway, or where the safety device was located. These data were not recorded on the police crash narrative because they were not inquired upon. It was also found that the sequence of events beyond 'ran-off-road' or 'struck fixed object' entries was unable to provide an answer as to why the crash occurred. Although the research team noted these limitations, it is believed that this crash analysis will aid practitioners in identifying potentially hazardous bridge sites across the state of Kansas, as well as provide background information as to which conditions, and, potentially, which contributing factors, resulted in a fixed-object crash by a large truck.

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