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Safety Evaluation of Raised Speed Limits on Kansas Freeways

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16 **Abstract**

Setting an appropriate speed limit is necessary to provide safe and efficient traffic operations for all road users. It must also be acceptable to the public and enforceable by police. Lower-than-required speed limits may make most drivers non-compliant, whereas higher-than-required speed limits may increase the number of crashes together with related injuries and fatalities. In 2011, the speed limit on a number of freeway segments in the state of Kansas increased from 70 to 75 miles per hour. The objective of this study is to evaluate the safety effects of freeway sections affected by speed limit change in Kansas. Sections where the speed limit changed from 70 mph to 75 mph and other comparable sections where the speed limit remained at 70 mph without any change were identified. Details of the crashes by severity level for 3 years before (2008–2010) and 3 years after (2012–2014) the speed limit change were collected using the state crash database. In order to get a general understanding, characteristics of crashes such as nighttime versus daytime, number of trucks involved, weather conditions, driver's gender, and other such factors were considered. Furthermore, several crash contributory causes were also investigated before and after the speed limit change. In order to evaluate the safety situation, three methods were utilized: (1) Empirical Bayes (EB) observational before-and-after studies; (2) Before-and-after method with comparison group; and (3) Cross-sectional method using the Negative Binomial (NB) regression model. The evaluation was conducted to see if the speed limit change has caused an increase in total crashes or fatal and injury crashes. In regard to speed analysis, the t-test was applied to see whether significant increases in the 85th percentile speed were observed between before-and-after conditions. Since the sample size was large, the Kolmogorov-Smirnov (K-S) test was also conducted to see if there was any difference between two sets of speed data distributions in the before period compared to the after period.

By performing the EB before-and-after study, it was seen that total crashes increased by 16 percent, while using the before-and-after method with the comparison group showed around 27 percent increase in total crashes. Total crash increases were statistically significant according to the EB method, and the before-and-after method with the comparison group. On the other hand, fatal and injury crashes increased by 35 percent based on the before-and-after with the comparison group after the speed limit change. This increase was statistically significant, but the EB method results indicated no significant increase in fatal and injury crashes when the speed limit was raised to 75 mph. Further, cross-sectional study results showed the speed limit increase had a significant effect on total crashes, an increase of 25 percent; it was also significant for fatal and injury crashes, with those increasing by 62 percent, which is the highest amount of increase compared to the EB method and the before-and-after method with the comparison group. By considering pros and cons of each methodology, it can be said that the before-and-after method with comparison group provided the most reliable results.

The t-test results showed the 5-mph increase in the speed limit caused a statistically significant increase in 85th percentile speed for the sections affected by speed limit change. However, there was also an increase for the sections without a speed limit change, but this was due to large sample sizes of speed data in the before-and-after period. The K-S test results also showed that the speed distribution of treated sites during the after period was different than the before period. Understanding the results of this study will help with future speed limit adjustments on freeways in Kansas.

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Final Report

Prepared by

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Kansas State University Transportation Center

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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Abstract

Setting an appropriate speed limit is necessary to provide safe and efficient traffic operations for all road users. It must also be acceptable to the public and enforceable by police. Lower-than-required speed limits may make most drivers non-compliant, whereas higher-than-required speed limits may increase the number of crashes together with related injuries and fatalities. In 2011, the speed limit on a number of freeway segments in the state of Kansas increased from 70 to 75 miles per hour. The objective of this study is to evaluate the safety effects of freeway sections affected by speed limit change in Kansas. Sections where the speed limit changed from 70 mph to 75 mph and other comparable sections where the speed limit remained at 70 mph without any change were identified. Details of the crashes by severity level for 3 years before (2008–2010) and 3 years after (2012–2014) the speed limit change were collected using the state crash database. In order to get a general understanding, characteristics of crashes such as nighttime versus daytime, number of trucks involved, weather conditions, driver's gender, and other such factors were considered. Furthermore, several crash contributory causes were also investigated before and after the speed limit change. In order to evaluate the safety situation, three methods were utilized: (1) Empirical Bayes (EB) observational before-and-after studies; (2) Before-and-after method with comparison group; and (3) Cross-sectional method using the Negative Binomial (NB) regression model. The evaluation was conducted to see if the speed limit change has caused an increase in total crashes or fatal and injury crashes. In regard to speed analysis, the t-test was applied to see whether significant increases in the 85^{th} percentile speed were observed between before-and-after conditions. Since the sample size was large, the Kolmogorov-Smirnov (K-S) test was also conducted to see if there was any difference between two sets of speed data distributions in the before period compared to the after period.

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The t-test results showed the 5-mph increase in the speed limit caused a statistically significant increase in 85^{th} percentile speed for the sections affected by speed limit change. However, there was also an increase for the sections without a speed limit change, but this was due to large sample sizes of speed data in the before-and-after period. The K-S test results also showed that the speed distribution of treated sites during the after period was different than the before period. Understanding the results of this study will help with future speed limit adjustments on freeways in Kansas.

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Chapter 1: Introduction

1.1 Background

Posted speed limits are those signs posted along the road that indicate the maximum allowable driving speeds under favorable conditions, which are enforceable by law. Properly set speed limits provide a safe, consistent, and reasonable speed to protect drivers, pedestrians, and bicyclists along the roadway. At the same time, speed limits can be a source of frustration and confusion; for example, not all drivers like to travel at the same speed, and some people may not understand why the speed limit changes on a particular road. Further, community residents often have concerns that traffic is moving very fast through their neighborhoods. Understanding the engineering principles and processes used to set speed limits and learning the terminology used to describe them are the first steps in reducing drivers' frustration or confusion and encouraging compliance (Federal Highway Administration, 2016).

The United States Congress adopted a National Maximum Speed Limit (NMSL) of 55 mph in 1974, during the Arab Oil Embargo and as traffic volumes were decreasing (Moore, 1999). The Congress voted to increase the NMSL to 65 mph in 1987. By the end of 1996, when Congress repealed a NMSL and gave the authority back to the states, more than 32 states passed bills to raise the posted speed limit on different types of roadways (Moore, 1999). As of 2017, each state has its own policy for the maximum speed limits for trucks and cars on rural and urban interstate roadways. Maximum speed limits for cars and trucks are classified for rural and urban interstates in different U.S. states in Table 1.1 (National Motorists Association, 2017).

Table 1.1: Maximum Speed Limit Policy in Each State

State	Rural Interstates		Urban Interstates	
	Cars (mph)	Trucks (mph)	Cars (mph)	Trucks (mph)
Alabama	70	70	65	65
Alaska	55	55	55	55
Arizona	75	75	65	65
Arkansas	70	70	60	60
California	70	55	65	55
Colorado	75	75	65	65
Connecticut	65	65	55	55
Delaware	55	55	55	55
D.C.	Not Applicable	Not Applicable	55	55
Florida	70	70	65	65
Georgia	70	70	55	55
Hawaii	60	60	60	60
Idaho	80	70	80	65
Illinois	70	70	55	55
Indiana	70	65	55	55
Iowa	70	70	55	55
Kansas	75	75	70	70
Kentucky	65	65	65	65
Louisiana	75	75	70	70
Maine	75	75	75	75
Maryland	70	70	70	70
Massachusetts	65	65	65	65
Michigan	75	65	70	60
Minnesota	70	70	65	65
Mississippi	70	70	70	70
Missouri	70	70	60	60
Montana	80	65	65	65
Nebraska	75	75	65	65
Nevada	80	80	65	65
New Hampshire	70	70	65	65
New Jersey	65	65	55	55
New Mexico	75	75	65	65
New York	65	65	55	55

Source: National Motorists Association (2017)

Table 1.1: Maximum Speed Limit Policy in Each State (Continued)

State	Rural Interstates		Urban Interstates	
	Cars (mph)	Trucks (mph)	Cars (mph)	Trucks (mph)
North Carolina	70	70	70	70
North Dakota	75	75	75	75
Ohio	70	70	65	65
Oklahoma	75	75	70	70
Oregon	70	65	55	55
Pennsylvania	65	65	65	65
Rhode Island	65	65	55	55
South Carolina	70	70	70	70
South Dakota	80	80	80	80
Tennessee	70	70	70	70
Texas	85	85	75	75
Utah	80	80	70	70
Vermont	65	65	55	55
Virginia	70	70	70	70
Washington	70	60	60	60
West Virginia	70	70	65	65
Wisconsin	70	70	70	70
Wyoming	80	80	65	65

Source: National Motorists Association (2017)

According to the Table 1.1, the speed limit for cars is higher than for trucks, particularly rural compared to urban interstates. The state of Texas has the highest maximum speed limit, which is 85 mph for both cars and trucks on a section of an interstate highway in a rural area. Alaska and Delaware have the lowest maximum speed limit value, which is 55 mph on rural interstates. In other cases, speed limit varies by state and ranges between 55 mph to 85 mph according to the National Motorists Association chart.

Legislative bill HB 2192 allowed the Secretary of Transportation in Kansas to set speed limits as high as 75 mph on select highways in Kansas. It was signed by the Governor and became effective on July 1, 2011 (“Kansas Legislature approves,” 2011). The bill’s supporters pointed out that drivers were already driving 5 to 10 miles above the posted speed limit and therefore it made sense to make this speed formal. It was also brought up that the increased speed limit would help the economic development of Kansas. On the other hand, opponents said drivers would not change their behavior and would still drive 5 to 10 miles above the posted speed limit bringing the actual speeds to even higher values. In this case, the primary concern was safety, as crash severities tend to increase with increased posted speed limits.

A task force was put together to determine on which freeways it would be appropriate to raise the speed limit from 70 mph to 75 mph. The following factors were used to determine whether to raise the speed limit on a certain roadway section to 75 mph or not. (1) Rural or urban nature of the area: if the population is less than 5,000, it would be rural; otherwise, it is urban. (2) Commuter traffic that has many of the same vehicles or familiar drivers passing on a regular basis on a specific section. (3) Geometrics of the roadway, which show several characteristics of a roadway section such as number of lanes, median type, rumble strip presence, and so forth. (4) Surrounding states' speed limits to show speed limits in neighboring states. (5) District experience for presenting how drivers have changed their behavior after speed limit change. (6) Traffic volumes that represent the total number of vehicles occupying the roadway. (7) Legal issues or concerns that may arise after speed limit change. (8) Number of crashes crucial to be considered for roadway safety before any changes are applied in the speed limit.

Freeways affected by speed limit change in 2011 in Kansas are shown in Figure 1.1. They include I-35 from a location in southwest Johnson County to US-50 east of Emporia; US-69 from southern Johnson County to north of US-54 near Fort Scott in Bourbon County; I-70 from just west of Topeka in Shawnee County to the Colorado state line; I-135 from I-70 near Salina to a location north of the 85th Street interchange in Harvey County; US-81 from I-70 near Salina north to K-106; and the Kansas Turnpike from the Oklahoma state line to K-7 in Wyandotte County (KDOT, 2011).

Figure 1.1: Freeways Affected by Speed Limit Change from 70 mph to 75 mph in July 2011

Affected freeway sections, along with their beginning and ending mile posts and total mileage of freeway sections with the speed limit of 75 mph, are summarized in Table 1.2. Some of the freeway sections are broken down into different sections as the entire freeway is not influenced by speed limit change, since geometric and other characteristics of sections are not always similar. Total mileage of freeway sections affected by speed limit change is about 808 miles, as summarized in Table 1.2.

Table 1.2: Freeway Sections Affected by Speed Limit Change from 70 mph to 75 mph

Route	Beginning Mile Post (miles)	End Mile Post (miles)	Total Mileage (miles)
I-35	0	127.34	198.41
	132.77	203.84	
I-70	0	352.42	393.15
	367.02	407.75	
I-135	17.71	95.73	78.02
I-335	0	50.17	50.17
I-470	6.69	13.72	7.03
US-69	67.68	131.50	63.82
US-81	151.78	169.04	17.26
Total mileage			**807.86 miles**

In order to have a general understanding of how speed limit increase could have an impact on traffic safety, fatal and injury crashes and total crashes were considered in the before period from 2008 to 2010 and again in the after period from 2012 to 2014. Figure 1.2 represents the crash distribution in 3 years before and 3 years after the speed limit change, based on total crashes and fatal and injury crashes for the roadways affected by speed limit change.

Figure 1.2 shows the distribution of crashes during each of the 3 years before and after the speed limit change, omitting the year 2011 during which the change occurred. According to the figure, total number of crashes in the 3-year after period compared to the 3-year before period have decreased by 532 crashes, but fatal and injury crashes have increased in the after period by 105 additional fatal and injury crashes. Observing crash experience just by looking at the numbers in this way does not provide any precise conclusions regarding the impact of speed limit change on the safety experience. Thus, further detailed statistical analysis is needed in order to show convincing results, and accordingly this study uses the methodologies provided in the Highway Safety Manual for that purpose.

Figure 1.2: Crash Distribution Before and After Speed Limit Change for Freeways Affected by Speed Limit Change

1.2 Research Objectives

Although the sections for speed limit increase may have been carefully selected by the Kansas Department of Transportation (KDOT) by considering factors such as traffic volumes, crash history, and roadway geometrics, what has actually occurred in terms of safety experience is yet to be known. Assessing the safety impact on freeways after speed limit change is very important and safety evaluation methods need to be implemented in order to understand whether speed limit increase has affected freeway safety or not. This project serves to quantitatively evaluate whether safety has been compromised by the higher speed limit on the freeway sections that have been affected. Accordingly, the specific objectives of this study are as follows:

1. To apply before-and-after study with Empirical Bayes (EB), before-and-after study with a comparison group, and cross-sectional study using Negative Binomial (NB) methods according to the Highway Safety Manual (HSM), in order to see if crashes have increased after speed limit change.
2. To evaluate drivers' speeds when the speed limit increased from 70 mph to 75 mph. The goal of the speed study is to examine whether any significant changes have occurred in 85^{th} percentile speed and average speed after the speed limit increase and compare before and after speed values by utilizing t-test. Furthermore, to compare two different speed distributions during before and after time periods using the Kolmogorov-Smirnov (K-S) test because of the very large sample size.
3. To identify crash contributory causes and various crash characteristics on the treated sections, and accordingly compare the sections affected by speed limit change versus the sections without any speed limit change.

1.3 Organization of the Report

This report contains six chapters and three appendices. Chapter 1 introduces the background of the problem and research objectives. Chapter 2 presents a general review of the most relevant literature in relation to the current study. Crash data, safety effectiveness methodologies according to the Highway Safety Manual (HSM), and speed data analysis methods are presented in Chapter 3. Chapter 4 discusses analysis results and presents discussions. Chapter 5 describes crash characteristics and contributory causes for crashes. Finally, Chapter 6 presents a summary and conclusions of the research. Appendices A and B present speed frequency distribution tables and curves for the available Automatic Traffic Recorders (ATRs) during the periods before and after speed limit changes. Finally, Appendix C presents light conditions and types of vehicles involved in crashes for treated and non-treated road sections.

Chapter 2: Literature Review

This chapter summarizes the review of literature, beginning with previous studies related to the effect of speed limit changes on crashes based on before-and-after studies, as well as implementation of different safety evaluation methods for estimating Crash Modification Factors (CMFs).

2.1 Before-and-After Comparison Analysis

The Empirical Bayes (EB) before-and-after study design is widely recognized as the state-of-the-art methodology for CMF development, though the EB method depends on the appropriate nature of the countermeasure. For example, if a research is related to evaluating the safety impact of widening the median width, it may not be feasible to actually increase roadway medians to different values and experiment. In such cases, before-and-after study cannot be implemented and instead a cross-sectional regression study could be used, where roadways with wide medians are compared to roadways with narrow medians (Carter, Srinivasan, Gross, & Council, 2012).

The EB method has been used for more than 20 years for conducting before-and-after studies on the safety impact of treatments implemented on roadway sites. Results from this method can be used in specifying crash modification factors for use in treatments of hazardous locations. The EB method not only overcomes regression to the mean, but also accounts for traffic volume changes. In the EB method, safety performance functions need to be calibrated for each year before and after. As a conclusion, if the EB method is properly undertaken, the results would be more valid and different from those older methods, such as a naïve before-and-after study (Persaud & Lyon, 2007).

The EB method has gained wide approval among researchers and is the most preferred before-and-after study evaluation of roadway safety treatments. The EB method accounts for the regression to the mean effects that result from the tendency to pick highly observed crash frequency of treated sites. On the other hand, the Full Bayesian (FB) approach is also suggested as a useful method when less data is required for a control group or reference group. The FB approach provides more detailed causal inferences and more flexibility in selecting crash count distributions (Persaud, Lan, Lyon, & Bhim, 2010). The FB approach can provide identical results to the EB method, even when the number of non-treated sites are not enough, which is a benefit over the EB method when the control group size is restricted due to cost and other practical limitations. Standard errors from the FB method are smaller than the EB method and the standard deviation from the FB method is relatively large. This implies the FB approach is more precise but is also more complex and needs much more experience in statistical calculations (Persaud et al., 2010).

When applying the EB method, minimum requirements for data needs and inputs are as follows (American Association of State Highway and Transportation Officials [AASHTO], 2014):

1. The minimum number of treatment sites should be 10 to 20.
2. At least 3 to 5 years of crash and traffic volume data for the period before treatment and 3 to 5 years of crash and traffic volume for the period after treatment are needed.
3. There should be Safety Performance Function (SPF) available for treatment site types.

Speed limit reductions can cause safety issues for drivers and affect crash severity. De Pauw, Daniels, Thierie, and Brijs (2014) considered the safety effects of reducing the speed limit from 90 km/h to 70 km/h on a number of highways in Belgium. Sixty-one road sections with a total length of 116 km were considered and a non-treated group consisted of 19 road sections with a total length of 53 km. Crash data for 6 years before and 6 years after speed limit change were considered in this study. The Odds Ratio (OR) formula was utilized in this study and it was applied according to Equation 2.1.

$$OR= \frac{\frac{R_t}{R_{t-1}}}{\frac{C_t}{C_{t-1}}}$$ **Equation 2.1**

Where:

R_t = Number of crashes in the treated group in year t

$R_t - 1$ = Number of crashes in the treated group in year t-1

C_t = Number of crashes in the non-treated group in year t, and

$C_t - 1$ = Number of crashes in the non-treated group in year t-1.

By calculating the Odds Ratio (OR) for injury crashes, it was seen in this study that the speed limit reduction had a decreasing effect on crashes, especially on fatal and injury crashes.

Islam and El-Basyouny (2015) assessed the safety effect of a posted speed limit reduction from 50 km/h to 40 km/h for eight urban residential areas in Canada. Traffic volume, road geometry, and crash data for both treated and reference sites were collected for 4 years before and 4 years after the speed limit change. The sites were all two-lane collector road segments in urban areas. The Empirical Bayesian (EB) and Full Bayesian (FB) methods were utilized in performing the before-and-after safety evaluation. Based on the FB method, speed limit reduction was found to be effective in reducing crashes and improving the safety of all crash severity types, while the EB method showed opposite results. Elvik (2013) used a before-and-after study approach using the Empirical Bayes method. By considering crash data on some major arterial roads and multilane divided highways for 6 years before and 6 years after speed limit decrease from 80 km/h to 60 km/h, there was a 7.5 percent reduction in total crashes in Oslo, Norway.

Høye (2015) investigated the safety effect of 14 sites in Norway when the speed limit was reduced from 80 km/h to 70 km/h. Basic road characteristics along with crash numbers in the before-and-after period were summarized. The speed limit was 80 km/h at most sites except for some parts where it had reduced by 10 kilometers per hour. Most sites had two lanes and all sites were outside of urban areas. The safety evaluation was conducted by considering fatal and injury crashes for 3 years before and 3 years after speed limit change. Traffic volumes had increased from the before to the after period at all sites except for one section among non-treated sites. In order to assess the safety impact of speed limit reduction, a before-and-after study using Empirical Bayes (EB) method was conducted. Based on the results, it was shown that fatal and injury crashes had decreased by 49 percent after speed limit reduction.

Mackenzie, Hutchinson, and Kloeden (2015) evaluated the speed limit reduction from 110 km/h to 100 km/h on rural arterial roads in Australia by considering 10 years before and 10 years after speed limit reduction for 73 road sections. The before-and-after study was utilized for control road segments where the speed limit did not change, and the subject road segments where the speed limit was reduced by 10 kilometers per hour. The average number of crashes on both road segments decreased after speed limit reduction but injury severity showed a slight increase after speed limit reduction. According to the ratios of total crashes in each year, the decrease in the number of casualty crashes from the before period to after period was greater on the subject road segments compared to the control road segments and this was true for all crash severity categories as well. An independent sample t-test was also applied to the crash ratios for identifying the upper and lower 95 percent confidence limits of the change in crash ratio between the before-and-after periods. According to the t-test results, it was shown that the number of crashes was 27.4 percent lower on subject roads compared to control roads and this result was statistically significant at the 95 percent confidence level.

Speed limit increases can cause higher crash severity compared to speed limit reductions. Renski, Khattak, and Council (1999) evaluated the impact of multiple speed limit increases from 55 mph to 60 mph, 55 mph to 65 mph, and 65 mph to 70 mph on interstate highways specifically for single-vehicle crashes in North Carolina for 1 year before and 1 year after the speed limit change. An ordered probit model was developed and the CMF was also calculated for each roadway segment at each level of injury severity. Increasing speed limits increased the probability of sustaining minor and non-incapacitating injuries. There were too few fatal crashes from which to draw conclusions, but speed limit increase did not show a significant effect on such high severity crashes. Wagenaar, Streff, and Schultz (1990) evaluated the speed limit increase from 55 mph to 65 mph on rural highways in Michigan. A monthly time series analysis was used to control for multi-year trends, seasonal cycles, and other patterns. Two methods, known as Box-Jenkins and Box-Tiao, were implemented for controlling the long-term and seasonal cycles for estimating changes at the beginning of the first month that the speed limit increased. Based on the results, fatalities, serious injuries, and moderate injuries increased due to the speed limit increase but there was no increase in the total number of crashes.

Rock (1995) considered speed limit increase from 55 mph to 65 mph on rural interstates and limited access highways in Illinois in April 1987. Data were collected for 5 years before and 4 years after the speed limit change. The Auto-Regressive Integrated Moving Average (ARIMA) model method for time series data was employed, which showed the higher speed limit led to 300 more crashes per month in rural areas in Illinois with associated increases in deaths and injuries. Baum, Wells, and Lund (1990) considered the speed limit increase from 55 mph to 65 mph on rural interstate highways for the states affected by speed limit increase in 1988. Crash data were collected for 5 years before and 2 years after the speed limit change and the statistical significance was tested by estimating CMF. As a result, the CMF for fatal crashes showed a 26 percent increased risk (CMF=1.26) compared to other rural roads, and the CMF was even higher when all multilane highways and rural two-lane roads were used in the comparison (CMF=1.29).

Najjar, Stokes, Russell, Ali, and Zhang (2000) considered speed limit increases from 55 mph to 65 mph on most urban interstates and two-lane rural highways, and 55 mph to 70 mph on most rural multilane highways in Kansas in March 1996. The before-and-after study approach (naive method) was used to compare the safety effect by considering 3 years before versus 3 years after speed limit changes, ignoring the year 1996 during which the speed limit changed. No statistically significant increase in fatal crashes on rural and urban interstate highways was shown; however, a statistically significant increase in total crashes, fatal crashes, and fatality rates on two-lane rural highways occurred.

The effect of speed limit increase from 55 mph to 65 mph on fatal, Property Damage Only (PDO), and injury crashes was evaluated on Ohio rural interstate highways by Pant, Adhami, and Niehaus (1992). Other factors such as weather conditions, time of day, light conditions, season, day of week, and vehicle type were also considered for 3 years before and 3 years after speed limit change. Crash data were analyzed by hypothesis testing and the comparison of the Poisson ratio was used to compare mean crash rates during before-and-after periods. It was concluded that the mean fatal crash rate for rural interstate highways had increased. Furthermore, mean injury and Property Damage Only (PDO) crash rates increased as well. However, when the data were categorized according to weather conditions, fatal crash rates had not significantly changed after implementation of the 65-mph speed limit.

The mortality rate of states that raised the speed limit from 55 mph to 65 mph for rural interstates versus states that did not raise the speed limit was considered by Baum, Wells, and Lund (1991). The odds ratio that a fatality occurred on rural interstate in the most recent 5 years was compared to the same odds ratio over the previous 5 years. Results showed 19 percent more fatalities on rural interstates after the speed limit change. Other factors, such as seatbelt usage, daytime versus nighttime crashes, and the proportion of single or multiple-vehicle fatal crashes were also compared but their effects were similar during before-and-after time periods.

Ledolter and Chan (1996) evaluated the impact of the 65-mph maximum speed limit on Iowa rural interstates after speed limits increased from 55 mph to 65 mph. Authors tried to examine whether a significant change in fatal and major injury crashes could be detected due to the speed limit change or not. For their preliminary analysis, the before-and-after comparison was carried out for 3 years before and 3 years after the speed limit change. Analysis results depicted a 20 percent increase in the number of statewide fatal crashes after the speed limit change and this impact was larger on rural interstates than urban interstates.

Godwin and Lave (1992) assessed the impact of a 65-mph speed limit on highway safety for 40 states, where speed limits increased from 55 mph to 65 mph on rural interstate highways. The odds ratio of fatalities on rural interstates was computed in the before period versus the after period. It was found that the fatalities on rural interstates were 15–25 percent higher in the after period than in the before period.

Schneider (2001) considered the impact of speed limit increase from 65 mph to 70 mph on the safety of rural interstate highways in Louisiana. A before-and-after study by considering 1 year before and 1 year after the speed limit change was conducted. It was shown that raising the speed limit on rural interstates led to a significant increase in the number of fatal crashes by 37 percent; however, it showed a 10 percent decline in number of injuries. On the other hand, the number of fatal crashes also increased by 13 percent for urban interstates that had no speed limit change, but this increase was much less than rural interstates affected by speed limit increase.

2.2 Regression-Based Analysis for Crash Frequency Modeling

Regression analysis is commonly used in traffic safety studies, especially when crash-frequency modeling is applied to consider the effect of different roadway geometric characteristics. Furthermore, different crash characteristics are needed to be evaluated in order to select the variable, which is mostly significant. The following research papers represent different regression analysis methods used in the literature review for evaluating safety effects of speed limit changes.

Farmer, Retting, and Lund (1999) considered the safety impact of raising the speed limit on interstates for 24 states in comparison to seven states that maintained unchanged speed limits. By using time series cross-sectional regression analysis, the impact of speed limit change was estimated and showed all fatal and injury crashes increased by 4 percent, and this increase was statistically significant. Ossiander and Cummings (2002) evaluated the effect of speed limit increase from 55 mph to 65 mph on rural freeways in Washington. Annual fatal and all other crash numbers were collected from the Washington State Traffic Safety Commission for both rural and urban freeways from 1970 to 1994. The Poisson regression model was developed as the research methodology for analyzing the relationship between the fatal-crash rate and speed limit increase. Results showed crash rates on urban freeways were about two times the rate on rural freeways and caused more fatal and injury crashes.

The effect of increasing the speed limit from 55 mph to 65 mph on number of fatalities especially based on gender and age was evaluated in the U.S. by Dee and Sela (2003). Dependent variable was identified as traffic fatality rate per 100,000 persons and independent variables were considered as unemployment rate, seatbelt use, alcohol involvement, and driver's license type. Time-series cross-sectional regression analysis was developed based on least squares estimations and p-values were estimated. Results showed that fatality rates after speed limit change increased by 9.9 percent for women but showed small and statistically insignificant effects among men. Further, speed limit increase caused fatality rates to increase by 13.2 percent for elderly people, with no significant impact for young people.

Renski et al. (1999) assessed the effect of speed limit increases on crash injury severity on North Carolina interstate highways for 1 year before and 1 year after speed limit changes. Ordered probit model was used and crash severity level was selected as the dependent variable. Independent variables were occupants (drivers), vehicle characteristics, environmental factors, driver characteristics, and road characteristics. In segments affected by speed limit change from 65 mph to 70 mph, there was no significant change in injury severity but high crash severity was observed when vehicles struck the guardrail after speed limit change.

Patterson, Frith, Povey, and Keall (2002) investigated fatality rates in 23 states for 3 years before and 3 years after speed limit change from 70 mph to 75 mph on rural interstates. The number of fatalities were gathered, and a regression model was developed to fit the data. Number of fatalities were identified as the dependent variable and variables such as road geometry characteristics were taken as independent variables. A dummy variable was used for speed limit change, i.e., zero for before time and one during after time. There was a statistically significant increase in fatality rate when the speed limit was changed to 75 mph, whereas there was 19 percent reduction in the fatality rate when the speed limit remained at 70 mph without any changes.

Gates, Savolainen, Kay, Finkelman, and Davis (2015) evaluated the speed limit increase from 55 mph to 65 mph for non-freeway sections in Michigan in early 2014. In their study, all factors that affect observed speed on such highways along with injuries and fatalities were collected. A multiple linear regression was employed, and results showed a 1 percent increase in traffic volume resulted in a 0.9 percent increase in total and injury crashes on average. In addition, crashes tended to be higher in urban areas, but fatal crashes tended to be less related to traffic volume.

The effect of speed limit change from 65 mph to 70 mph on crash severity for multilane non-interstates and rural interstate highways in Indiana, which was effective July 1, 2005, was considered by Malyshkina and Mannering (2008). Roadway and environmental-related data, vehicle type, and driver's age and gender were collected for 1 year before and 1 year after speed limit change. In order to assess the impact of speed limit change on crash severity, an ordered probit model was developed and the results showed that the number of Property Damage Only crashes was 1 percent more than the before time period, while the number of fatal and injury crashes in the after period was 1 percent less than the before time period. The severity modeling indicated speed limit change did not significantly influence crash injury severities on interstate highways; however, non-interstate highways showed that the higher speed limit resulted in a greater likelihood of injury, fatality, or both.

Houston (1999) evaluated the effect of 65-mph speed limit on traffic safety for all 50 states that had changed from 55 mph on four types of roadways, classified as rural interstates, rural non-interstate roadways, all roads except for rural interstate highways, and all other roads. Motor vehicle fatality rate, which in this study was defined as the number of fatalities per one billion vehicle miles of travel was taken as the dependent variable and independent variables were selected as seatbelt use, alcohol involvement, population density, weather condition, and speed limit change. Speed limit change was treated as a binary value; i.e., for 65 mph, one was assumed, and for 55 mph, zero. For seatbelt use also, binary value was assumed but for the state climate, the normal daily mean temperature for each state was recorded. Based on results of regression analysis, population density was negatively associated with traffic fatality rates, whereas alcohol consumption was positively related to fatality rate. In conclusion, the increase of speed limit on rural interstates seemed to have negative safety consequences for rural interstate roads. Although fatality rates would increase on rural interstate highways, the impact of speed limit change would be lower fatality rates on other roadway types and the entire traffic system. Accordingly, the study mentioned that the states have continued to raise the peak speed limits to even 70 mph and above.

The effect of different factors including speed limit change on number of fatalities for 47 states was considered in 1987 by Zlatoper (1991). Various factors included income, ratio of urban to rural driving, expenditures on highway police and safety, motor vehicle inspection laws, adult seatbelt-use laws, volume of driving, speed, speed variance, driving density, alcohol consumption, and temperature. A linear regression model was developed, and fatality rate was taken as the dependent variable with all other variables mentioned earlier selected as independent variables. Based on analysis results, income and ratio of urban to rural were insignificant at the 5 percent level, but all other variables were directly related to fatality rates and significant.

The relationship between crashes and speed, as well as with other traffic and geometric variables on motorways in the United Kingdom (UK), were examined by Imprialou, Quddus, and Pitfield (2016) in order to estimate the effect of speed limit increase from 70 mph to 80 mph on traffic safety. Different variables were considered, such as crash date, time, location, number of vehicles involved, type of crashes, and traffic conditions. Traffic variables considered were average speed and volume per 15 minutes. Full Bayesian Multivariate Poisson Lognormal Regression models were developed to the dataset using the condition-based approach for crashes by vehicle and severity while controlling for over dispersion and correlations between single-vehicle crashes and multiple-vehicle crashes. In summary, speed limit change caused changes in traffic conditions that could affect levels of safety on road networks. It was also seen that speed is positively related to all single-vehicle crashes, and fatal or serious multiple-vehicle crashes, but negatively related to multiple vehicle crashes with minor injuries, meaning higher speed led to fewer minor injuries.

Results from work by Gross and Donnell (2011) found that CMFs based on a cross-sectional regression study were similar to the CMFs from a case-control study as long as care was taken in selecting the appropriate distribution and functional form for the cross-sectional model.

When developing Negative Binomial models, it is important to identify the variables that are making a difference in the number of crashes. The following section identifies similar studies conducted in the past. Park and Abdel (2015a, 2015b) assessed the safety effects of multiple roadside treatments in Florida using Negative Binomial (NB) regression. Roadway characteristics considered were Annual Average Daily Traffic (AADT), segment length, lane width, maximum speed limit, degree of curve, shoulder width, driveway density, density of trees, density of roadside poles per mile, and average distance to trees and poles. It was understood that the AADT and driveway density correlation was very high, as more driveways tend to be a characteristic of high traffic volumes.

In a study conducted in Pennsylvania, the objective was to quantify the safety performance of horizontal curves on two-way, two-lane rural roads relative to tangent segments. The crash modification factor was estimated by employing the cross-sectional model using a negative binomial regression model from more than 10,000 miles of state-owned two-lane rural roads. Some independent variables were taken as degree of curve, roadway segment length, AADT, roadway width, shoulder width, shoulder type, surface type, number of lanes, functional classification, and posted speed limit. Results indicated the degree of curve was statistically significant on total number of crashes (Gooch, Gayah, & Donnell, 2016).

Russo, Busiello, and Dell’Acqua (2016) explored the effect of road features of two-lane rural road networks on crash injuries and fatalities in Italy. For this purpose, the negative binomial regression model was used, and lane width, AADT, curvature change rate, section length, and vertical grade were selected as independent variables. Results indicated all independent variables were statistically significant on fatal and injury crashes.

Crash occurrence on urban freeways was assessed based on geometric characteristics of freeways in Florida. Abdel-Aty, Pemmanaboina, and Hsia (2006) used a negative binomial regression model according to factors such as radius of freeway sections, median type, pavement condition, surface type, pavement roughness index, presence of on/off ramps, shoulder width, shoulder type, number of lanes, degree of curve, and median width. Results indicated presence of on/off ramps and degree of curve had a significant effect on total number of crashes.

Wood, Donnell, and Fariss (2016) considered several two-lane rural highway geometric characteristics, such as AADT, section length, total crashes per year, Roadside Hazard Rating (RHR), curve density, degree of curve, access density, speed limit, and shoulder rumble strips for crash frequency modeling, using a negative binomial regression model. Results showed the negative binomial model had been consistent with analysis and suitable for the study. Similarly, Garach, de Oña, López, and Baena (2016) developed SPFs for rural two-lane highways using negative binomial regression models. They considered variables such as AADT, percentage of heavy vehicles, section length, lane width, shoulder width, curve radius, total crashes, drive way density, and shoulder width.

Fitzpatrick, Lord, and Park (2008) developed CMFs for median characteristics on freeways and multilane rural highways in Texas by using negative binomial regression model. Facility type, median type, number of lanes, maximum speed limit, shoulder width, median width, pole density, and AADT were utilized for crash-frequency modeling. They found a change in total crash frequency when a particular geometric design element changes.

Park, Fitzpatrick, and Lord (2010) evaluated the effects of freeway design elements by using negative binomial regression modeling. They considered ramp density, horizontal curve, AADT, freeway segment length, inside shoulder width, lane width, outside shoulder width, median width, speed limit, number of interchanges on freeway segment, number of lanes, median type, and number of on/off ramps for their model. Results showed that speed limit had been statistically significant on total number of crashes.

2.3 Speed Data Analysis

The analysis of speed data commonly concentrates on 85th percentile speed, which is regarded by many traffic engineers as a major factor in evaluating operating speed as well as the main criteria in setting the reasonable speed limit. The following studies represent how 85th percentile speed analysis is commonly utilized.

Najjar et al. (2000) evaluated the 85th percentile speed according to the before-and-after posted speed limits on rural interstates and two-lane rural roads, which was changed from 55 mph to 65 mph. Standard deviation and 85th percentile speed was computed and for this purpose, the two-tailed t-test was employed to investigate whether a statistically significant difference in 85th percentile speed between before-and-after data could be noted with at least a 95 percent confidence level. It was concluded there was a statistically significant increase in the 85th percentile speed on rural interstates and two-lane rural roads after speed limit increase.

Jernigan, Strong, and Lynn (1994) conducted a speed study for rural interstates in Virginia when speed limit changed from 55 mph to 65 mph. Average speed and 85th percentile speed were computed for 3 years before and 4 years after the speed limit change. To compare the statistical significance for before versus after, the analysis of variance (ANOVA) was applied for both average speed and 85th percentile speed, and this increase was shown to be statistically significant.

Binkowski, Maleck, Taylor, and Czewski (1998) evaluated speed characteristics when speed limit increased from 65 mph to 70 mph on freeways in Michigan. There was an increase in both average and 85th percentile speed for some of the test sites. However, the statistical significance of the change in speed was not determined for the before-and-after analysis because the sample size was so large that any change in the speeds would be significant.

The speed limit on most rural interstates changed in Iowa from 65 mph to 70 mph in July 2005. In this study, speed data were available for 11 months before the speed limit change and 18 months after. Average speed and 85th percentile speed were computed before and after the speed limit increase. Results indicated a 2 mph increase for both average speed and 85th percentile speed after the speed limit change compared to the before period. In order to test the statistical significance of 85th percentile speed, a generalized regression model was employed by Souleyrette, Stout, and Carriquiry (2009). However, the regression model showed no statistically significant increase in the 85th percentile speed at the 95 percent confidence level, although several results were found to be significant at lower confidence levels.

Silvano and Bang (2015) considered the impact of speed limit changes and road characteristics on free-flow speed in urban areas in Sweden and two types of analysis were conducted in their study. Type A analysis identified standard deviation, 85^{th} percentile speed, and confidence interval for mean free-flow speed. A two-sample t-test was applied in this analysis and it was found that speed limit increase resulted in a statistically significant mean free-flow speed change. In the Type B analysis, the dependent variable was the mean free-flow speed and independent variables were road geometry characteristics. The result of Type B analysis showed that the decrease in the mean free-flow speed was statistically significant at the 5 percent level; however, the changes were not significant when classified based on road geometry characteristics.

Dissanayake and Liu (2011) evaluated criteria for setting speed limits on gravel roads. A two-sample t-test was used in their study in order to compare two sets of speed data. The study noted that reduced posted speed limits on gravel roads increased the number of speed limit violators significantly rather than helping improve conditions. Reviewing studies about the impact of speed limit changes will help us to apply others' methodologies in our research in order to compare results with previous studies.

Chapter 3: Data and Methodology

The most common crash database utilized in this study is the Kansas Crash Analysis and Reporting System (KCARS), which contains all police-reported crashes in Kansas. Any geometric characteristics used in this research for safety-effectiveness evaluation were obtained from the state's highway inventory database, Control Section Analysis System (CANSYS). Both databases are briefly described in this chapter and available speed dataset is also described so that comparison between before-and-after conditions could be carried out.

3.1 Crash Data: Kansas Crash Analysis and Reporting System Database

The KCARS database, which is a Microsoft Access-based database, contains different tables including ACCIDENTS, DRIVERS, OCCUPANTS, PEDESTRIANS, TRUCKS, VEHICLES, ACCIDENT_CANSYS, SPECIAL_CONDITIONS, COUNTY, CC_DRIVER, CC_ROADWAY, CC_ENVIRONMENT, CC_VEHICLE, etc. In order to obtain data for crash analysis, a query is produced by combining tables together. Common variables from these tables are Accident_Key, Rout_NBR, Route_Prefix, Lane_Class, Speed_Limit, Latitude, Longitude, Rural or Urban Area, and Reporting_Severity.

The ACCIDENTS table consists of the details of crashes such as crash location, light conditions, weather conditions, road surface type, road conditions, road character, road class, road maintenance information, crash date, crash time, class of crash, and manner of collision.

The VEHICLES table includes all characteristics related to the vehicle model, vehicle year, registration year, direction of travel, vehicle maneuver, vehicle damage, odometer, calculated speed, vehicle use, body type, color, and number of occupants.

The OCCUPANT table consists of age, gender, safety equipment use, injury severity, and ejection information of each occupant in the vehicle. The ACCIDENT_CANSYS table contains location details such as latitude and longitude, route number, speed limit value, county location, Annual Average Daily Traffic (AADT), and other geometric characteristics.

The field "UAB Code" in ACCIDENT_CANSYS and ACCIDENTS tables also shows whether the crash occurred on rural or urban roadways. The tables could be combined, and queries were made to filter out crashes that occurred on rural or urban roadways. Furthermore, in the

ACCIDENTS table, three types of crash severities are listed as fatal, injury, and Property Damage Only (PDO) crashes. The injury crashes are divided into three categories as possible injury, non-incapacitating injury, and disabled (incapacitating) injury (KDOT, 2014).

A fatal crash is any crash resulting in death to a person within 30 days of the crash. A possible injury is any reported or claimed injury that is not fatal, incapacitating, or non-incapacitating, including momentary unconsciousness, claim of injuries not evident, limping, or complaint of pain, nausea, or hysteria (KDOT, 2014).

A non-incapacitating injury is any injury, other than a fatal injury or incapacitating injury, which is evident to observers at the scene of the crash at which the injury occurred. An incapacitating (disabled) injury is any injury, other than fatal, that prevents the injured person from walking, driving, or performing regular activities the individual was capable of before the injury occurred (KDOT, 2014).

Lastly, KDOT considers crashes involving damage to public or private property totaling more than $1,000 threshold with no injuries to be PDO crashes. Multiple-vehicle crashes can have varying severity levels for each vehicle involved in the crash and are assigned a single crash severity based on the highest level of personal injury severity (KDOT, 2014).

3.2 Control Section Analysis System (CANSYS) Database

The CANSYS database includes information related to geometrics, conditions, and extent of 10,000-plus miles of roadways in Kansas that belong to the state highway system. Furthermore, CANSYS includes data on bridges, access permits, and at-grade rail crossings, which supports the work of various bureaus at KDOT, the Federal Highway Administration (FHWA), and the Kansas legislature (KDOT, 2014).

CANSYS data are collected at random intervals from different sources and are commonly used for high-level analysis for network screening and trend evaluations. Based on data requirement, county mile posts of beginning and ending of segments, coordinates of segments, lane width, shoulder width, median type, median width, side slope, speed limit, degree of curve, and AADT are obtained from this database. Additionally, CANSYS includes the ROUTE_ID, LANE_CLASS, SHOR_DESC (outer shoulder description), and SHIN_DESC (inner shoulder description). All of these data are needed in this research to conduct the before-and-after study using the cross-sectional method for identifying whether speed limit increase has been statistically significant compared to such geometric characteristics. The description of beginning and ending milepost, lane class, and AADT are included in the following sections.

3.2.1 Beginning and Ending Mileposts

As is common in the United States, milepost numbers increase from south to north for odd routes and west to east for even routes. KDOT has state mileposts and county mileposts that begin at the state line or county line. Beginning and ending mileposts are provided in the CANSYS database and the segment length is computed by subtracting the ending milepost from the beginning milepost for each section. There is no minimum roadway segment length for application of the predictive models for roadway segments. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation efforts and not affect results (AASHTO, 2014).

3.2.2 Lane Class and City Code

The lane class represents the facility type of the roadway, from undivided two-lane segments to divided eight-lane segments. In this study, segments are classified as Category 2, representing four-lane divided (4D) segments. The city code ID number depicts whether the segment is urban or rural. The city code 999 represents a rural segment; otherwise, it is considered as an urban section. According to the FHWA, an urban segment requires location in an area of a population equal to or greater than 5,000 people.

3.2.3 AADT

As mentioned earlier, Annual Average Daily traffic (AADT) was selected from the CANSYS database and it varied according to each segment length and location. It was identified for 3 years from 2008 to 2010 and another 3 years from 2012 to 2014 for 4D segments.

3.3 Study Segments

Four-lane divided segments where the speed limit had changed from 70 mph to 75 mph and where it remained at 70 mph were provided by KDOT. The CANSYS database was also used to identify the number of crashes for each segment. KDOT also uses a similar rule, according to the HSM, for identifying its segments. It recommends segments should be at least 0.1 mile long and have homogenous geometric characteristics and traffic volume within the segment length.

Using these criteria, a total of thirty-nine 4D segments with speed limit of 75 mph and twenty-seven 4D segments with speed limit of 70 mph were selected for 3 years before the speed limit change (2008–2010) and 3 years after (2012–2014). Data from year 2011 during which the change occurred was not considered in the analysis. ArcGIS 10.0 was utilized for showing the sections affected by speed limit change (treated sections) and the sections without speed limit change (control sections). Figures 3.1 and 3.2 represent the segments with speed limits of 75 mph and 70 mph.

Figure 3.1: 4D Segments with Speed Limit of 75 mph

Figure 3.2: 4D Segments with Speed Limit of 70 mph

To identify the total number of crashes in a segment before and after speed limit change, we need to consider the same section length. Figure 3.3 shows how the number of crashes were identified in this study for each segment.

Figure 3.3: Beginning Point and Ending Point of a 4D Segment with Crash Location

3.4 Variables Considered in the Cross-Sectional Method

There are several geometric characteristics for freeway and multilane highway sections and each are identified by the source of data from which they are collected. This information is needed for conducting the cross-sectional study; summaries are tabulated in Table 3.1.

Table 3.1: Explanatory Variables with Corresponding Data Sources

Number	Variable names	Data source
1	AADT	CANSYS database
2	Segment length	
3	Lane width	
4	Shoulder width	
5	Maximum speed limit	
6	Number of lanes	
7	Shoulder type	
8	Surface type	
9	Functional classification	
10	Rumble strip presence	
11	Degree of curve	
12	Median type	
13	Median width	
14	Cross slope	
15	Area type (rural/urban)	
16	Presence of curve	
17	Percentage of heavy vehicle	
18	International Roughness Index (IRI)	Pavement Management Information System (PMIS) database
19	Presence of on or off ramps	Google Maps
20	Side friction coefficient	KDOT
21	Access density	KDOT video-logs
22	Density of trees/mile	Google Maps
23	Density of poles/mile	Google Maps
24	Roadside Hazard Rating(RHR)	KDOT video-logs
25	Number of interchanges on freeway segment	Google Maps

A description of the Pavement Management Information System (PMIS) database and Google Maps data source are in included in the following sections. Furthermore, Roadside Hazard Rating (RHR) information for multilane highways and freeways in Kansas are provided in Table 3.2.

3.5 Pavement Management Information System (PMIS)

The PMIS database includes information about skid number, International Roughness Index (IRI) for both left and right side of the roadway, number of lanes, county mile posts, functional classifications, and rut depth for the roadways with asphalt surface type. The IRI is measured on both left and right wheel paths of the travel lane, where right wheel path values are usually higher (rougher) than the left wheel path (travel direction is right side). In order to obtain the IRI value for a section, an average of the left and right IRI values is taken so that it is more representative of the actual conditions (Islam, Hossain, Miller, & Zahir, 2018).

3.6 Google Maps

Google Maps was used to obtain information regarding the presence of on/off ramps, number of trees, number of poles, number of access points, and number of interchanges on freeway segments. The Roadside Hazard Rating (RHR) is also estimated by observing clear zone distance and side slope of freeway sections on Google Maps through the following RHR criterion in Kansas.

3.6.1 Roadside Hazard Rating (RHR)

The Roadside Hazard Rating (RHR) is determined by factors such as side slope, clear zone, and ability of a vehicle to recover if it deviated away from the roadway (Zegeer, Hummer, Reinfurt, Herf, & Hunter, 1987). The RHR will be assigned to each segment by comparing the side slope of the road from the CANSYS database to the data from Google Street View. A table in Chapter 13 of the HSM related to roadway segments (Table 13-25) presents ratings for RHR based on clear zone widths and side slopes from 1 to 7. Since the topography of Kansas is fairly flat, the RHR for multilane highway and freeway segments, which are the identified sections for this study, does not vary significantly among segments. Therefore, a previous study conducted in Kansas redefined the range from 1 to 4, with 1 showing the least hazardous conditions and 4 representing extremely hazardous, which was used in this study. Assigning RHR from 1 to 4 for multilane highways and freeways in Kansas is considered more appropriate than the range from 1 to 7. Details are provided in Table 3.2, reproduced from the previous report (Aziz, 2016).

Table 3.2: Roadside Hazard Rating Criterion

RHR	Clear Zone Distance	Side Slope	Recoverable	Special Features
1	>9 m (30 ft) from pavement edge line	Flatter than 1:4	Yes	-
2	6 and 7.5 m (20 and 25 ft) from pavement edge line	Approximately 1:4	Marginally Yes	-
3	3 m (10 ft) from pavement edge line	Approximately 1:3 to 1:4	Marginally Forgiving	Rough roadside surface
4	1.5 and 3 m (5 and 10 ft) from pavement edge line	Approximately 1:3 or 1:4	Virtually No	May have guardrail, exposed trees, poles, other objects

Data summary results related to the variables considered in cross-sectional method are summarized in the following tables according to their corresponding data sources as mentioned earlier.

Tables 3.3 and 3.4 present information about AADT, segment length, number of lanes, and lane width for selected freeway and multilane highway sections, for both treated and non-treated sites during the 3-year period after speed limit increase. These data are obtained from the CANSYS database for selected segments during the 3 years after speed limit increase.

Table 3.3: AADT, Length, Number of Lanes, and Lane Width for Non-Treated Sites in the After Period

Segment ID	AADT (veh/day) (2012)	AADT (veh/day) (2013)	AADT (veh/day) (2014)	Length (miles)	Number of lanes	Lane width (feet)
1	16,200	14,800	16,300	5.43	2	12
2	25,650	25,850	25,850	2.65	2	12
3	61,000	59,450	59,450	11.76	3	12
4	30,550	31,000	30,750	4.50	2	12
5	86,600	83,700	86,600	7.43	3	12
6	43,850	48,250	46,750	11.98	3	12
7	26,400	23,350	25,200	6.57	2	12
8	41,550	40,500	40,500	15.74	2	12
9	8,070	8,180	8,230	14.9	2	12
10	19,100	18,750	19,050	21.08	2	12
11	6,100	7,370	7,370	0.35	2	12
12	6,100	7,460	6,825	6.51	2	12
13	10,950	10,740	10,840	8.62	2	12
14	12,800	12,600	12,600	0.016	2	12
15	10,410	10,520	10,970	0.94	2	12
16	6,750	6,035	6,035	6.51	2	12
17	6,005	5,930	5,930	19.69	2	12
18	9,205	9,015	9,015	12.43	2	12
19	23,000	22,300	23,000	8.05	2	12
20	8,375	8,645	8,645	6.32	2	12
21	18,745	17,790	18,540	18.16	2	12
22	12,200	12,225	12,225	16.6	2	12
23	9,745	9,520	9,670	10.38	2	12
24	6,120	5,765	5,765	13.06	2	12
25	5,870	5,630	5,630	21.60	2	12
26	4,480	4,390	4,425	22.72	2	12
27	9,900	9,755	9,855	20.21	2	12

Table 3.4: AADT, Length, Number of Lanes, and Lane Width for Treated Sites in the After Period

Segment ID	AADT (veh/day) (2012)	AADT (veh/day) (2013)	AADT (veh/day) (2014)	Length (miles)	Number of lanes	Lane width (feet)
1	16,750	16,700	16,750	33.35	2	12
2	19,900	19,800	19,850	21.08	2	12
3	13,600	13,800	13,750	41.86	2	12
4	12,800	12,900	12,850	19.87	2	12
5	12,450	12,450	12,450	21.44	2	12
6	12,600	12,100	12,100	13.36	2	12
7	11,250	11,400	11,400	11.47	2	12
8	15,850	15,800	15,800	31.06	2	12
9	19,900	19,900	19,900	2.83	2	12
10	8,260	8,280	8,280	35.28	2	12
11	8,700	8,860	8,750	39.55	2	12
12	8,110	8,110	8,110	0.809	2	12
13	8,745	8,675	8,935	37.50	2	12
14	9,490	10,075	9,940	30.59	2	12
15	11,650	12,300	11,800	31.21	2	12
16	11,100	11,500	11,500	30.05	2	12
17	11,250	11,600	11,600	23.24	2	12
18	12,450	13,050	12,750	7.24	2	12
19	15,350	15,100	15,500	30.53	2	12
20	15,050	14,850	14,900	23.45	2	12
21	12,450	13,050	12,750	26.53	2	12
22	17,200	17,200	17,200	5.97	2	12
23	18,650	18,600	18,600	24.00	2	12
24	29,450	30,000	30,000	11.50	3	12
25	33,050	33,950	33,600	17.29	3	12
26	30,950	31,350	31,150	16.56	2	12
27	30,600	31,000	30,800	1.77	2	12
28	23,550	24,050	23,800	4.55	2	12
29	23,700	23,900	23,800	20.82	2	12
30	12,600	13,050	12,900	33.84	2	12
31	22,000	24,000	23,500	18.79	2	12
32	6,995	7,135	7,060	27.35	2	12
33	7,170	7,170	7,300	0.581	2	12
34	7,170	7,300	7,235	10.60	2	12
35	7,170	7,300	7,235	11.58	2	12
36	12,150	12,550	12,350	6.26	2	12
37	15,550	15,450	15,450	24.40	2	12
38	8,120	8,230	8,500	5.82	2	12
39	7,205	7,475	7,475	11.40	2	12

Tables 3.5 and 3.6 present other information about maximum speed limit, shoulder width, shoulder type, surface type, roadway facility type, rumble strip type, degree of curve, median type, and median width for both non-treated sites and treated sites during the period after speed limit increase. All these data are also obtained from the CANSYS database.

Table 3.5: Shoulder Width, Max Speed Limit, Shoulder Type, Surface Type, Roadway Type, Rumble Strip Type, Degree of Curve, Median Type, and Median Width for Non-Treated Sites

ID	Shoulder width (ft)		Shoulder type	Surface type	Roadway type	Rumble strip type	Degree of Curve	Median type	Median width (ft)
	Right	Inside							
1	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0	Depressed	40
2	9.8	8.9	Portland cement	Concrete	Freeway	Inside right	0	Cable bar.	60
3	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	0.4	Cable bar.	19.6
4	9.8	5.9	Bituminous base	Concrete	Freeway	Inside right	0.7	Depressed	60
5	9.8	9.8	Bituminous base	Concrete	Freeway	No rumble strip	0	Depressed	84
6	9.8	9.8	Bituminous base	Asphalt	Freeway	No rumble	0.2	Depressed	84
7	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	1	Depressed	60
8	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Depressed	60
9	9.8	5.9	Portland cement	Concrete	4LHighway	Inside right	0	Depressed	60
10	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.9	Depressed	60
11	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	0	Depressed	60
12	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	0	Depressed	60
13	9.8	5.9	Bituminous base	Concrete	4LHighway	Inside right	0	Depressed	60
14	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	1	Depressed	60
15	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	0	Depressed	36
16	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	0	Depressed	59.8
17	9.8	5.9	Bituminous base	Concrete	Freeway	Inside right	0.7	Depressed	59.8
18	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0.9	Depressed	59.8
19	9.8	5.9	Bituminous base	Concrete	Freeway	Inside right	0	Depressed	60
20	9.8	5.9	Bituminous base	Concrete	Freeway	Inside right	0	Depressed	60
21	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	1.5	Depressed	60
22	9.8	5.9	Portland cement	Concrete	4LHighway	Inside right	0	Depressed	60
23	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	2.5	Depressed	60
24	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	0	Depressed	60
25	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	0.2	Depressed	60
26	9.8	5.9	Bituminous base	Asphalt	4LHighway	Inside right	1.3	Depressed	60
27	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	0.3	Depressed	60

Table 3.6: Shoulder Width, Max Speed Limit, Shoulder Type, Surface Type, Roadway Type, Rumble Strip Type, Degree of Curve, Median Type, and Median Width for Treated Sites

ID	Shoulder width (ft)		Shoulder type	Surface type	Roadway type	Rumble strip type	Degree of curve	Median type	Median width (ft)
	Right	Inside							
1	9.8	8.9	Asphalt concrete	Asphalt	Freeway	Inside right	1.2	Cable bar.	20
2	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	1	Cable bar.	20
3	9.8	8.9	Asphalt concrete	Asphalt	Freeway	Inside right	0.3	Cable bar.	20
4	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	1.1	Cable bar.	20
5	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	0.8	Cable bar.	20
6	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Cable bar.	20
7	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	0	Depressed	59.8
8	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	0.5	Depressed	59.8
9	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	0	Depressed	59.8
10	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.9	Depressed	59.8
11	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.3	Depressed	59.8
12	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Depressed	59.8
13	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Depressed	60
14	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Depressed	60
15	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.6	Depressed	60
16	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.3	Depressed	60
17	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Depressed	60
18	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	0	Depressed	60
19	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0.6	Depressed	60
20	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0	Depressed	60
21	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0.5	Depressed	60
22	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0	Depressed	60
23	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0	Depressed	60
24	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0	Cable bar.	20
25	9.8	5.9	Bituminous base	Concrete	Freeway	Inside right	0.8	Cable bar.	20
26	9.8	8.9	Asphalt concrete	Asphalt	Freeway	Inside right	0.8	Cable bar.	20
27	9.8	8.9	Asphalt concrete	Asphalt	Freeway	Inside right	0	Cable bar.	20
28	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0.3	Cable bar.	20
29	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	0.4	Depressed	60
30	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0	Depressed	60
31	9.8	5.9	Portland cement	Concrete	Freeway	Inside right	1	Depressed	60
32	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	0	Cable bar.	20
33	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	0	Cable bar.	20
34	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	1.2	Cable bar.	20
35	9.8	8.9	Asphalt concrete	Concrete	Freeway	Inside right	1.1	Cable bar.	20
36	9.8	8.9	Asphalt concrete	Concrete	Freeway	Right only	0	Cable bar.	20
37	9.8	5.9	Portland cement	Asphalt	Freeway	Inside right	2	Depressed	60
38	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.4	Depressed	60
39	9.8	5.9	Bituminous base	Asphalt	Freeway	Inside right	0.2	Depressed	60

Tables 3.7 and 3.8 present data about percentage of heavy vehicles (PHV), area type, cross slope, presence of curves, International Roughness Index (IRI), and side friction coefficient for both non-treated and treated sites.

Table 3.7: PHV, Area Type, Cross Slope, Presence of Curve, and IRI for Non-Treated Sites in the After Period

Segment ID	PHV	Area type	Cross slope	Presence of curve (# of curves)	IRI (in/mile)			Side friction coefficient
					2012	2013	2014	
1	13.20	Urban	0.016	1	110	96	95.5	0.53
2	10.66	Urban	0.016	1	133	114	123	0.38
3	1.78	Urban	0.016	1	80.5	74.5	79.5	0.32
4	2.54	Urban	0.016	1	76.5	114	129.5	0.55
5	14.21	Urban	0.016	2	103	98.5	103	0.52
6	9.90	Urban	0.016	2	49.5	45	45	0.41
7	0.25	Rural	0.016	1	49	42.5	41.5	0.44
8	6.35	Urban	0.016	1	52	37	39.5	0.4
9	2.03	Rural	0.016	2	52.5	37	35.5	0.65
10	6.85	Rural	0.016	2	44	50	40.5	0.58
11	0.25	Rural	0.016	0	91.5	92	99.5	0.47
12	0.00	Rural	0.016	0	99.5	80	95.5	0.51
13	1.52	Urban	0.016	1	51	52.5	54.5	0.48
14	2.54	Rural	0.016	1	47.5	35	37	0.47
15	0.00	Rural	0.016	0	82	100	101	0.49
16	1.52	Rural	0.016	0	68	62	59.5	0.44
17	2.79	Rural	0.016	1	80	49.5	57	0.43
18	4.31	Rural	0.016	1	101.5	71	72.5	0.59
19	2.54	Urban	0.016	0	72	66.5	66.5	0.51
20	1.02	Rural	0.016	0	78	52	76.5	0.46
21	3.05	Urban	0.016	5	74.5	44	65	0.44
22	2.03	Rural	0.016	1	103.5	88.5	92.5	0.31
23	0.51	Rural	0.016	3	73.5	67	73	0.34
24	2.28	Rural	0.016	0	124	96	97.5	0.39
25	4.06	Rural	0.016	1	88	55	60	0.5
26	1.27	Rural	0.016	2	98	54	56	0.66
27	2.54	Urban	0.016	1	82.5	73	73	0.35

Table 3.8: PHV, Area Type, Cross Slope, Presence of Curve, and IRI for Treated Sites in the After Period

Segment ID	PHV	Area type	Cross slope	Presence of curve (# of curves)	IRI (in/mile)			Side friction coefficient
					2012	2013	2014	
1	6.59	Rural	0.016	1	81.5	75	70	0.61
2	4.54	Urban	0.016	3	82	52	63	0.49
3	5.22	Rural	0.016	1	112	94	95.5	0.33
4	2.04	Rural	0.016	3	124	93	91.5	0.43
5	3.94	Rural	0.016	1	82.5	85	76.5	0.48
6	1.44	Rural	0.016	0	77	38.5	29	0.47
7	0.91	Rural	0.016	1	74	60.5	61	0.43
8	4.77	Rural	0.016	1	82	54	50	0.34
9	0.23	Rural	0.016	0	57.5	81	63	0.41
10	4.01	Rural	0.016	1	158.5	143	56.5	0.49
11	3.18	Rural	0.016	1	80	43	45	0.33
12	0.08	Rural	0.016	0	81	42	47	0.34
13	3.33	Rural	0.016	1	69	46.5	44.5	0.36
14	3.03	Rural	0.016	0	51	93.5	51	0.53
15	3.26	Rural	0.016	3	81.5	44	42	0.45
16	3.18	Rural	0.016	1	79	36	36.5	0.54
17	3.03	Rural	0.016	1	50	41.5	40.5	0.55
18	1.36	Rural	0.016	0	85	58	52	0.42
19	4.01	Rural	0.016	2	69	24.5	21.5	0.47
20	2.12	Rural	0.016	1	105	75.5	69.5	0.32
21	3.86	Rural	0.016	2	132.5	107	107.5	0.53
22	1.06	Rural	0.016	0	108	89.5	90	0.49
23	2.95	Rural	0.016	1	111.5	89.5	89	0.43
24	3.18	Rural	0.016	0	74	42.5	37	0.47
25	5.90	Rural	0.016	2	71	40.5	38	0.57
26	6.74	Rural	0.016	1	68	25.5	23	0.46
27	0.53	Urban	0.016	0	105	72.5	68.5	0.58
28	0.76	Urban	0.016	1	100.5	77	85.5	0.39
29	3.48	Rural	0.016	1	99.5	66	66	0.46
30	2.80	Rural	0.016	1	109	75	78.5	0.42
31	2.80	Rural	0.016	1	101	76	81	0.37
32	0.91	Rural	0.016	0	100.5	76	81.5	0.74
33	0.00	Rural	0.016	0	109	72	81	0.53
34	0.68	Rural	0.016	1	68	42.5	37	0.48
35	1.51	Rural	0.016	1	105	72.5	68.5	0.49
36	1.06	Urban	0.016	2	125	104.5	109.5	0.49
37	0.53	Rural	0.016	2	98	81	78.5	0.54
38	0.38	Rural	0.016	1	77.5	50	37	0.37
39	0.61	Rural	0.016	2	68.5	50.5	42	0.39

Access density, density of trees, density of poles/mile, and Roadside Hazard Rating (RHR) information about selected freeway and multilane highway segments are included in Tables 3.9 and 3.10 for non-treated sites and treated sites, respectively.

Table 3.9: Access Density, Density of Trees, Density of Poles/Mile, and RHR for Non-Treated Sites in the After Period

Segment ID	Segment length (miles)	Number of access points	Density (access points/ mile)	Number of trees	Density (trees/ mile)	Number of poles	Density (poles/ mile)	RHR
1	5.43	0	0	17	3.13	8	1.47	2
2	2.65	0	0	10	3.77	3	1.13	1
3	11.76	0	0	13	1.10	9	0.76	1
4	4.50	0	0	4	0.88	2	0.44	1
5	7.43	0	0	8	1.07	5	0.67	2
6	11.98	0	0	20	1.67	14	1.17	2
7	6.57	0	0	4	0.60	3	0.45	2
8	15.74	0	0	15	0.95	12	0.76	2
9	14.90	8	0.53	12	0.80	10	0.67	2
10	21.08	0	0	30	1.42	17	0.80	1
11	0.35	0	0	2	5.71	0	0	3
12	6.51	1	0.15	6	0.92	2	0.30	3
13	8.62	0	0	10	1.16	6	0.69	2
14	14.30	4	0.28	16	1.11	9	0.63	3
15	0.94	0	0	2	2.12	1	1.06	3
16	6.51	3	0.46	9	1.38	5	0.76	2
17	19.69	0	0	22	1.11	17	0.86	2
18	12.43	0	0	10	0.80	7	0.56	1
19	8.05	0	0	10	1.24	8	0.99	1
20	6.32	0	0	6	0.95	6	0.95	1
21	18.16	0	0	16	0.88	12	0.66	1
22	16.60	8	0.48	20	1.20	10	0.60	1
23	10.38	5	0.48	10	0.96	8	0.77	1
24	13.06	4	0.30	12	0.92	8	0.61	1
25	21.60	7	0.32	22	1.01	16	0.74	1
26	22.72	0	0	23	1.01	18	0.79	1
27	20.21	0	0	16	0.79	11	0.54	1

Table 3.10: Access Density, Density of Trees, Density of Poles/Mile, and RHR for Treated Sites in the After Period

Segment ID	Segment length (miles)	Number of access points	Density (access points/ mile)	Number of trees	Density (trees/ mile)	Number of poles	Density (poles/ mile)	RHR
1	33.35	0	0	22	0.66	18	0.54	1
2	21.08	0	0	19	0.90	14	0.66	1
3	41.86	0	0	36	0.86	29	0.69	1
4	19.87	0	0	19	0.95	10	0.50	1
5	21.44	0	0	15	0.70	9	0.42	1
6	13.36	0	0	13	0.97	6	0.45	1
7	11.47	0	0	11	0.96	5	0.43	1
8	31.06	0	0	30	0.96	18	0.58	1
9	2.83	0	0	4	1.41	1	0.35	1
10	35.28	0	0	40	1.13	22	0.62	1
11	39.55	0	0	36	0.91	20	0.50	1
12	0.80	0	0	2	2.5	1	1.25	1
13	37.50	0	0	35	0.93	20	0.53	1
14	30.59	0	0	29	0.94	15	0.49	1
15	31.21	0	0	32	1.02	19	0.60	1
16	30.05	0	0	27	0.89	14	0.46	1
17	23.24	0	0	24	1.03	15	0.64	1
18	7.24	0	0	6	0.82	3	0.41	1
19	30.53	0	0	30	0.98	21	0.68	1
20	23.45	0	0	17	0.72	9	0.38	1
21	26.53	0	0	20	0.75	12	0.45	1
22	5.97	0	0	8	1.34	4	0.67	1
23	24.00	0	0	30	1.25	17	0.70	1
24	11.50	0	0	13	1.13	9	0.78	1
25	17.29	0	0	18	1.04	11	0.63	1
26	16.56	0	0	20	1.20	14	0.84	1
27	1.77	0	0	3	1.69	1	0.56	1
28	4.55	0	0	7	1.53	4	0.88	1
29	20.82	0	0	23	1.10	16	0.77	1
30	33.84	0	0	36	1.06	14	0.41	1
31	18.79	0	0	20	1.06	13	0.69	1
32	27.35	0	0	30	1.09	14	0.51	1
33	0.58	0	0	2	3.44	1	1.72	1
34	10.60	0	0	12	1.13	7	0.66	1
35	11.58	0	0	12	1.03	8	0.69	1
36	6.26	0	0	8	1.27	5	0.79	1
37	24.40	0	0	25	1.02	14	0.57	1
38	5.82	0	0	6	1.03	2	0.34	1
39	11.40	0	0	12	1.05	8	0.70	1

3.7 Speed Data

Speed data analysis is needed to identify how drivers' speed changes significantly in the before period compared to the after period. For this purpose, the average speed and 85th percentile speed are computed to conduct the speed analysis. Mostly, the analysis of speed data is concentrated on the 85th percentile speed, which is regarded by many traffic engineers as a major factor in evaluating operating speed as well as the primary criteria in establishing reasonable speed limits (Najjar et al., 2000). There are Automatic Traffic Recorders (ATRs) in Kansas that record the number of vehicles passing in a 1-hour time interval. In this study, data from 15 ATRs were used at non-treated sites and treated sites for some months before speed limit change (2010) and 12 months of data were gathered for after the speed limit change (2012). Thus, the speed data analysis was conducted for an equal number of comparable months in the before period versus the after period. In order to consider smaller sample size, 1-month speed data during the before period and 1-month data during the after period were also utilized.

Location of each ATR and number of vehicles in different speed bins, starting from 40 mph to 95 mph in divisions of 40–45 mph, 45–50 mph, and so forth, were provided to the research team by KDOT. Specifications and availability of data for each ATR are summarized in Table 3.11. The table presents the ATR characteristics with the information about site features, whether it belongs to non-treated or treated sites. Further, speed data for year 2010 and year 2012 for each specific ATR are also available; however, speed data for year 2010 is not available for all months.

In addition, the exact location of each ATR is plotted in Figure 3.4, while showing whether each ATR is in conformance with a control (C) or treated (T) site.

Table 3.11: ATR Characteristics with Available Data for Before and After Speed Limit Change

ATR number	Site Characteristic		Data availability	
	Non-treated site	Treated site	Year 2010	Year 2012
1-EFPRX3	✓		March, September, and December	January to December
2-F10VD5		✓	June	January to December
3-CXJUQ3		✓	June, September, November, and December	January to December
4-CXSRG1	✓		September, November, and December	January to December
5-E7PK42		✓	December	January to December
6-94J8N1		✓	September and December	January to December
7-A0OOS8	✓		March, June, September, and December	January to December
8-CB1U73		✓	September and December	January to December
9-CO1AY7		✓	March, June, and September	January to December
10-CTGTW8		✓	September, November, and December	January to December
11-0DT453		✓	September and December	January to December
12-4LGSU7		✓	September and December	January to December
13-7FGNB7		✓	September and December	January to December
14-9Q9OK1		✓	March to June, September, and December	January to December
15-91TFY5	✓		September and December	January to December

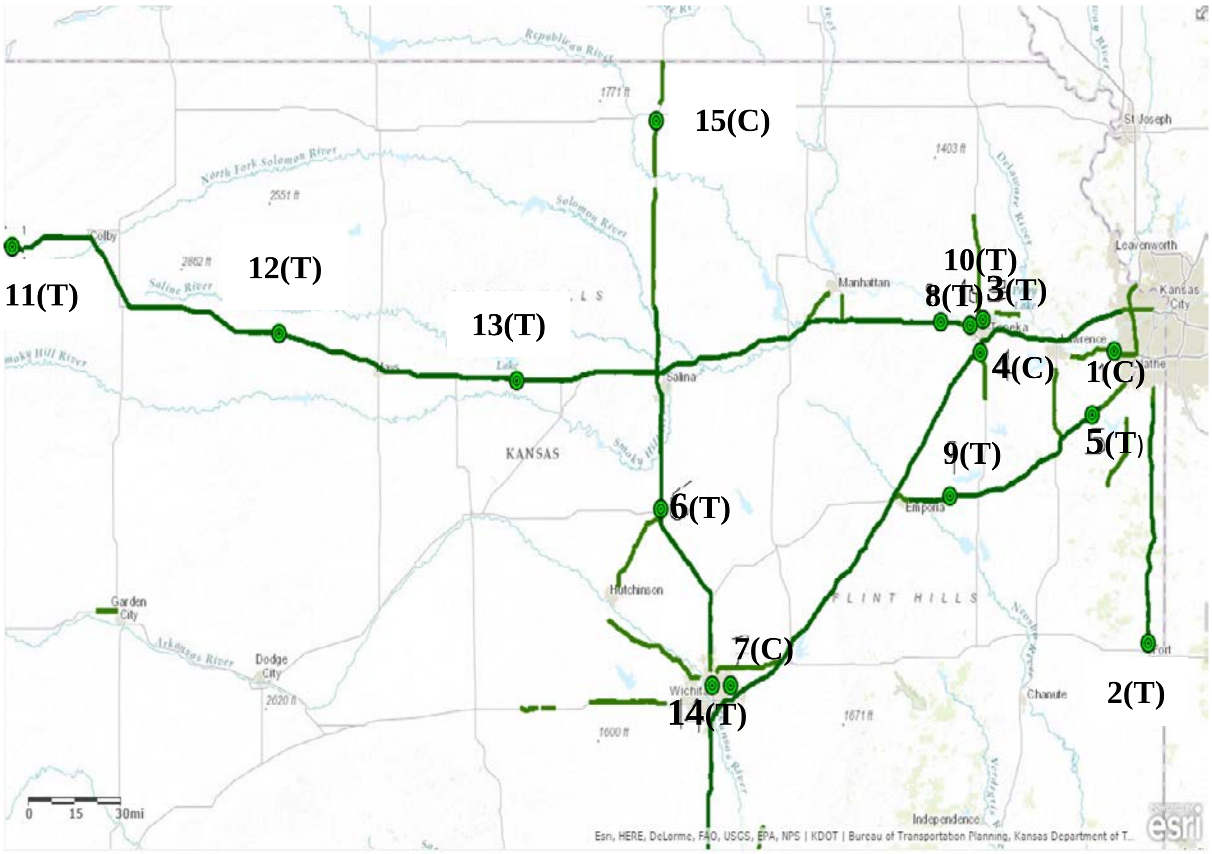

Figure 3.4: Location of Automatic Traffic Recorders (ATRs) on Treated and Non-Treated Sites

3.8 Methodology

Different safety evaluation methods are used to analyze the safety experience after speed limit change. A before-and-after study using the Empirical Bayes (EB) method, which is the state-of-the-art methodology; a before-and-after study with the comparison group method; and a before-and-after study using the cross-sectional method were used in this study to evaluate the safety effectiveness of speed limit increase, and the CMF was estimated to determine the percentage of crash changes after speed limit increase. Additionally, the one-tailed t-test was employed for analyzing the speed data to identify if the average speed and 85^{th} percentile speed during the after period were statistically different from the before period. Similarly, the two-tailed t-test was applied to check if the average speed and 85^{th} percentile speed in the after period were statistically different from the before period.

3.8.1 Crash Modification Factor (CMF)

Crash Modification Factor (CMF) is estimated in before/after studies according to the HSM for identifying how crash change happens after roadway treatments. CMF is a multiplicative factor used to estimate the change in the average expected number of crashes at a site after a treatment implementation. It is the ratio of the expected number of crashes after the change is implemented to the expected number of crashes if the change had not been implemented at the same geographic location (AASHTO, 2014).

CMF is a positive value, so the lower limit is zero and there is no upper limit. A CMF value of one indicates the expected number of crashes with the change is the same as the expected number of crashes without the change and means that the treatment has not had any effect on safety. Moreover, a CMF less than one shows the treatment has a safety benefit and on the contrary, a CMF greater than one means the treatment has had a safety disadvantage (Gayah & Donnell, 2014). In this study, three before-and-after studies are applied, and the description of the methods are included in the following sections.

3.8.2 Before-and-After Study with Empirical Bayes (EB) Method

A typical Bayesian analysis is outlined through the following steps (Glickman & van Dyk, 2007).

1. Formulate a probability model for the data.
2. Decide on a prior distribution, which quantifies the uncertainty in the values of the unknown model parameters before the data are observed.
3. Observe the data and construct the likelihood function according to the data and the probability model. The likelihood is then combined with the prior distribution to determine the posterior distribution, which quantifies the uncertainty in the values of the unknown model parameters after the data are observed.
4. Finally, the important features of the posterior distribution are summarized.

In this study, the probability model chosen for the crash data involves deciding on a probability distribution as well. If the n crash data values to be observed are $y_1, y_{2,} \dots, y_n$, with crash or without crash, and the vector of unknown parameters (randomly selected crashes or crash change) is denoted θ, then the probability function would be: $p(y_i|\,\theta) = \theta^{y_i}(1-\theta)^{1-y_i}$. Once the probability model is chosen, a Bayesian analysis requires a prior distribution for the unknown model parameters. A flexible choice of a prior distribution for a Bernoulli probability is $\theta \sim Beta(\alpha, \beta)$, that is θ has a beta distribution with specified parameters α, β. The beta function is given by:

$$p\,(\theta|\alpha,\beta)= \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\theta^{\alpha-1}(1-\theta)^{\beta-1}$$, where r() represents the gamma function.

Once the crash data has been observed, the likelihood function is constructed. Assuming the data values $y_1, y_{2,} \dots, y_n$ are obtained independently, the likelihood function is given by:

$$L(\theta \mid y)= p(y_1, y_{2,} \dots, y_n|\,\theta)= \prod_{i=1}^{n}(py_i \mid \theta)$$

In order to obtain the posterior distribution, p(θ| y), the probability distribution of the parameters once the data have been observed, the Bayes' theorem will be applied as:

$$p(\theta \mid y)= \frac{p(\theta)p(\theta \mid y)}{\int p(\theta)p(y \mid \theta)d\theta} = \frac{p(\theta)L(\theta \mid y)}{p(y)} \propto p(\theta)L(\theta \mid y)$$

The Empirical Bayes (EB) method is widely recognized as the common methodology for CMF development when conducting before-and-after studies for safety impact treatments implemented on roadways. Results from this method can be used in specifying CMFs for the safety impact treatments. The EB method increases the accuracy of estimates beyond the possibility of occurrence and it also controls regression to the mean (RTM) impact (Høye, 2015). The EB method is applied based on a step-by-step procedure for observational before/after safety effectiveness evaluations. In this study, the data meet the requirements provided in the HSM for applying the EB method and a step-by-step procedure for conducting the method is listed as follows based on the safety effectiveness evaluation chapter in the HSM. The following steps are applied to solve a Bayes problem and to identify the crash change (θ) in specific locations.

Step 1: Treated sections affected by speed limit change would be identified.

Step 2: The predicted crash frequency is calculated for treated sites during each year of the before period. In this step, the correct Safety Performance Function (SPF) should be identified. The freeway SPF computation according to the HSM is as follows:

$$N_{Spf,fs,n,mvorsv,z} = L^* \times \exp(a + b \times \ln[c \times AADT_{fs}])$$ **Equation 3.1**

Where:

$$L^* = L_{fs} - \left[0.5 \times \sum_{i=1}^{2} L_{en,seg,i}\right] - \left[0.5 \times \sum_{i=1}^{2} L_{ex,seg,i}\right]$$ **Equation 3.2**

$N_{spf,fs,n,mvorsv,z}$ = Predicted average multiple-vehicle crash frequency (*mv*) or single-vehicle crash frequency (*sv*) of a freeway segment (*fs*) with base conditions, *n* lanes, and severity *z* (z=FI: Fatal and Injury, PDO: Property Damage Only) (crashes per year)

L^* = Effective length of freeway segment (mi)

L_{fs} = Length of freeway segment (mi)

$L_{en,seg,i}$ = Length of ramp entrance *i* adjacent to subject freeway segment (mi)

$L_{ex,seg,i}$ = Length of ramp exit *i* adjacent to subject freeway segment (mi)

$AADT_{fs}$ = AADT volume of freeway segment (veh/day)

a, *b*, *c* = Regression coefficients

Since all treated sites are four-lane freeways, *a*, *b*, and *c* coefficients are obtained according to Tables 3.12 and 3.13, as provided in the HSM:

Table 3.12: SPF Coefficients for Multiple-Vehicle Crashes on Freeway Segments

Crash severity (Z)	Area type	Number of through lanes (*n*)	SPF coefficient			Inverse Dispersion Parameter $K_{fs,n,mv\ or\ sv,z}$ (mi^{-1})
			a	*b*	*c*	
Fatal and Injury (F&I)	Rural	4	-5.975	1.492	0.001	17.6
		6	-6.092	1.492	0.001	17.6
	Urban	4	-5.470	1.492	0.001	17.6
		6	-5.587	1.492	0.001	17.6
Property Damage Only (PDO)	Rural	4	-6.880	1.936	0.001	18.8
		6	-7.141	1.936	0.001	18.8
	Urban	4	-6.548	1.936	0.001	18.8
		6	-6.809	1.936	0.001	18.8

Source: Table 18-5 in the Highway Safety Manual (AASHTO, 2014)

Table 3.13: SPF Coefficients for Single-Vehicle Crashes on Freeway Segments

Crash severity (Z)	Area type	Number of through lanes (*n*)	SPF coefficient			Inverse Dispersion Parameter $K_{fs,n,mv\ or\ sv,z}$ (mi^{-1})
			a	*b*	*c*	
Fatal and Injury (F&I)	Rural	4	-2.126	0.646	0.001	30.1
		6	-2.055	0.646	0.001	30.1
	Urban	4	-2.126	0.646	0.001	30.1
		6	-2.055	0.646	0.001	30.1
Property Damage Only (PDO)	Rural	4	-2.235	0.876	0.001	20.7
		6	-2.274	0.876	0.001	20.7
	Urban	4	-2.235	0.876	0.001	20.7
		6	-2.274	0.876	0.001	20.7

Source: Table 18-7 in the Highway Safety Manual (AASHTO, 2014)

Step 3: The predicted crash frequency for treated sections during each year of the after period is calculated similar to Step 2 by using the appropriate SPF.

Step 4: The weighted adjustment factor (*w*) is computed for the before period. This factor is calculated based on over-dispersion parameter (*K*) for the applicable SPF; i.e., each SPF has a different *K* value as shown in Tables 3.12 and 3.13. The weighted adjustment factor formula is written based on Equation 3.3:

$$w = \frac{1}{1 + K \sum beforeyears N_{predicted}}$$ **Equation 3.3**

$$k_{fs,n,mvorsv,z} = \frac{1}{K_{fs,n,mvorsv,z} \times L^*}$$ **Equation 3.4**

Where:

w = weighted adjustment factor

$k_{fs,n,mvorsv,z}$ = over-dispersion parameter for freeway segments with *n* lanes, single-vehicle or multiple-vehicle crashes (*mv* or *sv*), and severity *z*

$K_{fs,n,mvorsv,z}$ = inverse dispersion parameter for freeway segments with *n* lanes, single vehicle crashes *sv* or multiple vehicle crashes *mv*, and severity *z* (mi^{-1})

L^* = effective length of freeway segment (mi)

Step 5: The expected crash frequency for treated sites is computed over the entire before period in the absence of the treatment. The expected crash frequency is calculated as follows:

$$N_{expected,B} = w \times N_{predictedbefore} + (1 - w_{before}) \times N_{observedbefore} \qquad \textbf{Equation 3.5}$$

Where:

$N_{expected,B}$ = Expected crash frequency in the before period

w = weighted factor

$N_{predictedbefore}$ = predicted crash frequency in the before period

$N_{observedbefore}$ = observed crash frequency in the before period

Step 6: The adjustment factor (r_i) is computed as:

$$r_i = \frac{\sum N_{predictedafteryears}}{\sum N_{predictedbeforeyears}} \qquad \textbf{Equation 3.6}$$

Where:

$\sum N_{predictedafteryears}$ = summation of predicted crashes in the after years

$\sum N_{predictedbeforeyears}$ = summation of predicted crashes in the before years

Step 7: The expected average crash frequency for treated sites in the after period is calculated as follows:

$$N_{expectedafter} = N_{expectedbefore} \times r_i \qquad \textbf{Equation 3.7}$$

Where:

$N_{expectedafter}$ = expected crashes in the after period

$N_{expectedbefore}$ = expected crashes in the before period

r_i = adjustment factor

Step 8: Estimation of the safety effectiveness of the treatment for each treated site is computed in the form of odds ratio, which is equivalent to the Crash Modification Factor (CMF). The formula is written as:

$$OR_i = \frac{N_{observed,after}}{N_{expected,after}}$$ **Equation 3.8**

Where:

OR_i = odds ratio related to each treated site

$N_{observed,after}$ = observed crashes in the after period

$N_{expected,after}$ = expected crashes in the after period

Step 9: The safety effectiveness index (θ), is computed as a percentage of crash change at each treated site and is written as follows:

$$\theta_i = 100 \times (1 - OR_i)$$ **Equation 3.9**

Step 10: Overall safety effectiveness for all combined treated sites with total crashes is computed as:

$$OR' = \frac{\sum AllsitesN_{observed,after}}{\sum AllsitesN_{expected,after}}$$ **Equation 3.10**

Where:

OR': overall safety effectiveness for all combined treated sites

$\sum AllsitesN_{observed,after}$ = summation of total observed crashes in the after period

$\sum AllsitesN_{expected,after}$ = summation of total expected crashes in the after period

Step 11: The adjusted overall odds ratio is computed. This needs to be conducted because the overall effectiveness mentioned in Equation 3.10 is biased due to the variability in effectiveness at individual sites. The adjusted odds ratio is calculated as follows:

$$OR = \frac{OR'}{1 + \frac{\mathrm{var}(\sum allsitesN_{\exp ected,after})}{\sum (allsitesN_{\exp ected,after})^2}}$$ **Equation 3.11**

Where:

$$\mathrm{var}(\sum allsitesN_{\exp ected,after}) = \sum allsites(r_i^2 \times N_{\exp ected,before} \times (1 - w_{i,B})$$ **Equation 3.12**

And:

$w_{i,B}$: weighted factor of treated sites in the before period

Step 12: The overall unbiased safety effectiveness index is computed as a percentage of change in crash frequency across all treated sites similar to Step 9, i.e., $\theta_i = 100 \times (1 - OR_i)$.

Step 13: The variance of the unbiased estimated safety effectiveness (OR) is computed as follows, using Equation 3.13.

$$Var(OR) = \frac{OR'^2 \times \left[\frac{1}{N_{observed,after}} + \frac{\mathrm{var}\left\{allsitesN_{\exp ected,after}\right\}}{\left\{\sum allsitesN_{\exp ected,after}{}^2\right\}} \right]}{\left[1 + \frac{\mathrm{var}\left\{allsitesN_{\exp ected,after}\right\}}{\left\{\sum allsitesN_{\exp ected,after}{}^2\right\}} \right]}$$ **Equation 3.13**

Step 14: The standard error of safety effectiveness is written according to Equation 3.14:

$$SE(OR) = \sqrt{\mathrm{var}(OR)}$$ **Equation 3.14**

Step 15: The standard error of safety effectiveness percentage is calculated as:

$$SE(\%OR) = 100 \times SE(OR)$$ **Equation 3.15**

Step 16: Statistical significance of estimated safety effectiveness is assessed according to the following equations:

1. If $\left|\frac{safetyeffectiveness}{SE(safetyeffectiveness)}\right| < 1.7$, treatment effect is not significant at the 90 percent confidence level.

2. If $\left|\frac{safetyeffectiveness}{SE(safetyeffectiveness)}\right| \geq 1.7$, treatment effect is significant at the 90 percent confidence level.

3. If $\left|\frac{safetyeffectiveness}{SE(safetyeffectiveness)}\right| \geq 2$, treatment effect is significant at the 95 percent confidence level.

Therefore, these 16 steps are needed to be completed for the before-and-after study using the EB method, and the overall CMF for the treatment is estimated at the end.

3.8.3 Before-and-After Study with Comparison Group Method

The observational before-and-after evaluation study using the comparison group method is also applied in this study, as an alternative evaluation. In this method, the comparison group (non-treated group) plays a significant role in the before-and-after study, since it estimates the change in crash frequency that has happened in the treated group if any treatment has not been made. The comparison group is applied to control for the trends in crash frequency whose causes may be unknown, but which affect the crash frequency and crash severity for both treated and non-treated groups equally. On the other hand, the comparison group is also applied to control for Regression to the Mean (RTM), which is the phenomenon where if a variable is extreme on its first measurement, it will tend to be closer to the average on its second measurement, and if it is extreme on its second measurement, it will tend to have been closer to the average on its first according to the HSM (AASHTO, 2014).

This method is applied in this study by the following steps as it is presented in the HSM.

Step 1: The treated sites (sections affected by speed limit change) and non-treated sites (sections without speed limit change) with AADT, fatal, injury, and PDO crashes for before-and-after speed limit change are identified.

Step 2: The predicted crash frequency is computed for treated sites in the before-and-after period, similar to Step 2 in the EB method.

Step 3: The predicted average crash frequency is calculated for each comparison site (non-treated site) in the before-and-after period. The SPF is applied based on the site characteristics. In this research, there are two different facility types for non-treated sites. Some sites are classified as freeways and others are rural four-lane divided highways. Two different SPFs should be utilized. Since there are two facility types, the SPF for freeways is similar to the treated sites; however, for the rural multilane highways, the SPF is applied as given in the HSM in Chapter 11.

$$N_{SPFrd} = e^{(a+b\times\ln(AADT)+\ln(L))}$$ **Equation 3.16**

Where:

N_{SPFrd} = predicted average crash frequency for the divided multilane highway segment

AADT = Annual Average Daily Traffic (vehicles/day) on the multilane highway segment

L = multilane highway segment length (miles)

a, *b* = regression coefficients (selected from Table 3.14 according to crash severity level)

Table 3.14: SPF Coefficients for Total and Fatal and Injury Crashes for Multilane Highways

Severity Level	*a*	*b*
Four-lane total	-9.025	1.049
Four-lane fatal and injury	-8.837	0.958

Source: Table 11-5 in the Highway Safety Manual (AASHTO, 2014)

Step 4: The adjustment factor of treated sites in the before period is calculated for each of the non-treated sites in the before period using the equation as follows:

$$Adj_{i,j,B} = \frac{N_{predicted,T,B}}{N_{predicted,C,B}} \times \frac{Y_{BT}}{Y_{BC}}$$ **Equation 3.17**

Where:

$N_{predicted,T,B}$= sum of predicted average crash frequencies at treatment site i in the before period using the appropriate SPF and AADT

$N_{predicted,C,B}$= sum of predicted average crash frequencies at non-treated site *j* in the before period using the correct SPF and specific AADT

Y_{BT} = years of before period for treatment site i

Y_{BC} = years of before period for non-treated site *j*

Step 5: The adjustment factor of treated sites in the after period is calculated for each of the non-treated sites in the after period using the following equation:

$$Adj_{i,j,A}=\frac{N_{predicted,T,A}}{N_{predicted,C,A}} \times \frac{Y_{AT}}{Y_{AC}}$$ **Equation 3.18**

Where:

$N_{predicted,T,A}$ = sum of predicted average crash frequencies at treatment site i in the after period using the appropriate SPF and AADT

$N_{predicted,C,A}$ = sum of predicted average crash frequencies at non-treated site *j* in the after period using the correct SPF and specific AADT

Y_{AT} = years of after period for treatment site i

Y_{AC} = years of after period for non-treated site *j*

Step 6: The expected crash frequency of treated site is calculated in the before period **(**$N_{expected,C,B}$) for an individual non-treated site using the following equation:

$$N_{expected,C,B} = \sum_{All\ sites} N_{observed,C,B} \times Adj_{i,j,B}$$ **Equation 3.19**

Step 7: The expected crash frequency is calculated in the after period ($N_{expected,C,A}$) for an individual comparison site using Equation 3.20:

$$N_{expected,C,A}=\sum_{All\ sites} N_{observed,C,A} \times Adj_{i,j,A}$$ **Equation 3.20**

Step 8: For each of the treated sites, the comparison ratio of the non-treated site is calculated by using the following equation:

$$r_{i,c} = \frac{N_{expected,C,A,total}}{N_{expected,C,B,total}}$$ **Equation 3.21**

Step 9: The expected average crash frequency for each of the treated sites without any treatment in the after period is calculated by the following equation:

$$N_{expected,T,A(without\ treatment)}=\sum_{All\ sites} N_{observed,T,B} \times r_{ic}$$ **Equation 3.22**

Where:

$N_{observed,T,B}$ = number of observed crashes for treated sites in the before period

Step 10: The safety effectiveness, expressed as an odds ratio (OR_i) at an individual treatment site i is calculated by using the following equation:

$$OR_i = \frac{N_{observed,T,A}}{N_{expected,T,A(without\ treatment)}}$$ **Equation 3.23**

Where:

OR_i = Crash Modification Factor (CMF) for treated sites

$N_{observed,T,A}$= number of observed crashes for treated sites in the after period

$N_{expected,T,A(without\ treatment)}$ = number of expected crashes for each treated site without any treatment in the after period

Step 11: The log-odds ratio (R) for each of the treated sites is calculated using Equation 3.24.

$$R_i = \ln(OR_i)$$ **Equation 3.24**

Step 12: The weighted adjustment factor (w_i) is calculated for each of the treated sites as follows:

$$w_i = \frac{1}{{R_i}^2_{(SE)}}$$ **Equation 3.25**

Where:

$${R_i}^2_{(SE)} = \frac{1}{N_{observed,T,B,total}} + \frac{1}{N_{observed,T,A,total}} + \frac{1}{N_{Expected,C,B,total}} + \frac{1}{N_{Expected,C,A,total}}$$

${R_i}^2_{(SE)}$ = squared standard error of log odds ratio

$N_{observed,T,B,total}$ = observed total crashes for treated site in the before period

$N_{observed,T,A,total}$ = observed total crashes for treated site in the after period

$N_{Expected,C,B,total}$ = expected total crashes for non-treated site in the before period

$N_{Expected,C,A,total}$ = expected total crashes for non-treated site in the after period

Step 13: The weighted average log-odds ratio (R) across all treated sites for total and fatal and injury crashes is calculated according to Equation 3.26.

$$R = \frac{\sum_n w_i R_i}{\sum_n w_i}$$ **Equation 3.26**

Step 14: Overall effectiveness of the treatment expressed as an odds ratio or CMF is averaged across all sites for both total crashes and fatal and injury crashes, and they are estimated according to Equation 3.27.

$$OR = e^{R}$$ **Equation 3.27**

Step 15: The overall safety effectiveness index (θ) is expressed as a percentage of change in crashes across all treated sites based on Equation 3.28.

$$\text{Safety effectiveness} = 100 \times (1 - OR)$$ **Equation 3.28**

Where:

OR = Overall Crash Modification Factor (CMF) across all treated sites

Step 16: The standard error of treatment effectiveness is computed in order to measure the precision of the treatment effectiveness using the following equation:

$$\text{SE (safety effectiveness)} = 100 \times \frac{OR}{\sqrt{\sum_n w_i}}$$ **Equation 3.29**

Where:

$\sum_n w_i$ = the total weighted adjustment factor across all treated sites

Step 17: The statistical significance of estimated safety effectiveness is assessed by making comparisons with the measure of Abs ($\left|\frac{safety\ effectiveness}{SE(safety\ effectivenss)}\right|$) and drawing conclusions based on the following criteria:

1. If Abs ($\left|\frac{safety\ effectiveness}{SE(safety\ effectivenss)}\right|$) < 1.7, the treatment effect is not significant at the 90 percent confidence level.
2. If Abs ($\left|\frac{safety\ effectiveness}{SE(safety\ effectivenss)}\right|$) ≥ 1.7, the treatment effect is significant at the 90 percent confidence level.
3. If Abs ($\left|\frac{safety\ effectiveness}{SE(safety\ effectivenss)}\right|$) ≥ 2, the treatment effect is significant at the 95 percent confidence level.

Therefore, 17 steps are required in order to apply the before-and-after study with the comparison group method. Finally, the overall CMF is estimated to evaluate the safety effectiveness of treated sites compared to non-treated sites. The last safety effectiveness evaluation method is also applied and the methodology description is included in the following section.

3.8.4 Cross-Sectional Studies

Cross-sectional studies use statistical modeling for considering the crash experience of sites with and without a certain treatment and it is commonly referred to as the "with and without study." This method is only available for the time period after implementation of the treatment and by considering both treatment and non-treatment sites (AASHTO, 2014).

Unlike the previous two methods, there is no step-by-step methodology for a cross-sectional study, because this method requires model development instead of sequence computations. In order to apply this method, all crash, traffic volume, and site characteristics are analyzed in a single model as an indicator variable such as binary variables for the presence or absence of the treatment at a site. A Generalized Linear Model (GLM) with a Negative Binomial (NB) distribution and a logarithmic link function is the standard approach for modeling the yearly crash frequencies. This approach can be implemented using any of several commercially available software packages. This study utilized STATA software package (StataCorp LLC, 2015) to conduct NB regression and estimate CMF, by calculating the exponential of the treatment factor coefficient.

A cross-sectional study might be thought of as comparable to a before-and-after study. Data are only available for the time period after implementation of the treatment; however, it is used for both treatment and non-treatment sites. Typically, when treatment installation dates are not available and when crash and traffic volume data for the period prior to treatment implementation are not available, implementing a cross-sectional study is more useful. However, for this study, the treatment date is already known and applying the cross-sectional method is still fine. Evaluations often use total crash frequency as the measure of effectiveness, but any specific crash severity level or crash type, or both, can also be considered. After that, the required crash and traffic volume data for each site and time period of interest are assembled (AASHTO, 2014).

In order to evaluate the safety effectiveness of a specific treatment, the HSM recommends a 3-year to 5-year comparison of crash data at sites with implemented treatment versus sites without a countermeasure to conduct the cross-sectional study model. Several roadway geometry characteristics are needed to be considered for crash frequency modeling in order to evaluate the safety effectiveness of a treatment using the cross-sectional studies.

3.8.5 Negative Binomial Regression Model

The Negative Binomial regression approach is commonly used to develop crash prediction models. Consider a set of n number segments of a roadway. Let Y_i be a random variable that represents the number of vehicles involved in crashes on a roadway section i during the analysis period. Further, suppose the amount of travel on this freeway segment V_i is also a random variable estimated through a freeway sampling system. For each roadway segment, i is a $k \times 1$ vector of explanatory variables, denoted by $xi = (x_{i1} = 1, x_{i2} \ldots x_{ik})'$, describing its geometric characteristics, traffic conditions, and other relevant attributes. Given V_i and x_i, crash involvements Y_i, $i = 1,2,3\ldots..$, n are presumed to be independent and each is Poisson distributed as follows (Park and Abdel, 2015a, 2015b):

$$P(Y_i = y_i) = \frac{(\lambda_i \theta_i)^{y_i} e^{-\lambda_i \theta_i}}{y_i!}$$ **Equation 3.30**

Where:

λ_i = motor vehicle crash involvement

θ_i = exponential of random error

If the log-linear rate function is used as shown in Equation 3.31, the model becomes a Negative Binomial regression model that gives the relationship between the expected number of crashes occurring at the i^{th} segment and K number of parameters as follows:

$$\lambda_i = \exp(\beta X_i + \varepsilon_i)$$ **Equation 3.31**

Where:

λ_i = the expected number of crashes per period at location *i*

X_i = the vector of explanatory variables

β = the vector of estimable parameters

exp(ε_i) = a gamma-distributed error term with mean 1 and variance α^1

Negative Binomial distribution is a consequence of gamma heterogeneity in Poisson means. The effect of the error term in the Negative Binomial regression model allows for over dispersion of the variance, such that:

$$Var(y_i) = E(y_i) + \alpha E(y_i)^2$$ **Equation 3.32**

Where:

α = an over-dispersion parameter

E (y_i) = an expected mean number of crashes on freeway segment *i*

Var (y_i) = a variance of the number of crashes y_i

Variance over the mean is called an over-dispersion rate; variance is explained in Equation 3.33.

$$\frac{\mathrm{var}(y_i)}{E(y_i)} = 1 + \alpha E(y_i)$$ **Equation 3.33**

Where:

E (y_i) = the expected mean number of crashes on roadway segment *i*

Var (y_i) = a variance of the number of crashes y_i

The maximum likelihood method in STATA software can be used to estimate parameters of the Negative Binomial regression model and over-dispersion parameter α .

The cross-sectional method is also known as SPFs or crash prediction models. The SPF relates the crash frequency to traffic and roadway geometrics. The functional form of SPF for fitting the NB regression models is shown in Equation 3.34 (AASHTO, 2014).

$$N_{predicted,i} = \exp\left(L_i + \beta_0 + \beta_1 \ln\left(AADT_i\right) + \ldots + \beta_K(\mathrm{X}k_i)\right)$$ **Equation 3.34**

Where:

$N_{predicted,i}$ = predicted crash frequency on segment *i*

L_i = roadway length of segment *i*

β_K = coefficients for the variables *k*

$AADT_i$ = Annual Average Daily Traffic for segment *i* (veh/day)

Xk_i = linear predictor k of segment *i*

The cross-sectional method is a useful method for estimating CMFs if there is not enough crash data during the periods before and after a specific treatment. Based on the HSM, cross-sectional studies could be utilized when the date of treatment installation is not known and data for the before period does not exist. Carter et al. (2012) stated the CMF is computed by taking the ratio of average crash frequency of sites with the feature to the average crash frequency of sites without the feature. So, the CMF can be estimated from the coefficients of the variable associated with the treatment as the exponent of the coefficient when the form of the model is log-linear as shown in Equation 3.35 (Lord & Bonneson, 2007).

$$\text{CMF} = \exp\{\beta_K \times (X_{kt} - X_{kb})\} \qquad \textbf{Equation 3.35}$$

Where:

X_{kt} = linear predictor *k* of treated sites

X_{kb} = linear predictor *k* of untreated sites (baseline condition)

The Standard Error (SE) of the CMF is also computed through Equation 3.36 (Harkey et al., 2008).

$$\text{SE} = \frac{\exp\left(\beta_K + SE_{\beta_K}\right) - \exp(\beta_K - SE_{\beta_K})}{2} \qquad \textbf{Equation 3.36}$$

Where:

SE = standard error of the CMF

SE_{β_K}= standard error of the coefficient β_K

If a geometric characteristic is expressed in a binary variable (i.e., treatment [=1] or no treatment [=0]), the CMF will be exp (β_K) or the odds ratio of the linear predictor k (X_k).

3.8.6 Two-Sample t-Test

This section introduces basic information about the t-test method applied for speed data analysis to check whether or not the average speed and 85th percentile speed during the after period are statistically significant compared to the before period. To apply the t-test, the following assumptions must be met (Brandt, 1999):

1. Observations from two groups are normally distributed.
2. Variances of two groups should be checked for equality.
3. Observations from two groups are independent of each other.

The null hypothesis for the two-tailed t-test is that the means of the two groups are equal, while the alternative hypothesis is that the means of the two data groups are not equal (Brandt, 1999). An α value is typically specified for determining the significant level of whether to accept or reject the null hypothesis.

Hypothesis testing for the two-tailed t-test is shown according to Equations 3.37 and 3.38 (Brandt, 1999):

$$H_0 : \mu_0 = \mu_1$$ **Equation 3.37**

$$H_1 : \mu_0 \neq \mu_1$$ **Equation 3.38**

Where:
H_0 = null hypothesis
H_1 = alternative hypothesis
μ_0 = average speed or 85th percentile speed before speed limit change
μ_1 = average speed or 85th percentile speed after speed limit change

On the other hand, the null hypothesis for the one-tailed t-test shows no difference between the means of the two groups, and the alternative hypothesis is identified as the mean of the first data group being greater or less than the second group. Hypothesis testing for a one-tailed t-test is according to Equations 3.39 and 3.40.

$$H_0 : \mu_0 = \mu_1$$ **Equation 3.39**

$$H_1 : \mu_0 \langle \mu_1$$ **Equation 3.40**

When applying the t-test for independent groups, there are different equations for computing the t-statistic, which depend on the variance equality of each groups. The t-statistic is calculated by the following equations (SAS Institute Inc., 1990; Dissanayake & Liu, 2011).

3.8.6.1 Equal Sample Sizes

When the sample sizes of two groups are equal, the t-statistic is calculated according to Equation 3.41.

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{(S_1)^2 + (S_2)^2}{n}}}$$, Degree of Freedom (D.O.F.) = $2n - 2$ **Equation 3.41**

Where:

t = estimated t-value

$\overline{X_1}$ = mean of Group 1

$\overline{X_2}$ = mean of Group 2

S_1 = standard deviation of Group 1

S_2 = standard deviation of Group 2

n = number of observations in each group

3.8.6.2 Unequal Sample Sizes with Equal Variance

The t-statistic for two groups of data with different sample sizes and equal variance is computed according to Equation 3.42.

$$t = \frac{\overline{X_1} - \overline{X_2}}{S_{\overline{X_1} - \overline{X_2}}}$$, Degree Of Freedom (D.O.F.) = $n_1 + n_2 - 2$ **Equation 3.42**

Where:

t = estimated t-value

$\overline{X_1}$ = mean of Group 1

$\overline{X_2}$ = mean of Group 2

$S_{\overline{X_1} - \overline{X_2}}$ = grand standard deviation = $\sqrt{\frac{(n_1 - 1)S_1{}^2 + (n_2 - 1)S_2{}^2}{n_1 + n_2 - 2}(\frac{1}{n_1} + \frac{1}{n_2})}$

Where:

S_1 = standard deviation of Group 1

S_2 = standard deviation of Group 2

n_1 = number of observations in Group 1

n_2 = number of observations in Group 2

3.8.6.3 Unequal Sample Sizes with Unequal Variance

When the variance of two groups are not equal to each other and the sample sizes are also not equal, the t-statistic computation is based on Equation 3.43.

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$ **Equation 3.43**

Where:

t = estimated t-value

$\overline{X_1}$ = mean of Group 1

$\overline{X_2}$ = mean of Group 2

S_1 = standard deviation of Group 1

S_2 = standard deviation of Group 2

n_1 = number of observations in Group 1

n_2 = number of observations in Group 2

The Degree of Freedom (D.O.F.) for this type of data is calculated using Equation 3.44.

$$\text{D.O.F.} = \frac{(S_1^2/n_1 + S_2^2/n_2)^2}{(S_1^2/n_1)^2/(n_1-1) + (S_2^2/n_2)^2/(n_2-1)}$$ **Equation 3.44**

To check variance equality, the F-test statistic is commonly used. The F-test hypothesis is defined according to Equations 3.45 and 3.46 (Montgomery, Runger, & Hubele, 2010).

$$H_0 : \sigma_1^2 = \sigma_2^2$$ **Equation 3.45**

$$H_1 : \sigma_1^2 \neq \sigma_2^2$$ **Equation 3.46**

Where:

H_0 = null hypothesis

H_1 = alternative hypothesis

σ_1^2 = variance of Group 1

σ_2^2 = variance of Group 2

In order to compute the F statistic value, Equation 3.47 is applied.

$$F = \frac{S_1{}^2}{S_2{}^2}$$ **Equation 3.47**

Where:

$S_1{}^2$ = variance of the first group

$S_2{}^2$ = variance of the second group

The critical t-value and F-value are obtained from a standard t-table and F-table according to the significance level, which is 95 percent in this study, and the degree of freedom.

The null hypothesis is rejected or accepted based on the comparison between the calculated t-value and F-value with their critical values. The t-test and F-test procedure of STATA (StataCorp LLC, 2015) is utilized in this study to compute the probability value (p-value) for testing the significance level.

The p-value is the primary indicator for validating the null hypothesis and it is interpreted as follows. If the p-value is greater than 5 percent, the null hypothesis is approved, and the alternative hypothesis is rejected at a 95 percent confidence level. On the other hand, when the p-value is less than 5 percent, the null hypothesis is rejected, and the alternative hypothesis will be approved.

3.8.7 Kolmogorov-Smirnov (K-S) Test

The Kolmogorov-Smirnov (K-S) test is based on the Empirical Distribution Function (EDF). This test is defined for comparing two different data distributions of sizes *m* and *n*, and the hypothesis test for checking two different distributions is as follows (Pham, 2006):

H_0: The distribution for one set of data is the same as the second set of data

H_a: The distribution for one set of data is different than the second set of data

The Kolmogorov-Smirnov test statistic is defined as:

$$D_{n,m} = \sup_x \left| F_{1,n}(x) - F_{2,m}(x) \right|$$ **Equation 3.48**

Where:

$D_{n,m}$ = test statistic for difference between two distributions

$F_{1,n}(x)$ & $F_{2,m}(x)$ = empirical distribution functions for the first and second samples

Sup = supremum function

n, *m* = sizes of first and second sample, respectively

The null hypothesis regarding the distributional form is rejected if:

$$D_{n,m} \rangle c(\alpha)\sqrt{\frac{n+m}{nm}}$$ **Equation 3.49**

Where:

Critical D = $1.36 \times \sqrt{\frac{m+n}{mn}}$ **Equation 3.50**

The value of $c(\alpha)$ is given for the most common statistical significance level of α and the values are given in Table 3.15 (Kres, 2012).

Table 3.15: Critical Values for Distribution of Two Sets of Data Based on Different Significance Levels

α	0.10	0.05	0.025	0.01	0.005	0.001
$c(\alpha)$	1.22	1.36	1.48	1.63	1.73	1.95

The null hypothesis that the distribution of two sets of data is the same was verified using the R software package (R Development Core Team, 2013), which is very common to apply to a K-S test, and to check whether the probability (p-value) is greater than 0.05 at the 95 percent confidence level; otherwise, there is no evidence the two sets of data come from the same distribution.

Chapter 4: Results and Discussion

In this chapter, results of the methodologies applied in this study are presented. Results of the Empirical Bayes (EB) method are described in Section 4.1, results of before-and-after study with the comparison group method are discussed in Section 4.2, and the cross-sectional studies model using Negative Binomial (NB) regression results is included in Section 4.3. Additionally, the two-sample t-test results for speed data analysis, along with K-S test results, are presented in Section 4.4.

4.1 Results of the Empirical Bayes Method

Results from the EB method are presented in a step-by-step format according to the descriptions provided in the methodology section. In this research, results from the before-and-after study were collected by considering 3 years before the speed limit change (2008–2010) and 3 years after the speed limit change (2012–2014). The year 2011 is not considered since the speed limit change was made effective during this year, which in fact became effective on July 1, 2011 (KDOT, 2011).

Step 1: Table 4.1 presents fatal, injury, and PDO crashes on treated sections affected by speed limit change for 3 years before and 3 years after the speed limit change. Treated sections consist of 39 sections as shown in Figure 1.1, with total length of 808 miles, which are the only sections considered in the EB method. Total number of crashes during the before period is more than the after period but fatal and injury crashes for the majority of sites in the after period have increased compared to the before period. Sites 12 and 33 have the least number of crashes, perhaps because the lengths of those sections are too short and are not expected to be comparable to larger sections.

Table 4.1: Details of Treated Sites Before and After Speed Limit Change

ID	County	Length (mile)	AADT(veh/day)		Crash count					
			Average 3 years (before)	Average 3 years (after)	Before			After		
					F	I	PDO	F	I	PDO
1	Sumner	33.35	17,025	16,750	5	80	356	4	73	302
2	Sedgwick	21.08	18,145	19,850	2	68	294	7	86	315
3	Butler	41.86	13,075	13,750	2	77	409	2	93	421
4	Chase	19.87	12,640	12,850	2	59	184	1	38	124
5	Lyon	21.44	15,150	12,450	1	52	267	2	44	202
6	Coffey	13.36	12,165	12,100	0	21	105	2	17	92
7	Osage	11.47	10,800	11,400	0	25	58	4	16	45
8	Franklin	31.06	15,110	15,800	4	69	305	1	63	246
9	Miami	2.83	19,520	19,900	1	11	31	0	10	21
10	Sherman	35.28	8,230	8,280	5	25	108	4	35	115
11	Thomas	39.55	8,890	8,750	2	31	145	2	42	135
12	Logan	0.80	8,110	8,110	0	1	3	0	1	3
13	Gove	37.50	8,595	8,935	4	38	141	1	46	115
14	Trego	30.59	9,460	9,940	0	17	117	3	25	141
15	Ellis	31.21	11,270	11,800	3	30	252	5	44	193
16	Russell	30.05	10,700	11,500	3	28	158	0	27	163
17	Ellsworth	23.24	10,935	11,600	2	28	126	1	43	111
18	Linclon	7.24	12,100	12,750	0	11	30	1	11	43
19	Saline	30.53	14,250	15,500	1	49	215	2	50	234
20	Dickinson	23.45	15,300	14,900	2	37	184	0	32	180
21	Geary	26.53	12,100	12,750	4	77	261	6	99	311
22	Riley	5.97	16,750	17,200	1	15	47	2	28	50
23	Wabaunsee	24.00	18,300	18,600	2	67	243	2	87	259
24	Shawnee	11.50	28,850	30,000	3	58	278	1	53	246
25	Douglas	17.29	32,175	33,600	1	116	561	1	108	417
26	Leavenworth	16.56	29,325	31,150	1	101	422	2	99	392
27	Wyandotte	1.77	34,550	30,800	9	232	795	8	263	710
28	Sedgwick	4.55	28,750	23,800	1	37	179	1	15	64
29	Harvey	20.82	22,500	23,800	1	54	220	4	53	243
30	Mcpherson	33.84	12,450	12,900	1	30	202	2	45	217
31	Saline	18.79	21,800	23,500	2	47	164	1	59	178
32	Lyon	27.35	6,790	7,060	1	32	217	0	18	147
33	Wabaunsee	0.58	6,780	7,300	0	0	4	0	0	2
34	Osage	10.60	6,980	7,235	1	15	86	0	11	60
35	Shawnee	11.58	6,980	7,235	0	26	141	2	16	120
36	Shawnee	6.26	11,635	12,350	0	24	111	2	21	86
37	Miami	24.40	15,850	15,450	0	17	80	3	25	207
38	Saline	5.82	8,165	8,500	0	4	24	1	6	28
39	Ottawa	11.40	7,315	7,475	0	11	97	2	8	44
Total					**1,787**		**7,620**	**1,891**		**6,982**

Step 2: Predicted crash frequency in the before period for all treated sites is tabulated in Table 4.2. Sample calculations are computed for the first treated site based on multiple-vehicle crashes with fatal and injury severity as follows:

$$N_{spf,fs,n,mv,z} = L^* \times \exp(a + b \times ln[c \times AADT_{fs}]) = 33.35 \times \exp.(-5.975+1.492 \times \ln(0.001 \times 17{,}025)) = 5.82 \text{ crashes}$$

The *a*, *b*, and *c* were obtained from Table 3.12 and the AADT was also substituted according to Table 4.1 during the before period for the first treated site.

Step 3: Predicted crash frequency in the after period for all of the treated sites is tabulated in Table 4.3 and for the first treated site based on single-vehicle, PDO crashes are computed as follows:

$$N_{spf,fs,n,sv,z} = L^* \times \exp(a + b \times ln[c \times AADT_{fs}]) = 33.35 \times \exp.(-2.235+0.876 \times \ln(0.001 \times 16{,}750)) = 42.14 \text{ crashes}$$

The *a*, *b*, and *c* were obtained from Table 3.13 and the AADT was also substituted according to Table 4.1 during the before period for the first treated site.

Step 4: The over-dispersion parameter value and weighted adjustment factor for all of the treated sites during the before period are tabulated in Table 4.4.

The weighted factor for the first treated site with the summation of single/multiple-vehicle crashes and with fatal, injury, and PDO crashes during the before period is computed as follows:

$$w = \frac{1}{1 + K \sum beforeyearsN_{predicted}} = \frac{1}{1 + 0.006 \times 242.83} = 0.40$$

The *K* value is the summation of the over-dispersion parameter for single-vehicle crashes and multiple-vehicle crashes for both total crashes and fatal and injury crashes, which would be 0.006 for the first treated site. For example, the over-dispersion parameter value for the first treated site based on single-vehicle crashes and with fatal and injury severity is computed as follows:

$$K_{fs,n,sv,z} = \frac{1}{K_{fs,n,sv,z \times L^*}} = \frac{1}{30.1 \times 33.35} = 0.00099$$

The value of 30.1 in the denominator is obtained from Table 3.13 and the segment length of the first treated site is 33.35 miles. The predicted crash frequency is also computed for the first treated site according to Equation 3.1, which would be the summation for single-vehicle with fatal and injury and PDO crashes and multiple-vehicle crashes with fatal and injury and PDO crashes, i.e., 242.83 crashes. Tables 4.2, 4.3, and 4.4 will present summary results of all treated sections from Steps 2 to 4 during before-and-after periods.

Step 5: The expected total crash frequency for the first treated site in the entire before period is computed as follows:

$$N_{expected,B} = \mathrm{W} \times N_{predicted\ before} + \left(1 - W_{before}\right) \times N_{observed\ before}$$
$$= 0.4 \times 242.83 + (1 - 0.4) \times 441 = 360.34 \text{ crashes}$$

The weighted factor (W) is already computed and is included in Table 4.4, which is 0.40 for the first treated site. The predicted crash frequency based on Equation 3.1 is also 242.83, and total observed crashes for the first treated site is 441 according to Table 4.1 during the before period. The expected total crash frequency for the rest of the treated sites is shown in Table 4.5.

Table 4.2: Predicted Total Crash Frequency in the Before Period from 2008 to 2010

Site characteristics			Predicted crash frequency			Total predicted crashes
Site number	Route ID	Site length (mi)	2008	2009	2010	
1	I0003500	33.358	80.217	80.905	81.709	242.831
2	I0003500	21.089	59.934	58.410	59.917	178.261
3	I0003500	41.863	79.048	78.766	80.034	237.848
4	I0003500	19.87	36.451	36.451	36.824	109.726
5	I0003500	21.445	50.686	49.510	47.023	147.219
6	I0003500	13.369	24.615	23.897	23.924	72.436
7	I0003500	11.474	19.741	19.280	18.436	57.456
8	I0003500	31.068	74.070	67.489	67.954	209.514
9	I0003500	2.839	8.692	7.653	7.938	24.283
10	I0007000	35.28	45.213	43.349	44.576	133.138
11	I0007000	39.554	52.540	52.355	53.465	158.360
12	I0007000	0.809	1.005	1.005	1.009	3.019
13	I0007000	37.508	50.023	49.372	49.221	148.616
14	I0007000	30.594	44.090	43.171	43.682	130.943
15	I0007000	31.215	53.704	51.657	52.116	157.477
16	I0007000	30.051	49.489	47.441	47.882	144.812
17	I0007000	23.248	37.664	37.291	37.773	112.728
18	I0007000	7.247	12.711	12.711	12.905	38.327
19	I0007000	30.532	67.156	64.666	63.217	195.039
20	I0007000	23.455	52.069	50.952	51.910	154.931
21	I0007000	26.533	46.538	46.538	47.249	140.325
22	I0007000	5.97	14.685	14.480	14.397	43.562
23	I0007000	24.009	64.215	63.546	63.045	190.806
24	I0007000	11.503	47.706	47.098	47.793	142.598
25	I0007000	17.297	80.225	78.214	80.696	239.135
26	I0007000	16.568	70.724	69.214	70.031	209.970
27	I0007000	1.779	10.847	10.132	10.235	31.214
28	I0013500	4.555	22.695	22.442	21.227	66.364
29	I0013500	20.829	72.167	71.410	67.049	210.625
30	I0013500	33.842	60.946	61.855	61.855	184.657
31	I0013500	18.797	63.081	58.088	58.624	179.793
32	I0033500	27.359	28.564	28.564	29.283	86.411
33	I0033500	0.581	0.620	0.621	0.621	1.862
34	I0033500	10.604	11.321	11.335	11.621	34.278
35	I0033500	11.586	12.370	12.385	12.697	37.452
36	I0047000	6.267	11.531	11.390	11.470	34.391
37	U0006900	24.402	56.839	56.839	55.837	169.515
38	U0008100	5.823	7.529	7.186	7.307	22.021
39	U0008100	11.409	13.789	12.802	13.017	39.608

Table 4.3: Predicted Total Crash Frequency in the After Period from 2012 to 2014

Site characteristics			Predicted crash frequency			Total predicted crashes
Site number	Route ID	Site length (mi)	2012	2013	2014	
1	I0003500	33.358	80.447	80.218	80.447	241.111
2	I0003500	21.089	65.939	65.592	65.765	197.296
3	I0003500	41.863	82.998	84.129	83.846	250.974
4	I0003500	19.87	37.252	37.520	37.386	112.158
5	I0003500	21.445	39.196	39.196	39.196	117.589
6	I0003500	13.369	24.705	23.807	23.807	72.319
7	I0003500	11.474	19.126	19.356	19.356	57.839
8	I0003500	31.068	71.091	70.878	70.878	212.847
9	I0003500	2.839	8.090	8.090	8.090	24.270
10	I0007000	35.28	44.718	44.812	44.812	134.342
11	I0007000	39.554	52.461	53.306	52.725	158.493
12	I0007000	0.809	1.009	1.009	1.009	3.028
13	I0007000	37.508	49.973	49.622	50.925	150.520
14	I0007000	30.594	43.804	46.194	45.642	135.640
15	I0007000	31.215	53.704	56.425	54.331	164.460
16	I0007000	30.051	49.489	51.098	51.098	151.685
17	I0007000	23.248	38.752	39.842	39.842	118.435
18	I0007000	7.247	13.246	13.831	13.538	40.614
19	I0007000	30.532	67.780	66.740	68.405	202.925
20	I0007000	23.455	51.111	50.473	50.633	152.217
21	I0007000	26.533	48.496	50.637	49.566	148.699
22	I0007000	5.97	14.767	14.767	14.767	44.302
23	I0007000	24.009	64.215	64.047	64.047	192.309
24	I0007000	11.503	48.841	49.805	49.805	148.451
25	I0007000	17.297	83.061	85.513	84.557	253.131
26	I0007000	16.568	74.151	75.174	74.662	223.987
27	I0007000	1.779	8.897	9.030	8.963	26.890
28	I0013500	4.555	17.035	17.427	17.230	51.692
29	I0013500	20.829	70.654	71.258	70.956	212.868
30	I0013500	33.842	62.537	64.586	63.903	191.026
31	I0013500	18.797	59.161	64.580	63.217	186.957
32	I0033500	27.359	30.038	30.553	30.277	90.869
33	I0033500	0.581	0.652	0.652	0.662	1.965
34	I0033500	10.604	11.892	12.077	11.984	35.953
35	I0033500	11.586	12.993	13.195	13.094	39.283
36	I0047000	6.267	11.955	12.334	12.145	36.434
37	U0006900	24.402	54.837	54.504	54.504	163.846
38	U0008100	5.823	7.272	7.357	7.568	22.197
39	U0008100	11.409	12.848	13.262	13.262	39.372

Table 4.4: Over-Dispersion Parameter and Weighted Factor During Before Period

Site characteristics			*K*	*W*
Site number	Route ID	Site length (mi)		
1	I0003500	33.358	0.006	0.407
2	I0003500	21.089	0.009	0.384
3	I0003500	41.863	0.005	0.457
4	I0003500	19.87	0.010	0.477
5	I0003500	21.445	0.009	0.430
6	I0003500	13.369	0.014	0.496
7	I0003500	11.474	0.017	0.506
8	I0003500	31.068	0.006	0.443
9	I0003500	2.839	0.067	0.381
10	I0007000	35.28	0.005	0.600
11	I0007000	39.554	0.005	0.558
12	I0007000	0.809	0.237	0.583
13	I0007000	37.508	0.005	0.574
14	I0007000	30.594	0.006	0.560
15	I0007000	31.215	0.006	0.514
16	I0007000	30.051	0.006	0.535
17	I0007000	23.248	0.008	0.526
18	I0007000	7.247	0.026	0.501
19	I0007000	30.532	0.006	0.461
20	I0007000	23.455	0.008	0.447
21	I0007000	26.533	0.007	0.504
22	I0007000	5.97	0.032	0.418
23	I0007000	24.009	0.008	0.396
24	I0007000	11.503	0.017	0.292
25	I0007000	17.297	0.011	0.275
26	I0007000	16.568	0.012	0.284
27	I0007000	1.779	0.108	0.229
28	I0013500	4.555	0.042	0.264
29	I0013500	20.829	0.009	0.345
30	I0013500	33.842	0.006	0.474
31	I0013500	18.797	0.010	0.357
32	I0033500	27.359	0.007	0.623
33	I0033500	0.581	0.330	0.619
34	I0033500	10.604	0.018	0.618
35	I0033500	11.586	0.017	0.611
36	I0047000	6.267	0.031	0.484
37	U0006900	8.876	0.022	0.211
38	U0008100	5.823	0.033	0.579
39	U0008100	11.409	0.017	0.598

Step 6: The adjustment factor for all treated sites is summarized in Table 4.6, and for the first treated site is as follows:

$$r_i = \frac{\sum N_{predictedafteryears}}{\sum N_{predictedbeforeyears}} = \frac{241.11}{242.83} = 0.99$$

The predicted crash frequency in the after period is computed for the first treated site according to Equation 3.1, which would be the summation for single-vehicle with fatal and injury and PDO crashes and multiple-vehicle crashes with fatal and injury and PDO crashes, i.e., 241.11 crashes. The same computations have been repeated for predicted crash frequency in the before period, which is 242.83 crashes.

Step 7: The expected crash frequency in the after period of all treated sites is presented in Table 4.7, and for the first treated site is computed as follows:

$$N_{\text{exp}ectedafter} = N_{\text{exp}ectedbefore} \times r_i = 360.34 \times 0.993 = 357.79 \text{ crashes}$$

Expected crashes in the before period are computed in Step 5, which is 360.34 crashes for the first treated site, and the adjustment factor is included in Table 4.6, which is 0.99 for the first site.

Step 8: The CMF for all of the treated sites is summarized in Table 4.8 and for the first treated site based on total crashes is computed as follows:

$$OR_1 = \frac{N_{observed,After}}{N_{expected,After}} = \frac{379}{357.79} = 1.05$$

Total observed crashes for the first treated site during the after period is 379 according to Table 4.1 and expected crashes are also included in Table 4.7. The following tables present summary results from Steps 5 to 8.

Table 4.5: Expected Average Total Crash Frequency During the Before Period

Site characteristics			Expected crash frequency in the before period
Site number	Route ID	Site length (mi)	
1	I0003500	33.358	360.345
2	I0003500	21.089	292.681
3	I0003500	41.863	373.736
4	I0003500	19.870	180.500
5	I0003500	21.445	245.685
6	I0003500	13.369	99.406
7	I0003500	11.474	70.078
8	I0003500	31.068	302.795
9	I0003500	2.839	35.875
10	I0007000	35.280	135.081
11	I0007000	39.554	167.039
12	I0007000	0.809	3.428
13	I0007000	37.508	163.274
14	I0007000	30.594	132.288
15	I0007000	31.215	219.431
16	I0007000	30.051	165.356
17	I0007000	23.248	133.247
18	I0007000	7.247	39.661
19	I0007000	30.532	232.763
20	I0007000	23.455	192.605
21	I0007000	26.533	240.261
22	I0007000	5.970	54.880
23	I0007000	24.009	264.030
24	I0007000	11.503	281.642
25	I0007000	17.297	557.117
26	I0007000	16.568	434.778
27	I0007000	1.779	806.130
28	I0013500	4.555	177.226
29	I0013500	20.829	252.768
30	I0013500	33.842	210.066
31	I0013500	18.797	201.132
32	I0033500	27.359	148.068
33	I0033500	0.581	2.676
34	I0033500	10.604	60.119
35	I0033500	11.586	87.847
36	I0047000	6.267	86.305
37	U0006900	8.876	112.333
38	U0008100	5.823	24.537
39	U0008100	11.409	0.017

Table 4.6: Adjustment Factor for Treated Sites

Site characteristics			r_i
Site number	Route ID	Site length (mi)	
1	I0003500	33.358	0.993
2	I0003500	21.089	1.107
3	I0003500	41.863	1.055
4	I0003500	19.87	1.022
5	I0003500	21.445	0.799
6	I0003500	13.369	0.998
7	I0003500	11.474	1.007
8	I0003500	31.068	1.016
9	I0003500	2.839	0.999
10	I0007000	35.28	1.009
11	I0007000	39.554	1.001
12	I0007000	0.809	1.003
13	I0007000	37.508	1.013
14	I0007000	30.594	1.036
15	I0007000	31.215	1.044
16	I0007000	30.051	1.047
17	I0007000	23.248	1.051
18	I0007000	7.247	1.060
19	I0007000	30.532	1.040
20	I0007000	23.455	0.982
21	I0007000	26.533	1.060
22	I0007000	5.97	1.017
23	I0007000	24.009	1.008
24	I0007000	11.503	1.041
25	I0007000	17.297	1.059
26	I0007000	16.568	1.067
27	I0007000	1.779	0.861
28	I0013500	4.555	0.779
29	I0013500	20.829	1.011
30	I0013500	33.842	1.034
31	I0013500	18.797	1.040
32	I0033500	27.359	1.052
33	I0033500	0.581	1.055
34	I0033500	10.604	1.049
35	I0033500	11.586	1.049
36	I0047000	6.267	1.059
37	U0006900	8.876	0.967
38	U0008100	5.823	1.008
39	U0008100	11.409	0.994

Table 4.7: Expected Total Average Crash Frequency During the After Period

Site characteristics			Expected crash frequency in the after period
Site number	Route ID	Site length (mi)	
1	I0003500	33.358	357.79
2	I0003500	21.089	323.93
3	I0003500	41.863	394.36
4	I0003500	19.870	184.50
5	I0003500	21.445	196.24
6	I0003500	13.369	99.24
7	I0003500	11.474	70.54
8	I0003500	31.068	307.61
9	I0003500	2.839	35.86
10	I0007000	35.280	136.30
11	I0007000	39.554	167.18
12	I0007000	0.809	3.44
13	I0007000	37.508	165.37
14	I0007000	30.594	137.03
15	I0007000	31.215	229.16
16	I0007000	30.051	173.20
17	I0007000	23.248	139.99
18	I0007000	7.247	42.03
19	I0007000	30.532	242.17
20	I0007000	23.455	189.23
21	I0007000	26.533	254.60
22	I0007000	5.970	55.81
23	I0007000	24.009	266.11
24	I0007000	11.503	293.20
25	I0007000	17.297	589.72
26	I0007000	16.568	463.80
27	I0007000	1.779	694.46
28	I0013500	4.555	138.04
29	I0013500	20.829	255.46
30	I0013500	33.842	217.31
31	I0013500	18.797	209.15
32	I0033500	27.359	155.71
33	I0033500	0.581	2.82
34	I0033500	10.604	63.06
35	I0033500	11.586	92.14
36	I0047000	6.267	91.43
37	U0006900	8.876	108.58
38	U0008100	5.823	24.73
39	U0008100	11.409	66.73

Table 4.8: CMF for Total Crashes and Fatal and Injury Crashes for Treated Sites

ID	County	Beginning location	Length (mile)	CMF (Total crashes)	CMF (fatal and injury crashes)
1	Sumner	2.7M N State LN	33.35	1.059	0.860
2	Sedgwick	Suab Wichita	21.08	1.260	1.234
3	Butler	SCL Andover	41.86	1.308	1.002
4	Chase	1.3 M N Scol	19.87	0.883	0.833
5	Lyon	Thorndale Rd	21.44	1.264	1.006
6	Coffey	I35/K131	13.36	1.118	0.697
7	Osage	1.45 M N CO L	11.47	0.907	0.857
8	Franklin	I35/K273	31.06	1.008	0.805
9	Miami	2.6 MI N W CO L	2.83	0.865	1.044
10	Sherman	I70/K267	35.28	1.130	0.742
11	Thomas	0.9 MI E WCOL	39.55	1.071	0.720
12	Logan	LG/GO CO LN	0.80	1.163	0.814
13	Gove	I70/U40	37.50	0.980	0.790
14	Trego	1.1 MI E Wcol	30.59	1.233	0.561
15	Ellis	K247 RS 230	31.21	1.056	0.813
16	Russell	RS 48	30.05	1.097	0.481
17	Ellsworth	I70/K232	23.24	1.107	0.984
18	Linclon	RS 1751	7.24	1.309	0.789
19	Saline	RS 447	30.53	1.181	0.715
20	Dickinson	I70/K221	23.45	1.120	0.586
21	Geary	RS 270	26.53	1.634	1.681
22	Riley	RS 1315	5.97	1.433	1.815
23	Wabaunsee	Wabaunsee Rd	24.00	1.308	1.257
24	Shawnee	1470 Undrpas/I70	11.50	1.023	0.996
25	Douglas	1.1 MI E W CO L	17.29	0.892	1.136
26	Leavenworth	0.7 MI E W CO LN	16.56	1.063	1.189
27	Wyandotte	1.4 MI E WCOL	1.77	1.413	3.328
28	Sedgwick	RS 612	4.55	0.580	0.701
29	Harvey	I135/K196	20.82	1.174	0.805
30	Mcpherson	SJCT I135/K260	33.84	1.215	0.694
31	Saline	SJCT I135/U81/K4	18.79	1.138	0.952
32	Lyon	0.04 MN I35/KTA/I335	27.35	1.060	0.473
33	Wabaunsee	WB/OS CO LN	0.58	0.708	0.000
34	Osage	OS/SN CO LN	10.60	1.126	0.717
35	Shawnee	1.5 M NE S CO L	11.58	1.498	1.015
36	Shawnee	I470/KTA	6.26	1.192	1.393
37	Miami	U69/K68	24.40	2.164	0.523
38	Saline	0.4 MI N I70	5.82	1.415	0.818
39	Ottawa	1.0 MI N S CO L	11.40	0.809	0.628

Step 9: The safety effectiveness index for the first treated site is -5.9 percent, which represents a 5.9 percent increase in crashes. Any negative percentage shows an increase for crashes and a positive percentage means a crash decrease.

Step 10: Overall effectiveness for all combined treated sites with total crashes is computed as follows:

$$OR' = \frac{\sum AllsitesN_{observed,after}}{\sum AllsitesN_{expected,after}} = \frac{8{,}873}{7{,}638.06} = 1.161 \text{ (total crashes)}$$

Total observed crashes in the after period are 8,873 crashes according to Table 4.1, and expected total crashes are 7,638.06 according to Table 4.7. However, overall effectiveness for all treated sites by considering fatal and injury crashes is different than that of total crashes and is computed as follows, which shows almost no changes in the number of fatal and injury crashes between observed and expected values.

$$OR' = \frac{\sum AllsitesN_{observed,after}}{\sum AllsitesN_{expected,after}} = \frac{1{,}892}{1{,}876.93} = 1.008 \text{ (fatal and injury crashes)}$$

Step 11: The adjusted overall odds ratio is computed based on the following computation:

$$OR = \frac{OR'}{1 + \frac{\text{var}(\sum allsitesN_{expected,after})}{\sum (allsitesN_{expected,after})^2}} = \frac{1.161}{1 + \frac{4,536.764}{7,638.06^2}} = 1.160 \text{ (total crashes)}$$

$$\text{var}(\sum allsitesN_{expected,after}) = \sum allsites(r_i^2 \times N_{expected,before} \times (1 - w_{i,B}) = 4{,}536.764$$

And, the overall CMF for all treated sites with fatal and injury crashes is computed as:

$$OR = \frac{OR'}{1 + \frac{\text{var}(\sum allsitesN_{expected,after})}{\sum (allsitesN_{expected,after})^2}} = \frac{1.008}{1 + \frac{372.141}{1{,}876.93^2}} = 1.007 \text{ (fatal and injury crashes)}$$

According to CMF definition, the CMF of greater than 1 indicates an increase in crash frequency.

Step 12: The overall unbiased safety effectiveness index is computed as a percentage of change in crash frequency across all treated sites:

$\theta = 100 \times (1 - 1.160) = -16\%$ increase for total crashes

$\theta = 100 \times (1 - 1.007) = -0.7\%$ increase for fatal and injury crashes

Step 13: The variance of the unbiased estimated safety effectiveness (OR) is computed as follows:

Var (OR) = 0.00025 (total crashes)

Var (OR) = 0.00064 (fatal and injury crashes)

Step 14: The standard error of safety effectiveness is calculated for total crashes and fatal plus injury crashes as follows:

$SE(OR) = \sqrt{var(OR)} = \sqrt{0.00025} = 0.016$ (for total crashes)

$SE(OR) = \sqrt{var(OR)} = \sqrt{0.00064} = 0.025$ (for fatal and injury crashes)

Step 15: The Standard Error (SE) of safety effectiveness percentage is calculated for total crashes and fatal and injury crashes as follows:

$100 \times SE\ (OR)$ = 1.60% (for total crashes)

$100 \times SE\ (OR)$ = 2.53% (for fatal and injury crashes)

Step 16: Statistical significance of estimated safety effectiveness is assessed according to Step 17 criteria for both total crashes and fatal and injury crashes separately. The values are calculated as follows:

$\left|\frac{safety\ effectiveness}{SE(safety\ effectiveness}\right| = \frac{16}{1.6} = 10 \geq 2$, the treatment effect is significant at 95 percent confidence level (for total crashes).

$\left|\frac{safety\ effectiveness}{SE(safety\ effectiveness}\right| = \frac{0.7}{2.53} = 0.27 < 1.7$, the treatment effect is not significant at 90 percent confidence level (for fatal and injury crashes).

Statistical significance of estimated safety effectiveness for total crashes shows that the treatment effect is statistically significant at the 95 percent confidence level because it is greater than 2. However, the statistical significance of estimated safety effectiveness for fatal and injury crashes shows that the treatment effect has not been statistically significant, since it is much less than 1.7 according to HSM recommendations as shown in Step 17 in the Methodology Section 3.8.

4.2 Results of Before-and-After Study with Comparison Group Method

In this section, results from the before-and-after study with the comparison group method are presented in a step-by-step format according to the methodology presented in Section 4.1. A 3-year before period and 3-year after period are considered for the safety analysis similar to the previous method.

Step 1: The treated sites (sections affected by speed limit change) and non-treated sites (sections without speed limit change) with AADT, fatal, injury, and PDO crashes for before-and-after speed limit change are identified. The treated sites are already included in Table 4.1 and non-treated sites are presented in Table 4.9.

Table 4.9: Observed Crashes on Non-Treated Sites Before and After Speed Limit Change

ID	County	Length (mile)	AADT(veh/day)		Crash count					
			Average 3 Years Before	Average 3 Years After	Before			After		
					F	I	PDO	F	I	PDO
1	LYON	5.43	15,150	16,300	1	51	266	1	46	138
2	SHAWNEE	2.65	27,850	25,850	3	58	278	0	32	130
3	WYANDOTTE	11.768	51,000	59,450	9	232	795	8	255	668
4	SEDGWICK	4.50	28,750	30,750	1	37	179	0	21	117
5	JOHNSON	7.43	84,400	86,600	2	104	324	4	80	309
6	WYANDOTTE	11.982	42,800	46,750	3	93	330	3	82	312
7	DOUGLAS	6.57	25,200	25,200	1	29	98	0	21	98
8	JOHNSON	15.746	42,100	40,500	3	98	465	3	99	500
*9	RENO	14.9	8,090	8,230	0	27	66	0	25	67
10	SEDGWICK	21.085	18,755	19,050	1	46	202	1	55	174
*11	GEARY	0.35	5,470	7,370	0	0	2	0	0	2
*12	RILEY	6.51	6,115	6,825	0	6	29	1	4	15
*13	SEDGWICK	8.62	10,405	10,840	3	25	70	2	18	66
*14	BUTLER	14.305	12,150	11,900	0	35	138	4	29	110
*15	SHAWNEE	0.94	10,185	10,970	0	3	21	0	2	16
*16	JEFFERSON	6.516	5,670	6,035	0	10	29	1	7	44
17	KINGMAN	19.691	5,765	5,930	0	4	77	1	13	80
18	SEDGWICK	12.432	9,565	9,015	0	28	110	0	22	79
19	JOHNSON	8.051	21,060	23,000	1	39	143	1	28	110
20	OSAGE	6.328	8,510	8,645	0	18	60	0	10	54
21	SHAWNEE	18.162	18,835	18,540	1	54	212	3	49	191
*22	JACKSON	16.60	12,850	12,225	3	46	129	0	23	101
*23	COWLEY	10.38	9,955	9,670	2	19	69	0	20	102
*24	OTTAWA	13.06	6,495	5,765	0	11	97	2	9	45
*25	CLOUD	21.603	5,340	5,630	0	16	98	3	8	81
*26	REPUBLIC	22.723	4,365	4,425	0	12	63	1	5	33
27	MIAMI	20.214	9,560	9,855	3	22	172	0	20	132
Total					**1,160**		**4,522**	**1,022**		**3,774**

Table 4.9 presents the details of non-treated sections, which shows total crashes have decreased during the after period compared to the before period, similar to the treated sites. However, fatal and injury crashes during the after period are less than the before period for most sites and the combined group, which is contrary to the results from the fatal and injury crashes on treated sites.

Step 2: The predicted crash frequency is computed for treated sites during the before-and-after periods and the results are the same as presented in Tables 4.2 and 4.3.

Step 3: The predicted crash frequency for the non-treated sites during the before-and-after period is computed according to the Equations 3.1 and 3.16. Final results are tabulated in Tables 4.10 and 4.11.

Table 4.10: Predicted Total Crash Frequency for Non-Treated Sites in the Before Period

ID	Route ID	Length (mile)	Predicted crash frequency			Total predicted crashes
			2008	2009	2010	
1	I0003500	5.430	13.91	13.58	12.85	40.35
2	I0007000	2.650	12.37	12.21	11.92	36.50
3	I0007000	11.768	115.26	105.87	108.83	329.97
4	I0013500	4.509	22.46	22.22	21.01	65.70
5	I0043500	7.433	135.17	138.00	134.84	408.02
6	I0043500	11.982	95.77	88.05	89.06	272.88
7	K0001000	6.575	25.93	24.18	23.74	73.85
8	K0001000	15.746	122.95	115.71	114.71	353.37
9	K0009600	14.900	18.18	18.10	22.55	58.83
10	K0009600	21.085	52.95	54.23	56.70	163.89
11	K0017700	0.350	0.39	0.35	0.35	1.10
12	K0017700	6.517	8.20	7.37	7.35	22.93
13	K0025400	8.629	14.68	14.91	15.24	44.84
14	K0025400	14.305	34.60	34.46	33.17	102.22
15	U0002400	0.940	1.88	1.77	1.81	5.47
16	U0002400	6.516	7.85	7.26	6.79	21.91
17	U0005400	19.691	17.37	17.23	18.34	52.95
18	U0005400	12.432	16.66	16.98	17.93	51.57
19	U0006900	8.051	25.57	26.17	26.72	78.46
20	U0007500	6.328	8.18	8.10	8.23	24.52
21	U0007500	18.162	56.23	52.64	53.63	162.51
22	U0007500	16.600	49.68	50.53	40.82	141.04
23	U0007700	10.380	17.89	18.53	19.53	55.95
24	U0008100	13.060	16.73	15.38	15.70	47.82
25	U0008100	21.603	23.16	20.92	21.14	65.22
26	U0008100	22.723	18.99	17.66	18.00	54.65
27	U0016900	20.214	33.10	32.91	30.76	96.78

Table 4.11: Predicted Total Crash Frequency for Non-Treated Sites in the After Period

Site characteristics			Predicted crash frequency			Total predicted crashes
Site number	Route ID	Site length (mi)	2012	2013	2014	
1	I0003500	5.430	13.75	12.56	13.83	40.14
2	I0007000	2.650	10.88	10.97	10.97	32.82
3	I0007000	11.768	137.20	132.63	132.63	402.47
4	I0013500	4.509	22.51	22.89	22.68	68.07
5	I0043500	7.433	139.82	133.27	139.82	412.91
6	I0043500	11.982	91.75	103.32	99.32	294.40
7	K0001000	6.575	24.91	21.97	23.74	70.62
8	K0001000	15.746	112.89	109.44	109.44	331.76
9	K0009600	14.900	22.49	22.81	22.96	68.26
10	K0009600	21.085	57.72	56.69	57.57	171.98
11	K0017700	0.350	0.39	0.48	0.48	1.36
12	K0017700	6.517	7.33	9.06	8.25	24.64
13	K0025400	8.629	16.14	15.79	15.96	47.89
14	K0025400	14.305	32.88	32.45	32.45	97.78
15	U0002400	0.940	1.85	1.87	1.96	5.69
16	U0002400	6.516	8.16	7.25	7.25	22.66
17	U0005400	19.691	18.99	18.79	18.79	56.56
18	U0005400	12.432	17.33	17.01	17.01	51.35
19	U0006900	8.051	99.30	96.33	96.49	292.12
20	U0007500	6.328	8.12	8.35	8.35	24.81
21	U0007500	18.162	53.36	50.57	52.76	156.69
22	U0007500	16.600	38.65	38.74	38.74	116.13
23	U0007700	10.380	19.10	18.63	18.94	56.67
24	U0008100	13.060	14.75	13.85	13.85	42.45
25	U0008100	21.603	23.35	22.35	22.35	68.05
26	U0008100	22.723	18.50	18.11	18.26	54.87
27	U0016900	20.214	31.77	31.34	31.64	94.75

Step 4: The adjustment factor of the first treated site is computed for the first non-treated site during the before period:

$$Adj_{1,1,B} = \frac{N_{predicted,T,B}}{N_{predicted,C,B}} \times \frac{Y_{BT}}{Y_{BC}} = (242.83/40.35)\times 3/3 = 6.02$$

The numerator, 242.83, is substituted according to Table 4.2 for the first treated site and the denominator, 40.35, is substituted according to Table 4.10 for the first non-treated site. In addition, the number of years during the before-and-after periods are also 3 years, which would be three divided by three. Accordingly, adjustment factors for all other treated sites are computed for non-treated sites during the before period.

Step 5: The adjustment factor of the first treated site is computed for the first non-treated site during the after period.

$$Adj_{1,1,B} = \frac{N_{predicted,T,A}}{N_{predicted,C,A}} \times \frac{Y_{BT}}{Y_{BC}} = (241.11/40.14)\times 3/3 = 6.01$$

The numerator, 241.11, is substituted according to Table 4.3 for the first treated site during the after period and the denominator, 40.14, is substituted according to Table 4.11 for the first non-treated site during the after period. In addition, the number of years during the before-and-after periods are also 3 years, which would be three divided by three. Similarly, the adjustment factors for all other treated sites are also computed for non-treated sites during the after period.

Step 6: The expected crash frequency of the first treated site in the before period for the first non-treated site is computed as:

$$N_{expected,C,B} = 318\times 6.02 = 1{,}914 \text{ crashes}$$

Total number of crashes for the first non-treated site during the before period is 318 crashes and the adjustment factor for the non-treated site is 6.02 according to Step 4. Expected crash frequencies for all other sites during the before period are also computed based on Equation 3.19.

Step 7: The expected crash frequency of the first treated site in the after period for the first non-treated site is computed as:

$$N_{expected,C,A} = 185\times 6.01 = 1{,}112 \text{ crashes}$$

Total number of crashes for the first non-treated site during the after period is 185 crashes and the adjustment factor for the non-treated site is 6.01 according to Step 5. Expected crash frequencies for all other sites during the after period are also computed based on Equation 3.20.

Step 8: The comparison ratio of the non-treated site is calculated for the first treated site:

$$r_{i,c} = \frac{N_{expected,C,A,total}}{N_{expected,C,B,total}} = \frac{12{,}015}{16{,}448} = 0.730$$

Total expected crashes for the non-treated sites during before-and-after periods are 16,448 and 12,015 according to Table 4.12.

Step 9: The expected average crash frequency is calculated for the first treated site if there was not any treatment during the after period.

$$N_{expected,T,A(without\ treatment)} = \sum_{All\ sites} N_{observed,T,B} \times r_{1c} = 441 \times 0.730 = 321.93 \text{ crashes}$$

Observed crashes (441 crashes) during the before period for the first treated site are obtained from Table 4.1 and the comparison ratio of the first treated site is included in Table 4.12. Expected fatal and injury crashes for all treated sites are also included in Table 4.13.

Step 10: The safety effectiveness, expressed as an odds ratio (OR_1) for the first treated site, is calculated using the following equation.

$$OR_1 = \frac{N_{observed,T,A}}{N_{expected,T,A(without\ treatment)}} = \frac{379}{321.93} = 1.18$$

Both observed crashes and expected crashes without treatment during the after period for the first treated site and other treated sites are included in Table 4.12.

Table 4.12: CMF and Expected Crashes in the Before and After Period for Treated Sites

Site number	$N_{expected,C,B}$	$N_{expected,C,A}$	$r_{i,c}$	$N_{expected,T,A}$ (without treatment)	$N_{observed,T,A}$	CMF (total crashes)	CMF (fatal and injury crashes)
1	16,448	12,015	0.730	321.93	379.00	1.18	1.18
2	12,060	9,830	0.815	296.66	408.00	1.38	1.57
3	16,100	12,504	0.777	379.18	516.00	1.36	1.49
4	7,427	5,589	0.753	184.49	163.00	0.88	0.81
5	9,972	5,851	0.587	187.84	248.00	1.32	1.36
6	4,903	3,606	0.735	92.61	111.00	1.20	1.17
7	3,877	2,875	0.742	61.59	65.00	1.06	1.03
8	14,177	10,604	0.748	282.00	310.00	1.10	1.12
9	1,642	1,206	0.734	31.56	31.00	0.98	1.08
10	9,013	6,691	0.742	102.40	154.00	1.50	1.67
11	10,726	7,893	0.736	131.01	179.00	1.37	1.72
12	205	155	0.756	3.02	4.00	1.32	1.29
13	10,052	7,491	0.745	136.34	162.00	1.19	1.43
14	8,961	6,763	0.755	101.17	169.00	1.67	2.07
15	10,487	8,201	0.782	222.87	242.00	1.09	1.85
16	9,866	7,563	0.767	144.96	190.00	1.31	1.08
17	7,697	5,902	0.767	119.65	155.00	1.30	1.82
18	2,790	2,027	0.727	29.81	55.00	1.85	1.34
19	13,188	10,106	0.766	202.99	286.00	1.41	1.30
20	10,482	7,590	0.724	161.45	212.00	1.31	1.08
21	9,395	7,410	0.789	269.84	416.00	1.54	1.60
22	3,191	2,206	0.691	43.53	80.00	1.84	2.39
23	12,931	9,586	0.741	231.19	348.00	1.51	1.66
24	9,696	7,396	0.763	258.66	300.00	1.16	1.11
25	15,977	12,610	0.789	534.94	526.00	0.98	1.15
26	14,253	11,170	0.784	410.82	493.00	1.20	1.21
27	2,111	1,342	0.636	658.90	981.00	1.49	1.64
28	4,491	2,586	0.576	124.99	80.00	0.64	0.67
29	14,264	10,608	0.744	204.60	300.00	1.47	1.33
30	12,503	9,515	0.761	177.31	264.00	1.49	1.91
31	12,172	9,310	0.765	162.95	238.00	1.46	1.53
32	5,847	4,529	0.775	193.75	165.00	0.85	0.67
33	133	96	0.722	2.89	2.00	0.69	0.00
34	2,318	1,796	0.775	79.05	71.00	0.90	0.85
35	2,541	1,960	0.771	128.76	138.00	1.07	0.86
36	2,324	1,812	0.780	105.30	109.00	1.04	1.18
37	11,471	8,166	0.712	69.06	235.00	3.40	2.19
38	1,493	1,112	0.745	20.86	35.00	1.68	2.28
39	2,685	1,966	0.732	79.06	54.00	0.68	1.18

Table 4.13: Expected and Observed Total Crashes and Fatal and Injury Crashes for Treated Sites

ID	County	Expected fatal and injury crashes in the after period without treatment	Expected total crashes in the after period without treatment	Observed fatal and injury crashes in the after period	Observed total crashes in the after period
1	Sumner	65.37	321.93	77	379
2	Sedgwick	59.06	296.66	93	408
3	Butler	63.93	379.17	95	516
4	Chase	48.10	184.48	39	163
5	Lyon	33.93	187.84	46	248
6	Coffey	16.23	92.61	19	111
7	Osage	19.44	61.58	20	65
8	Franklin	57.19	281.99	64	310
9	Miami	9.24	31.56	10	31
10	Sherman	23.36	102.39	39	154
11	Thomas	25.54	131.00	44	179
12	Logan	0.78	3.024	1	4
13	Gove	32.83	136.33	47	162
14	Trego	13.56	101.17	28	169
15	Ellis	26.48	222.87	49	242
16	Russell	24.95	144.96	27	190
17	Ellsworth	24.21	119.65	44	155
18	Linclon	8.94	29.80	12	55
19	Saline	39.96	202.99	52	286
20	Dickinson	29.72	161.45	32	212
21	Geary	65.81	269.83	105	416
22	Riley	12.56	43.53	30	80
23	Wabaunsee	53.67	231.19	89	348
24	Shawnee	48.68	258.65	54	300
25	Douglas	94.70	534.94	109	526
26	Leavenworth	83.22	410.81	101	493
27	Wyandotte	164.83	658.89	271	981
28	Sedgwick	23.71	124.99	16	80
29	Harvey	42.91	204.60	57	300
30	Mcpherson	24.66	177.31	47	264
31	Saline	39.09	162.94	60	238
32	Lyon	26.68	193.75	18	165
33	Wabaunsee	0.00	2.88	0.00	2
34	Osage	12.90	79.05	11	71
35	Shawnee	20.94	128.75	18	138
36	Shawnee	19.49	105.30	23	109
37	Miami	12.77	69.06	28	235
38	Saline	3.06	20.86	7	35
39	Ottawa	8.46	79.05	10	54

Step 11: The log odds ratio (*R*) for the first treated site based on total crashes is calculated according to the following equation.

$$R_1 = \ln(OR_1) = \ln(1.18) = 0.165$$

The Odds Ratio (*OR*), which is equivalent to CMF, is included in Table 4.12 for the first treated site and all other treated sites. In addition, the log odds ratio for the remaining treated sites is included in Table 4.14.

Step 12: The squared standard error of the log odds ratio (${R_i}^2{}_{(SE)}$) and weighted factor (w_i) for the first treated site is computed according to Equation 3.25.

$${R_1}^2{}_{(SE)} = \frac{1}{441} + \frac{1}{379} + \frac{1}{16{,}448} + \frac{1}{12{,}015} = 0.005$$

$$w_1 = \frac{1}{{R_1}^2{}_{(SE)}} = \frac{1}{0.005} = 198.02$$

The squared error of the log odds ratio and weighted factor for all other treated sites are included in Table 4.14.

Step 13: The weighted average log odds ratios (*R*) across all treated sites are as follows:

$$\text{R} = \frac{\sum_n w_i R_i}{\sum_n w_i} = \frac{1{,}005.99}{4{,}187.19} = 0.240 \text{ (for total crashes)}$$

$$\text{R} = \frac{\sum_n w_i R_i}{\sum_n w_i} = \frac{247.69}{814.66} = 0.304 \text{ (for fatal and injury crashes)}$$

The numerator and denominator values of *R* have been obtained from Table 4.14.

Step 14: Overall effectiveness of the treatment expressed as an odds ratio, averaged across all treated sites, is estimated as follows. This is also the CMF, which shows the safety effectiveness of increased speed limit. Any value greater than one shows an increase in number of crashes and any value less than one shows a decrease in number of crashes.

OR(CMF) = $e^R = e^{0.240}$ = 1.271 (for total crashes), where *R* is 0.240 according to Step 13.

OR (CMF) = $e^{0.304}$ = 1.355 (for fatal and injury crashes), where *R* is 0.304 according to Step 13.

Table 4.14: Log Odds Ratio, Squared Standard Error, and Weighted Factor for Treated Sites

Site number	Log odds ratio (R)	${R_1}^2_{SE}$	W_i	Weighted product ($W \times R$)
1	0.165	0.005	198.01	32.32
2	0.319	0.005	185.77	59.20
3	0.308	0.004	242.17	74.62
4	-0.124	0.011	94.97	-11.76
5	0.278	0.007	134.62	37.40
6	0.181	0.017	57.38	10.39
7	0.054	0.028	35.67	1.92
8	0.095	0.006	165.48	15.67
9	-0.018	0.057	17.56	-0.32
10	0.408	0.014	71.43	29.15
11	0.312	0.011	87.53	27.32
12	0.280	0.511	1.96	0.55
13	0.172	0.012	84.24	14.53
14	0.513	0.014	73.32	37.62
15	0.082	0.008	127.25	10.48
16	0.271	0.011	92.70	25.08
17	0.259	0.013	75.98	19.67
18	0.613	0.043	23.03	14.11
19	0.343	0.007	134.32	46.05
20	0.272	0.009	106.06	28.89
21	0.433	0.006	179.56	77.72
22	0.609	0.029	34.32	20.88
23	0.409	0.006	159.74	65.32
24	0.148	0.007	153.34	22.74
25	-0.017	0.004	284.26	-4.79
26	0.182	0.004	244.11	44.52
27	0.398	0.003	312.16	124.24
28	-0.446	0.018	56.44	-25.19
29	0.383	0.007	140.17	53.65
30	0.398	0.008	121.00	48.16
31	0.379	0.009	110.06	41.70
32	-0.161	0.010	95.67	-15.37
33	-0.367	0.768	1.30	-0.48
34	-0.107	0.025	40.20	-4.32
35	0.069	0.014	70.73	4.90
36	0.035	0.018	56.94	1.97
37	1.225	0.015	67.69	82.88
38	0.518	0.066	15.18	7.86
39	-0.381	0.029	34.89	-13.30
Total			**4,187.19**	**1,005.99**

*Negative log odds ratio means decrease in number of crashes

Step 15: The overall safety effectiveness index (θ) is expressed as percentage of change in crashes across all treated sites:

Safety effectiveness (θ)=100×(1-OR) = 100×(1-1.271) = -27.12% (for total crashes)

Safety effectiveness=100×(1-OR) = 100×(1-1.355) = -35.53% (for fatal and injury crashes)

The negative estimate of the safety effectiveness indicates a negative effectiveness, which means there was a 27 percent increase in total crashes and 35 percent increase for fatal and injury crashes as the result of increased speed limits on freeways in Kansas.

Step 16: The standard error of treatment effectiveness is computed in order to measure the precision of the treatment effectiveness as follows:

SE (safety effectiveness) $=100\times \frac{OR}{\sqrt{\sum_n w_i}}=100\times \frac{1.271}{\sqrt{4,187.19}}$ = 1.96 % (for total crashes)

SE (safety effectiveness) $=100\times \frac{OR}{\sqrt{\sum_n w_i}}=100\times \frac{1.355}{\sqrt{814.66}}$ = 4.74 % (for fatal and injury crashes)

The standard error for total crashes is 0.0196, and the standard error for fatal and injury crashes is 0.0474. Both standard errors are very small and according to Equation 4.1, which shows the confidence interval based on the HSM, they do not contain 1; this means the CMF of this change is statistically significant at the 95 percent confidence level.

Confidence Interval (CI) = CMF±(cumulative probability×standard error)

CI = 1.27 ±(1.96×0.0196) = 1.23 to 1.30, that does not contain 1 (for total crashes)

CI = 1.35± (1.96×0.0474) = 1.25 to 1.44, that does not contain 1 (for fatal and injury crashes)

Equation 4.1

Step 17: The statistical significance of estimated safety effectiveness is assessed by making comparisons with the measure of Abs ($\left|\frac{safety\ effectiveness}{SE(safety\ effectivenss)}\right|$).

Abs $\left|\frac{\boldsymbol{safety\ effectiveness}}{\boldsymbol{SE(safety\ effectivenss)}}\right| = \frac{27.12}{1.96}$ = 13.80 ≥ 2, the treatment effect is significant at 95% confidence level (for total crashes).

Abs $\left|\frac{safety\ effectiveness}{SE(safety\ effectivenss)}\right| = \frac{35.53}{4.74}$ = 7.49 ≥ 2, the treatment effect is significant at 95% confidence level (for fatal and injury crashes).

The before-and-after with the comparison group method results showed that total crashes increased by 27 percent and fatal and injury crashes increased by 35 percent, which is 8 percent more than the increase for total crashes. This method considered both treated and non-treated sites and the CMF for total crashes was significant at the 95 percent confidence level.

Furthermore, the statistical significance of estimated safety effectiveness for fatal and injury crashes showed that the treatment effect was statistically significant at a 95 percent confidence level. The main difference in the results between the before-and-after with the comparison group method and EB method is that fatal and injury crashes also increased using the before-and-after with the comparison group method and the increase was statistically significant. Based on the EB method, results showed the increase in fatal and injury crashes was not statistically significant.

4.3 Results of Cross-Sectional Study

Binary values were used for the impact of speed limit increase, median type, rumble strip type, functional classification type, shoulder type, and area type. A total of 25 variables were considered in the cross-sectional model development and Table 4.15 shows the description of all variables initially considered in the analysis along with their corresponding averages, minimums, maximums, and standard deviations.

Table 4.15: Description of Variables Considered in the NB Model

Variables	Average	Std. dev.	Minimum	Maximum	Description
Average_adt	16,806	13,472	4,431	85,633	-
length	16.28	10.73	0.35	41.86	-
num_lanes	2.080	0.27	2	3	-
Speed limit	0.59	0.50	0.0	1.00	=1 if speed limit is 70mph =0 if speed limit is 75mph
lane_width	12	0.0	12	12	
Median_type	6.55	0.90	0.0	1.0	=1 if it is depressed/cable barrier; =0 otherwise
median_width	49.72	18.56	19.60	84	
Rumble_strip_type	0.95	0.21	0.0	1.0	=1 if there is inside right; =0 otherwise
functional_class	0.82	0.39	0.0	1.0	=1 if it is freeway; =0 otherwise
Degree_of_curve	0.42	0.54	0.0	2.5	-
shoulder_type	0.32	0.47	0.0	1.0	=1 if it is Portland cement; =0 otherwise
Shoulder_width_inside	6.65	1.35	5.90	9.80	-
surface_type	0.45	0.50	0.0	1.0	=1 if it is concrete; =0 otherwise
average_IRI	73.17	22.31	38.33	123.33	-
# of on/off_ramps	6.33	5.96	0.0	24	-
# of interchanges	0.27	0.35	0.0	2.13	-
PHV	3.03	2.92	0.0	14.21	-
area_type	0.23	0.42	0.0	1.0	=1 if it is rural; =0 otherwise
# of curves	0.08	0.09	0.0	0.38	-
Side_friction_coefficient	0.46	0.09	0.31	0.74	-
Access_density	0.05	0.13	0.0	0.53	-
Tree_density	1.26	0.81	0.60	5.71	-
Pole_density	0.67	0.27	0.0	1.72	-
RHR	1.26	0.56	1.0	3.0	-

A cross-sectional study was conducted to test if the speed limit increase had been statistically significant compared to other roadway geometric characteristics. Twenty-five variables were considered in the model development using STATA software package (StataCorp LLC, 2015) to conduct the negative binomial regression model as the standard approach to model yearly crash frequencies. The negative binomial regression model results for total crashes are summarized in Table 4.16.

Table 4.16: Negative Binomial Regression Model Results (Total Crashes)

Negative Binomial Regression				Number of obs.		66
				LR chi2(3)		38.63
Dispersion = mean				Prob> chi^2		0.0000
Log likelihood=-291.5192				Pseudo R^2		0.0560
Variables	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
Average_adt	0.000043	8.99E-06	4.80	0.000	0.000	0.000
length	0.043	0.009	4.59	0.000	0.0245	0.0611
num_lanes	-0.354	0.369	-0.96	0.337	-1.077	-0.369
Speed limit	0.228	0.112	1.98	0.006	0.154	0.912
lane_width	0.166	0.200	0.83	0.407	-0.226	0.557
Median_type	0.116	0.254	0.46	0.647	-0.381	0.614
median_width	-0.006	0.010	-0.61	0.544	-0.026	0.013
Rumble_strip_type	0.271	0.474	0.57	0.568	-0.658	1.199
functional_class	-0.455	0.337	-1.35	0.061	-1.114	0.205
Degree_of_curve	0.191	0.153	1.25	0.211	-0.108	0.490
shoulder_type	0.012	0.010	1.19	0.234	-0.007	0.030
Shoulder_width_inside	-0.062	0.096	-0.64	0.519	-0.249	0.126
surface_type	0.010	0.151	0.07	0.945	-0.284	0.305
average_IRI	-0.002	0.003	-0.65	0.514	-0.008	0.004
# of on/off_ramps	0.015	0.014	1.07	0.282	-0.012	0.043
# of interchanges	0.680	0.286	2.38	0.018	0.118	1.241
PHV	0.061	0.034	1.79	0.043	-0.005	0.128
area_type	0.663	0.238	2.79	0.005	0.196	1.129
# of curves	0.091	0.093	3.26	0.009	-0.273	0.091
Side_friction_coefficient	0.958	0.678	1.41	0.158	-0.371	2.287
Access_density	2.108	0.806	2.61	0.331	0.527	3.688
Tree_density	-0.218	0.150	-1.45	0.147	-0.512	0.076
Pole_density	-0.161	0.375	-0.43	0.667	-0.896	0.574
RHR	0.011	0.164	0.07	0.947	-0.311	0.333
constant	3.609	2.789	1.29	0.196	-1.856	9.075
Likelihood-ratio test of alpha=0: chibar2(01) =536.78 Prob>=chibar2 = 0.000						

The regression model is developed, and the model summary is summarized in Equation 4.2.

$$y = e^{3.60+0.000043*ADT+0.042*L+0.228*S+0.680i+0.061*PHV+0.663*a+0.090*c}$$ **Equation 4.2**

Where:

y = total number of crashes

ADT = Average Daily Traffic

L = segment length

S = maximum speed limit

i = number of interchanges

PHV = percentage of heavy vehicles

a = area type

c = curve presence

According to Table 4.16, some variables have a negative sign, and this means that they have a decreasing effect on the total number of crashes; those with the positive sign have an increasing impact on total number of crashes.

In order to understand if the Negative Binomial (NB) regression model is the best approach for a cross-sectional study, it is important to identify any over-dispersion in the available data. Because the NB model is used if over-dispersion exists in the data and since in this study the variance value (4,135.38) far exceeds the mean (69.04), over-dispersion exists in the data. Therefore, the NB model is suitable for this type of data (Hilbe, 2011).

The CMF calculation is according to Equation 4.3.

CMF= EXP (CV) **Equation 4.3**

Where:

C = coefficient of the treatment effect (speed limit increase) = 0.228

V = value at which one needs the CMF = 1 (when the improved speed limit of 75 mph is present)

CMF= EXP (0.228 *1) = 1.25

Standard error = 0.112140

It is also necessary to consider the effect of 25 explanatory variables on fatal and injury crashes. By applying the NB regression model, it can be seen if the speed limit increase has had any significant effect on fatal and injury crashes. The same variables have been considered but instead of total crashes, fatal and injury crashes are obtained for each of the treated and non-treated sections. The NB regression model results are summarized in Table 4.17.

Table 4.17: Negative Binomial Regression Model Results (Fatal and Injury Crashes)

Negative binomial regression				Number of obs.		66
				LR chi2(3)		104.50
Dispersion = mean				Prob> chi^2		0.0000
Log likelihood= -264.33773				Pseudo R^2		0.1650
Variables	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
Average_adt	0.000038	0.00001	3.44	0.001	.00001	.00005
length	0.045	0.012	3.72	0.000	0.021	0.069
num_lanes	0.138	0.431	0.32	0.749	-0.706	0.982
Speed_limit	0.485	0.245	1.98	0.048	0.005	0.964
lane_width	0.166	0.200	0.83	0.407	-0.226	0.557
Median_type	0.245	0.297	0.82	0.410	-0.337	0.827
median_width	0.013	0.013	0.95	0.341	-0.013	0.039
Rumble_strip_type	1.106	0.575	1.92	0.054	-0.020	2.232
functional_class	-0.558	0.389	-1.43	0.152	-1.321	0.205
Degree_of_curve	0.373	0.179	2.09	0.037	0.023	0.723
shoulder_type	0.020	0.011	1.76	0.078	-0.002	0.042
Shoulder_width_inside	-0.069	0.105	-0.66	0.512	-0.275	0.137
surface_type	-0.065	0.180	-0.36	0.718	-0.416	0.287
average_IRI	-0.003	0.004	-0.93	0.351	0.351	0.003
# of on/off_ramps	-0.028	0.020	-1.37	0.170	-0.067	0.011
# of interchanges	0.749	0.356	2.11	0.035	0.051	1.44
PHV	0.121	0.042	2.86	0.004	0.038	0.204
area_type	0.998	0.285	3.50	0.000	0.439	1.556
Curve_presence	2.929	1.355	2.16	0.031	-5.584	-.274
Side_friction_coefficient	0.268	0.820	0.33	0.743	-1.338	1.875
Access_density	2.546	0.919	2.77	0.006	.745	4.347
Trees_density	-0.226	0.186	-1.21	0.225	-0.591	0.139
Poles_density	-0.347	0.453	-0.77	0.444	-1.234	0.540
RHR	0.081	0.187	0.43	0.664	-0.285	0.448
constant	-2.188	3.036	-0.72	0.471	-8.139	3.762
Likelihood-ratio test of alpha=0: chibar2(01) =359.79 Prob>=chibar2 = 0.000						

The NB model is used when over-dispersion exists in the data, and since in this study, the variance value of the cross-sectional model for fatal and injury crashes is 2,430 and it very far exceeds the mean (44.15), over-dispersion exists in the data. Therefore, the NB model is suitable for this type of data (Hilbe, 2011).

The regression equation for fatal and injury crashes is written according to Equation 4.4 and the CMF results are as follows:

$$y = e^{-2.18+0.000038*ADT+0.045*L+0.485*S+0.373D+0.748i+0.121*PHV+0.997*a+2.92*c+2.54AD}$$

Equation 4.4

Where:

y = fatal and injury crashes

ADT = Average Daily Traffic

L = segment length

S = maximum speed limit

D = degree of curve

i = number of interchanges

PHV = percentage of heavy vehicle

a = area type

c = curve presence

AD = access density

The CMF calculation is same as Equation 4.3.

CMF= EXP (CV)

Where:

C = coefficient of the treatment effect (speed limit increase) = 0.485

V = value at which one needs the CMF = 1 (when speed limit of 75 mph is present)

CMF= EXP (0.485 *1) = 1.62

Standard error = 0.24477

Results from the cross-sectional method showed that fatal and injury crashes increased by 62%, and total crashes increased by 25%, where both of which were statistically significant.

4.4 Summary Results of Safety Effectiveness Methods

All three safety effectiveness methods provided in the Highway Safety Manual were applied in this study, since each method has pros and cons. Namely, the three methods were before-and-after study using the EB method, before-and-after study with the comparison group method, and cross-sectional study. Each method provided different CMFs for total crashes and fatal and injury crashes; however, all three methods showed that safety got worse after the speed limit increase. Summary results for each method are included in Table 4.18 with the estimated CMFs and Standard Errors (SE).

Table 4.18: CMF and Standard Error Results for Three Safety Effectiveness Methods (Total Crashes and Fatal and Injury Crashes)

Methods	Fatal and injury crashes		Total crashes	
	CMF	Standard Error (SE)	CMF	Standard Error (SE)
1. Before-and-after with EB method	1.007*	0.025	1.16	0.016
2. Before-and-after with comparison group method	1.35	0.047	1.27	0.019
3. Cross-sectional method	1.62	0.244	1.25	0.112

* Not statistically significant

According to Table 4.18, the highest CMF for fatal and injury crashes is related to the cross-sectional method, which shows a 62 percent increase for fatal and injury crashes, which is the highest of all three applied methods. However, the highest CMF for total crashes is related to before-and-after with the comparison group method, which shows a 27 percent increase compared to other methods. Furthermore, according to the Standard Error (SE) values, the CMFs for each method are statistically significant at a 95 percent confidence level except for the CMF for fatal and injury crashes related to the EB method, which is 1.007 and its confidence level boundary contains one. CMF values for total crashes seem more stable (1.16, 1.27, and 1.25) irrespective of the method that was utilized; however, CMF for fatal crashes show a wide variation from 1.007 (not significant) to 1.62. One possibility is that the sample size of number of fatal and injury crashes is much smaller compared to total crashes, and hence more randomness is associated with that.

Among the three methods, the more reliable method could be considered as the before-and-after study with comparison group method, since it takes into consideration what happened on treated sections in comparison to the safety experience at non-treated sections. Hence, it could be concluded that fatal and injury crashes increased by 35% while total crashes increased by 27% after the speed limit increase was implemented.

4.5 Results of Speed Data Analysis

This section discusses results of statistical analyses of speed data conducted for checking whether the speed data is normally distributed. Prior to the analyses, speed data obtained from each location related to the available ATRs were checked for normal distribution with the Kolmogorov-Smirnov (K-S) test, because any statistical analysis should come from normal distribution. Since the sample size in this study is too large, the K-S test is applicable for the normality test (Thode, 2002). The null hypothesis is that the data fit normal distribution can be verified if the p-value is greater than 0.05 at a 95 percent confidence level; otherwise, there would be no evidence for the data to be normally distributed. K-S test results are shown in Table 4.19, in which the d-statistics are the outputs of the K-S test with corresponding p-values.

Table 4.19: K-S Test Results and Related Statistics for Speed Data by Available ATRs

ATR number	Treated/Non-treated site	d-statistic	p-value	Normality distributed (Yes/No)
1-EFPRX3	Non-treated	0.0013	0.869	Yes
2-F10VD5	Treated	0.0058	0.764	Yes
3-CXJUQ3	Treated	0.0012	0.461	Yes
4-CXSRG1	Non-treated	0.0027	0.150	Yes
5-E7PK42	Treated	0.0031	0.411	Yes
6-94J8N1	Treated	0.0018	0.046	No
7-A0OOS8	Non-treated	0.0017	0.071	Yes
8-CB1U73	Treated	0.0019	0.068	Yes
9-CO1AY7	Treated	0.0024	0.552	Yes
10-CTGTW8	Treated	0.0018	0.091	Yes
11-0DT453	Treated	0.0035	0.006	No
12-4LGSU7	Treated	0.0036	0.669	Yes
13-7FGNB7	Treated	0.0035	0.784	Yes
14-9Q9OK1	Treated	0.00079	0.084	Yes
15-91TFY5	Non-treated	0.0046	0.112	Yes

The p-values for each dataset are greater than 5 percent except for ATRs 6 and 11. ATRs 6 and 11 will be removed because their p-values are less than 5 percent and speed analysis cannot be conducted for a not normally distributed dataset. So, speed data for all ATRs fit normal distribution and the speed analysis and t-test can be applied for them except for ATRs 6 and 11. In order to analyze speed characteristics under before-and-after conditions, average speed and 85th percentile speed need to be computed, but the 85th percentile speed is more common among traffic engineers for evaluating the operating speed as the main criteria in identifying reasonable speed limits (Najjar et al., 2000).

Average speed, standard deviation, and 85th percentile speed are computed according to the following equations (Roess, Prassas, & McShane, 2011).

The average speed is computed according to Equation 4.5.

$$\bar{x} = \frac{\sum NS}{\sum N}$$ **Equation 4.5**

Where:

$\bar{x}$ = average speed

N = number of vehicles in each speed group

S = middle speed (mph)

Standard deviation (s) is also computed according to Equation 4.6.

$$s = \sqrt{\frac{\sum NS^2 - N \times \bar{x}^2}{N-1}}$$ **Equation 4.6**

Where:

s = standard deviation

$\bar{x}$ = average speed

N = number of vehicles in each speed group

S = middle speed (mph)

Data from the first ATR were used to develop the frequency distribution, and the sample calculation is shown here. The speed group data, average speed, and standard deviation the before-and-after periods are presented in Table 4.20. These were computed by considering all speed data available to the researchers at the time of the study.

Similar data for the remaining speed datasets from the other traffic recorders are presented in Appendix A.

Table 4.20: Speed Frequency Distribution for the First ATR During Before and After Speed Limit Change by Considering All Months

Speed Group		Middle speed (S) (mph)	Before			After		
Lower Limit (mph)	Upper limit (mph)		Number of vehicles in group (N)	Average Speed (mph)	Standard Deviation (mph)	Number of vehicles in group (N)	Average Speed (mph)	Standard Deviation (mph)
40	45	42.5	728			2,006		
45	50	47.5	1,619			3,868		
50	55	52.5	6,029			13,523		
55	60	57.5	25,094			59,424		
60	65	62.5	96,628			213,778		
65	70	67.5	295,702	71.95	5.43	633,992	72.00	5.61
70	75	72.5	584,331			1,264,078		
75	80	77.5	340,852			680,593		
80	85	82.5	44,676			141,992		
85	90	87.5	4,660			14,849		
90	95	92.5	869			3,587		
Total			1,401,188			3,031,690		

Table 4.20 presents the speed groups with lower speed limit and upper speed limit values, and the middle speed is also computed. Further, the number of vehicles in each speed group is presented during the before-and-after speed limit increase. Additionally, the average speed and standard deviation for the first ATR are computed according to Equations 4.5 and 4.6 for both the before and the after periods. There is an increase in both average speed and standard deviations during the after period compared to the before period, showing not only higher speeds, but also a wider variation in speeds. Summary of the final results are also tabulated in Tables 4.21 and 4.22 during the before and after time periods.

Table 4.21: Summary of Speed Characteristics for 13 ATRs in the Before and After Speed Limit Changes by Considering All Months

ATR #	Treated/ Control site	Before			After		
		Average speed (mph)	85^{th} percentile speed (mph)	Standard deviation (mph)	Average speed (mph)	85^{th} percentile speed (mph)	Standard deviation (mph)
1	Control	71.95	77.65	5.43	72.00	77.83	5.61
2	Treated	71.09	76.82	5.63	73.56	79.65	6.58
3	Treated	69.04	74.42	5.43	68.68	74.28	5.67
4	Control	70.08	75.50	5.94	69.71	75.67	6.48
5	Treated	71.74	77.32	5.34	73.66	79.72	6.44
6	Control	67.34	72.50	4.76	67.15	72.37	4.91
7	Treated	73.15	78.40	5.14	73.46	80.89	7.54
8	Treated	72.04	77.72	5.31	74.07	80.02	6.41
9	Treated	63.21	69.11	5.76	63.53	69.33	5.80
10	Treated	71.26	77.03	5.50	74.19	81.29	7.20
11	Treated	71.50	77.37	5.50	74.34	81.23	7.24
12	Treated	64.03	68.94	4.68	64.31	69.21	4.92
13	Control	70.76	76.13	5.35	70.38	75.72	5.70

Table 4.21 presents the summary of speed characteristics for before-and-after speed limit increase. There is no increase in the 85^{th} percentile speed values for the sections without speed limit increase during after period compared to before period, but there is an increase in the 85^{th} percentile speed of drivers in the after period compared to before period for treated sections. This increase represents that on the majority of the sections in which the speed limit increased, the drivers were influenced by the speed limit change and decided to speed up. For example, the ATRs 8, 10, and 11 present a 3 to 4 mile per hour increase in the 85^{th} percentile speed during the after period, which is the highest increase among the ATRs 1 to 13. A summary of speed characteristics for available ATRs during the 1-month before period and the 1-month after period is tabulated in Table 4.22.

Table 4.22: Summary of Speed Characteristics for 13 ATRs in 1-Month Period Before and 1-Month Period After Speed Limit Change

ATR #	Treated/ Control Site	Before			After		
		Average Speed (mph)	85th Percentile Speed (mph)	Standard Deviation (mph)	Average Speed (mph)	85th Percentile Speed (mph)	Standard Deviation (mph)
1	Control	71.82	77.48	5.31	72.13	77.71	5.35
2	Treated	71.09	76.82	5.63	73.67	79.66	6.52
3	Treated	67.44	73.63	6.16	68.27	74.04	5.88
4	Control	70.14	75.94	6.00	70.64	76.16	5.74
5	Treated	71.74	77.32	5.34	73.66	79.72	6.44
6	Control	67.57	72.66	4.62	67.05	72.22	4.78
7	Treated	73.04	78.32	5.17	75.74	82.06	6.47
8	Treated	71.95	77.59	5.21	73.76	79.80	6.43
9	Treated	63.17	69.13	5.79	63.26	69.11	5.74
10	Treated	71.78	77.47	5.36	73.53	79.95	6.76
11	Treated	71.96	77.77	5.44	74.73	80.46	6.52
12	Treated	63.58	68.60	4.81	64.16	69.04	4.95
13	Control	70.73	75.36	5.31	70.18	75.06	5.46

According to results from Table 4.22, average speed and 85th percentile speeds have increased during the after period compared to the before period for all treated sections affected by the speed limit change, with one exception. The only location where the 85th percentile speed has decreased after the speed limit change is related to the ATR 9. At this location, the sample size in the after period is larger than the before period, which may not help to easily compare the impact of speed limit change. On the other hand, the average speed and 85th percentile speeds have decreased in the after period compared to the before period at the locations which were not affected by speed limit change. Nevertheless, for one of the non-treated sections where ATR 1 is located, both average speed and 85th percentile speeds have increased regardless of no speed limit change, and this could be interpreted to be due to a large sample size during the after period.

4.5.1 Two Sample t-Test Results

In order to apply the t-test as discussed in Chapter 3, variance equality should be checked according to the F-test results to use the corresponding t-test.

F-test results using the STATA software package (StataCorp LLC, 2015) are presented in Table 4.23 with the probability values (p) during before-and-after periods.

Table 4.23: F-Test Results for Each Speed Dataset During Before and After Periods

ATR #	Treated/ control site	Before		After		p-value	Variance equality (Yes/No)
		Sample size (one month)	Sample size (all months)	Sample size (one month)	Sample size (all months)		
1	Control	442,719	1,401,188	942,343	3,031,690	0.00	No
2	Treated	77,496	77,496	152,091	397,177	0.00	No
3	Treated	37,016	1,409,912	953,618	5,226,224	0.00	No
4	Control	25,597	315,487	462,564	1,272,566	0.00	No
5	Treated	282,760	282,760	601,588	601,588	0.00	No
6	Control	12,623	816,304	716,500	2,646,833	0.00	No
7	Treated	563,903	868,023	592,773	1,127,571	0.00	No
8	Treated	187,411	427,132	418,832	1,216,287	0.00	No
9	Treated	505,814	676,551	772,573	2,326,592	0.00	No
10	Treated	127,364	231,817	110,519	375,564	0.00	No
11	Treated	157,385	273,166	244,498	310,952	0.00	No
12	Treated	456,793	4,411,134	521,687	8,814,389	0.00	No
13	Control	71,639	144,368	77,871	222,132	0.00	No

Since the p-value of each dataset is less than 5 percent, the null hypothesis (equal variances) is rejected and the alternative hypothesis (unequal variances) will be approved. The t-statistic is computed based on unequal sample sizes with unequal variances according to Equation 3.43. The one-tailed t-test is utilized to show if the average speed and 85th percentile speed during the after period are statistically greater than the before period. Moreover, the two-tailed t-test is also applied to find if there is any statistical difference in the average speed and 85th percentile speed during the after period compared to the before period. The one-tailed t-test and two-tailed t-test results are summarized in Table 4.24 related to all months of data during before-and-after periods.

Table 4.24: Results of t-Test for Each Speed Dataset by Considering All Months During Before and After Speed Limit Change

ATR#	Treated/ control site	County name	Before	After	t-value	One-tailed t-test		Two-tailed t-test	
			85th Percentile speed (mph)	85th Percentile speed (mph)		p-value	Statistical significant increase (Yes/No)	p-value	Statistical significant difference (Yes/No)
1	Control	Johnson	77.65	77.83	-32.14	0.00	Yes	0.00	Yes
2	Treated	Barber	76.82	79.65	-128	0.00	Yes	0.00	Yes
3	Treated	Shawnee	74.42	74.28	26.92	0.99	No	0.00	Yes
4	Control	Shawnee	75.50	75.67	-14.16	0.00	Yes	0.00	Yes
5	Treated	Franklin	77.32	79.72	-184	0.00	Yes	0.00	Yes
6	Control	Sedgwick	72.50	72.37	21	0.99	No	0.00	Yes
7	Treated	Wabaunsee	78.40	80.89	-276	0.00	Yes	0.00	Yes
8	Treated	Coffey	77.72	80.02	-232	0.00	Yes	0.00	Yes
9	Treated	Shawnee	69.11	69.33	-27.5	0.00	Yes	0.00	Yes
10	Treated	Trego	77.03	81.29	-266	0.00	Yes	0.00	Yes
11	Treated	Ellsworth	77.37	81.23	-241	0.00	Yes	0.00	Yes
12	Treated	Sedgwick	68.94	69.21	-100	0.00	Yes	0.00	Yes
13	Control	Republic	76.13	75.72	22.77	0.99	No	0.00	Yes

According to the one-tailed t-test results presented in Table 4.24, average speed and 85th percentile speed in the after period are statistically greater than the before period for the treated sites except for one section, located in Shawnee County. It is related to ATR 3. This means that drivers have driven at higher speeds when the speed limit increased from 70 mph to 75 mph. Furthermore, two-tailed t-test results show the 85th percentile speed increased on both treated and non-treated sections and average speed and 85th percentile speeds during the after period are statistically different than the before period due to large sample sizes.

Table 4.25 presents the one-tailed and two-tailed t-test results according to 1-month data in the before period and 1-month data in the after period. Only 1-month data consideration is applied in order to have a meaningful sample size.

Table 4.25: Results of t-Test for Each Speed Dataset in 1-Month Period Before and 1-Month Period After Speed Limit Change

ATR#	Treated/ control site	County name	Before	After	t-value	One-tailed t-test		Two-tailed t-test	
			85th Percentile speed (mph)	85th Percentile speed (mph)		p-value	Statistical significant increase (Yes/No)	p-value	Statistical significant difference (Yes/No)
1	Control	Johnson	77.48	77.71	-23.71	0.00	Yes	0.00	Yes
2	Treated	Barber	76.82	79.66	-108	0.00	Yes	0.00	Yes
3	Treated	Shawnee	73.63	74.04	-12.58	0.00	Yes	0.00	Yes
4	Control	Shawnee	75.94	76.16	-5.72	0.00	Yes	0.00	Yes
5	Treated	Franklin	77.32	79.72	-184	0.00	Yes	0.00	Yes
6	Control	Sedgwick	72.66	72.22	10.60	0.99	No	0.00	Yes
7	Treated	Wabaunsee	78.32	82.06	-344	0.00	Yes	0.00	Yes
8	Treated	Coffey	77.59	79.80	-141	0.00	Yes	0.00	Yes
9	Treated	Shawnee	69.13	69.11	1.91	0.97	No	0.00	Yes
10	Treated	Trego	77.47	79.95	-98.10	0.00	Yes	0.00	Yes
11	Treated	Ellsworth	77.77	80.46	-141	0.00	Yes	0.00	Yes
12	Treated	Sedgwick	68.60	69.04	-44.53	0.00	Yes	0.00	Yes
13	Control	Republic	75.36	75.06	10.76	0.99	No	0.00	Yes

According to the one-tailed t-test results from Table 4.25, the average speed and 85th percentile speeds in the after period are statistically greater than the before period based on 1-month speed data in the before-and-after periods. There is only one treated section located in Shawnee County, belonging to the ATR 9, for which there was no statistically significant increase during the after period compared to the before period. Here the sample size in the after period was still larger than the before period, and it cannot help to compare the impact of speed limit change easily. Moreover, the two-tailed t-test results show that the 85th percentile speed and average speed for both treated sections and non-treated sections in the after period are statistically different than the before period due to a large sample size where any change in 85th percentile speed would be significant (Binkowski et al., 1998).

4.5.2 K-S Test Results

Since the sample size for this study is very large, the K-S test is applied to check if two sets of speed data are differently distributed or not. For this purpose, the distribution curve of each ATR representing the upper speed limit versus number of vehicles in each speed group is drawn separately for both the before the period and the after period. The first two ATR distribution curves for corresponding months are presented in the Figure 4.1 to show how speed data is differently distributed and the curves for remaining ATRs are summarized in Appendix B.

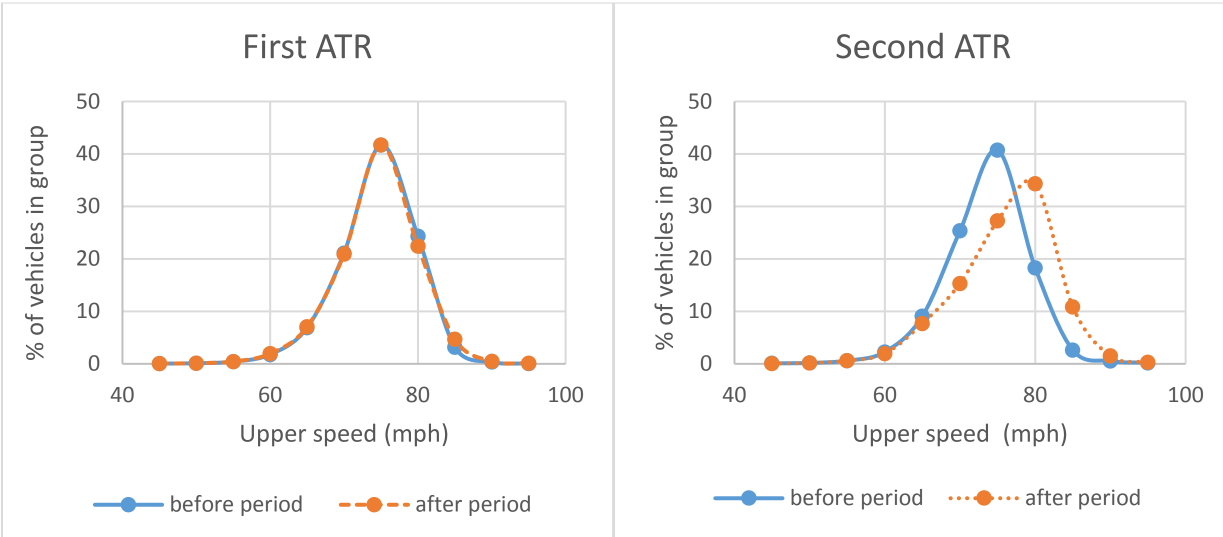

Figure 4.1: Sample K-S Test Distributions for the First Two ATRs for the Months of March, September, and December During the Periods Before and After Speed Limit Increase

According to Figure 4.1, it is clear that the speed distribution during the before period for the first ATR is similar to the after period, and there is no difference between the before-and-after speed limit increase. However, speed distribution during the before period for the second ATR is differently distributed than the after period. This means the drivers' speed in the period before speed limit increase is not equal to the drivers' speed during the after period. In order to evaluate the statistically significant difference of the remaining ATRs in the before period compared to the after period, the K-S test application of R software package (R Development Core Team, 2013) was used to obtain the test statistic (D) and critical D along with the probability value (p-value) for identifying the statistical significant difference between before and after periods. Results are summarized in Table 4.26.

Table 4.26: K-S Test Results with D, Critical D, and Corresponding P-Values for Available ATRs

ATR #	Treated/ Control site	Test statistic (D)	Critical D	p-value	Statistical significant difference (Yes/No)
1	Control	0.0012	0.0013	0.99	No
2	Treated	0.0912	0.0050	0.046	Yes
3	Treated	0.0010	0.0012	0.99	No
4	Control	0.0019	0.0027	0.99	No
5	Treated	0.2723	0.0031	0.038	Yes
6	Control	0.0011	0.0017	0.99	No
7	Treated	0.2774	0.0019	0.042	Yes
8	Treated	0.1845	0.0024	0.046	Yes
9	Treated	0.0943	0.0018	0.039	Yes
10	Treated	0.2245	0.0036	0.042	Yes
11	Treated	0.3674	0.0035	0.038	Yes
12	Treated	0.0064	0.0007	0.041	Yes
13	Control	0.0032	0.0046	0.99	No

According to results from Table 4.26, it is clear speed data for the majority of treated sites which are affected by speed limit change are differently distributed, and statistical significant difference exists between the periods before and after speed limit increase. However, there is only one treated site that belongs to ATR 3 that showed no statistically significant difference during the before period compared to the after period. The reason for this could be because the sample size in the after period is much larger than the before period and it may not help to easily compare the significant difference. On the other hand, no statistical significant difference exists in the speed data distribution for non-treated sites not affected by speed limit increase. It was seen that speed limit increase has had an effective impact on drivers' behaviors in the after period versus the before period.

Chapter 5: Crash Contributory Causes and Crash Characteristics for Sections Affected by Speed Limit Change and Without Change

5.1 Crash Contributory Causes

In this section, all causes that contribute to crash occurrence for both treated sections (affected by speed limit change) and non-treated sections (sections without speed limit change) are considered for 3 years before and 3 years after the speed limit change. Contributory causes can be broadly classified as driver-related, vehicle-related, environment-related, and road-related.

5.1.1 Driver's Crash Contributory Causes

In order to assess the causes of crashes based on driver's errors, a folder in the KCARS database named CC_DRIVER shows all drivers' causes for crashes. According to the query between the CC_DRIVER folder and identified sections with speed limits of 70 mph and 75 mph in the ACCIDENT_CANSYS folder, all causes of drivers' errors are listed in Tables 5.1 and 5.2 for both the before period and after period.

5.1.2 Environmental Crash Contributory Causes

To evaluate crash causes due to environmental conditions, a query was made between the CC_ENVIRONMENT and ACCIDENT_CANSYS folders in the KCARS database for both treated and non-treated sections. Results are summarized in Tables 5.3 and 5.4.

Table 5.1: Drivers' Crash Contributory Causes for Treated Sites in the Before and After Period

Driver's causes	Total drivers' CC			
	Before	% Before	After	% After
Too fast for conditions	2,490	37.08	1,543	22.50
Inattention (general)	1,413	21.04	1,017	14.83
Fell asleep/fatigued	405	6.03	464	6.77
Followed too closely	399	5.94	298	4.35
Avoidance/evasive action	349	5.20	386	5.63
Improper lane change	283	4.21	231	3.37
Under alcohol	206	3.07	184	2.68
No driver cont. circum.	154	2.29	537	7.83
Right of way violation	116	1.73	78	1.14
Other distraction in/on vehicle	109	1.62	150	2.19
Steering over correction	98	1.46	296	4.32
Traffic signs/signals/markings	92	1.37	89	1.30
Illness/Medical condition	87	1.30	91	1.33
Careless/reckless driving	69	1.03	55	0.80
Speeding	51	0.76	30	0.44
Too slow impeding traffic	44	0.66	38	0.55
Improper turn	44	0.66	40	0.58
Improper backing	39	0.58	49	0.71
Improper passing	38	0.57	22	0.32
Mobile phone	33	0.49	47	0.69
Under drug condition	28	0.42	34	0.50
Other type	27	0.40	59	0.86
Unknown	27	0.40	955	13.93
Aggressive driving	24	0.36	27	0.39
Wrong side/way	24	0.36	25	0.36
License restriction-non comply	23	0.34	17	0.25
Other electronic devices	11	0.16	29	0.42
Improper parking	9	0.13	8	0.12
Distraction not in/on vehicle	8	0.12	9	0.13
Under medication	7	0.10	27	0.39
Emotional condition	5	0.07	19	0.28
Improper no turn signal	3	0.04	3	0.04
Ran red light	1	0.01	1	0.01
Total # of driver's CC	**6,716**	100.00	**6,858**	100.00
Total # of crashes	**9,407**		**8,873**	

According to Table 5.1, there are many contributory causes for drivers involved in crashes but total crash causes because of driver errors have increased during the after period compared to before speed limit change for treated sites. Table 5.2 shows crash contributory causes for non-treated sites during the before and after periods.

Table 5.2: Drivers' Crash Contributory Causes for Non-Treated Sites in the Before and After Period

Driver's causes	Total drivers' CC			
	Before	% Before	After	% After
Too fast for conditions	1,904	22.84	1,521	17.58
Inattention (general)	1,521	18.24	855	9.88
Followed too closely	835	10.02	940	10.86
Improper lane change	687	8.24	675	7.80
Avoidance/evasive action	552	6.62	583	6.74
No driver cont. circum.	515	6.18	902	10.42
Under alcohol	397	4.76	329	3.80
Right of way violation	354	4.25	271	3.13
Fell asleep/fatigued	197	2.36	236	2.73
Traffic signs/signals/markings	162	1.94	137	1.58
Other distraction in/on vehicle	124	1.49	176	2.03
Careless/reckless driving	114	1.37	97	1.12
Unknown	106	1.27	790	9.13
Steering over correction	103	1.24	284	3.28
Improper turn	94	1.13	75	0.87
Wrong side/way	88	1.06	77	0.89
Improper passing	87	1.04	59	0.68
Mobile phone	67	0.80	86	0.99
Illness/Medical condition	63	0.76	70	0.81
License restriction-non comply	51	0.61	19	0.22
Speeding	50	0.60	50	0.58
Aggressive driving	45	0.54	61	0.70
Other type	36	0.43	112	1.29
Too slow impeding traffic	29	0.35	24	0.28
Other electronic devices	27	0.32	36	0.42
Improper no turn signal	25	0.30	13	0.15
Under drug condition	23	0.28	37	0.43
Distraction not in/on vehicle	23	0.28	61	0.70
Under medication	20	0.24	40	0.46
Improper backing	16	0.19	14	0.16
Emotional condition	14	0.17	20	0.23
Improper parking	5	0.06	3	0.03
Ran red light	3	0.04	1	0.01
Total # of driver's CC	**8,337**	100.00	**8,654**	100.00
Total # of crashes	**5,682**		**4,796**	

Based on Table 5.2, total contributory causes have increased in the after period compared to the before period, and the more important thing is that the speeding-cause difference for non-treated sites is not considerable and not too much change is observed for the after period versus the before period. According to results from Tables 5.1 and 5.2, it can be interpreted that the speed limit change for treated sites has been more effective on driver behavior than on non-treated sites. Table 5.3 presents environmental-related crash contributory causes for treated sites during before-and-after periods.

Table 5.3: Environment-Related Crash Contributory Causes for Treated Sites in the Before and After Period

Environment contributory causes in crashes	**Total Environmental CC**			
	Before	**% Before**	**After**	**% After**
Animal wild/domestic	2,450	54.30	2,360	61.96
Rain mist/drizzle	716	15.87	513	13.47
Falling/blowing snow	650	14.41	441	11.58
Sleet/hail/freezing rain	349	7.73	234	6.14
Strong winds	241	5.34	173	4.54
Fog/smoke/smog	47	1.04	22	0.58
Cloudy skies	19	0.42	7	0.18
Vision obstruct-glare	19	0.42	10	0.26
Other type	9	0.20	31	0.81
Vision obstruct-structural	8	0.18	12	0.32
Blowing sand/soil/dirt	2	0.04	4	0.11
Vision obstruct-vegetation	1	0.02	0	0.00
Unknown	1	0.02	2	0.05
Total # of environmental CC	**4,512**	100.00	**3,809**	100.00

Total environmental crash causes have decreased in the after period compared to the before period for treated sites. For example, share of crash causes of animals, other type crashes, vision obstruct-structural, and blowing sand or dirt have increased in the after period versus the before period. However, share of rain, snow, sleet, strong winds, fog, cloudy skies, and vision obstruct-glare causes for crash have decreased. Table 5.4 presents the environmental crash causes for non-treated sites in the before-and-after periods.

Table 5.4: Environment-Related Crash Contributory Causes for Non-Treated Sites in the Before and After Period

Environment contributory causes in crashes	Total Environmental CC			
	Before	**% Before**	**After**	**% After**
Animal wild/domestic	2,444	67.55	2,813	75.84
Rain mist/drizzle	483	13.35	319	8.60
Falling/blowing snow	335	9.26	250	6.74
Sleet/hail/freezing rain	147	4.06	124	3.34
Strong winds	90	2.49	77	2.08
Fog/smoke/smog	46	1.27	37	1.00
Vision obstruct-glare	39	1.08	45	1.21
Vision obstruct-structural	14	0.39	6	0.16
Blowing sand/soil/dirt	5	0.14	6	0.16
Cloudy skies	5	0.14	5	0.13
Other type	5	0.14	24	0.65
Vision obstruct-vegetation	3	0.08	1	0.03
Unknown	2	0.06	2	0.05
Total # of environmental CC	**3,618**	100.00	**3,709**	100.00

Contrary to environmental crash causes of treated sites, results from Table 5.4 show that total environmental crash causes have increased in the after period compared to the before period for non-treated sites. Moreover, the vision obstruct-glare, wild animal crashes, blowing sand or dirt, blowing sand or soil, and other crash types have increased for non-treated sites rather decreasing, but the remaining environmental crash causes have decreased the same as treated sites.

5.1.3 Roadway Crash Contributory Causes

In this section, all causes related to roadway conditions such as: icy/slushy, wet, snow-packed, and so forth are considered for both treated and non-treated sections during the 3 years before speed limit change and the 3 years after. To obtain results for crash contributory causes of roadway conditions, a query was made between the ACCIDENT_CANSYS folder and the CC_ROADWAY folder in the KCARS database. Final results are tabulated in Tables 5.5 and 5.6.

Table 5.5: Roadway Crash Contributory Causes for Treated Sites in the Before and After Period

Roadway contributory causes for crashes	Total Roadway CC			
	Before	% Before	After	% After
Icy/slushy	1,056	44.02	688	36.36
Wet	698	29.10	532	28.12
Snow-packed/accumulation	403	16.80	347	18.34
Debris/obstruction	170	7.09	232	12.26
Road under construction	43	1.79	31	1.64
Other type	16	0.67	50	2.64
Ruts/holes/bumps	4	0.17	3	0.16
Traffic control device inoperative	3	0.13	1	0.05
Shoulders: low-soft-high	3	0.13	4	0.21
Unknown	3	0.13	3	0.16
Worn travel polished surface	0	0.00	1	0.05
Total # of roadway CC	**2,399**	100.00	**1,892**	100.00

Total roadway crash contributory causes have decreased in the after period compared to the before period for all treated sites. The only roadway crash contributory causes that showed increase are the snow-packed condition, debris or obstruction of the roadway, and other type of conditions or unknown crashes, but total causes show a decrease during the after period. The roadway crash contributory causes for non-treated sites are tabulated in Table 5.6.

Table 5.6: Roadway Crash Contributory Causes for Non-Treated Sites in the Before and After Period

Roadway contributory causes for crashes	Total Roadway CC			
	Before	% Before	After	% After
Icy/slushy	801	42.16	485	29.75
Wet	537	28.26	458	28.10
Snow-packed/accumulation	262	13.79	238	14.60
Debris/obstruction	150	7.89	185	11.35
Road under construction	80	4.21	109	6.69
Other type	31	1.63	98	6.01
Unknown	29	1.53	49	3.01
Ruts/holes/bumps	4	0.21	2	0.12
Shoulders: low-soft-high	4	0.21	5	0.31
Traffic control device inoperative	2	0.11	1	0.06
Worn travel polished surface	0	0.00	0	0.00
Total # of roadway CC	**1,900**	100.00	**1,630**	100.00

Total crash contributory causes according to the roadway conditions for non-treated sites have also decreased in the after period compared to before period. In addition to the snow-packed and debris conditions, the road under construction cause has also increased during the after period compared to before period for non-treated sites.

5.1.4 Vehicle Crash Contributory Causes

In order to consider causes related to vehicle issues, such as problems with tires, wheels, brakes, etc., a separate query was made in the KCARS database between the CC_VEHICLE folder and the ACCIDENT_CANSYS folder for both sections affected by speed limit change and sections without speed limit change. Results are summarized in Tables 5.7 and 5.8.

Table 5.7: Vehicle Crash Contributory Causes for Treated Sites in the Before and After Period

Vehicle contributory causes for crashes	Total vehicle CC			
	Before	**% Before**	**After**	**% After**
Tires	240	47.24	259	41.57
Wheels	74	14.57	53	8.51
Cargo	66	12.99	62	9.95
Trailer coupling	29	5.71	24	3.85
Power train	24	4.72	63	10.11
Other type	15	2.95	59	9.47
Brakes	14	2.76	28	4.49
Unknown	9	1.77	32	5.14
Unattended/driverless (not in motion)	8	1.57	10	1.61
Windows-windshield	8	1.57	4	0.64
Headlights	7	1.38	4	0.64
Exhaust	5	0.98	1	0.16
Steering	4	0.79	17	2.73
Suspension	4	0.79	6	0.96
Unattended/driverless (in motion)	1	0.20	0	0.00
Mirrors	0	0.00	0	0.00
Wipers	0	0.00	1	0.16
Total # of vehicle CC	**508**	100.00	**623**	100.00

Table 5.7 shows that total vehicle crash contributory causes have increased during the period after speed limit change compared to the before period for all treated sites. The most increasing causes are brakes, steering, power train, suspension, and unattended or without driver

causes. Table 5.8 shows the same vehicle conditions for non-treated sites during the periods before and after speed limit change.

Table 5.8: Vehicle Crash Contributory Causes for Non-Treated Sites in the Before and After Period

Vehicle contributory causes for crashes	Total vehicle CC			
	Before	**% Before**	**After**	**% After**
Tires	99	30.84	141	31.26
Cargo	54	16.82	54	11.97
Wheels	39	12.15	32	7.10
Brakes	29	9.03	38	8.43
Unknown	21	6.54	29	6.43
Other type	16	4.98	48	10.64
Power train	14	4.36	41	9.09
Headlights	11	3.43	10	2.22
Trailer coupling	11	3.43	22	4.88
Unattended/driverless (not in motion)	11	3.43	7	1.55
Steering	6	1.87	13	2.88
Unattended/driverless (in motion)	4	1.25	3	0.67
Windows-windshield	2	0.62	7	1.55
Exhaust	2	0.62	2	0.44
Wipers	1	0.31	2	0.44
Suspension	1	0.31	1	0.22
Mirrors	0	0.00	1	0.22
Total # of vehicle CC	**321**	100.00	**451**	100.00

Table 5.8 shows that total vehicle crash contributory causes have increased for non-treated sites, which is similar to treated sites. The increasing percentage for vehicle contributory causes is related to problems with tires, power train, trailer coupling, steering, windows-windshield, and mirrors that have increased during the after period versus the before period.

5.2 Crash Characteristics

In this section, different crash characteristics such as: light conditions, vehicle body type, alcohol involvement, weather conditions, day of the week, gender of driver, age of driver, type of crash, license type of driver, and seatbelt use for driver are considered for both treated and non-treated sections.

5.2.1 Light Conditions

In this study, nighttime and daytime crashes were defined for light conditions. The KCARS database has five light conditions, classified as daylight, dawn, dusk, dark-street lights on, and dark-no street lights. This information is used to understand if crashes have happened during day or night. In this research, the daytime crash is recorded when the light condition is set as "daylight" in the crash database. All other light conditions are considered as nighttime condition. For this purpose, a query was made between the ACCIDENTS folder in the KCARS database with the option of light condition and the ACCIDENT_CANSYS folder for identified sections in the periods before and after speed limit change. The number of crashes for light condition of treated and non-treated sections during the 3 years before and the 3 years after speed limit change are tabulated in Appendix C.

Figure 5.1 represents nighttime crashes versus daytime crashes for treated sites and non-treated sites in before-and-after periods.

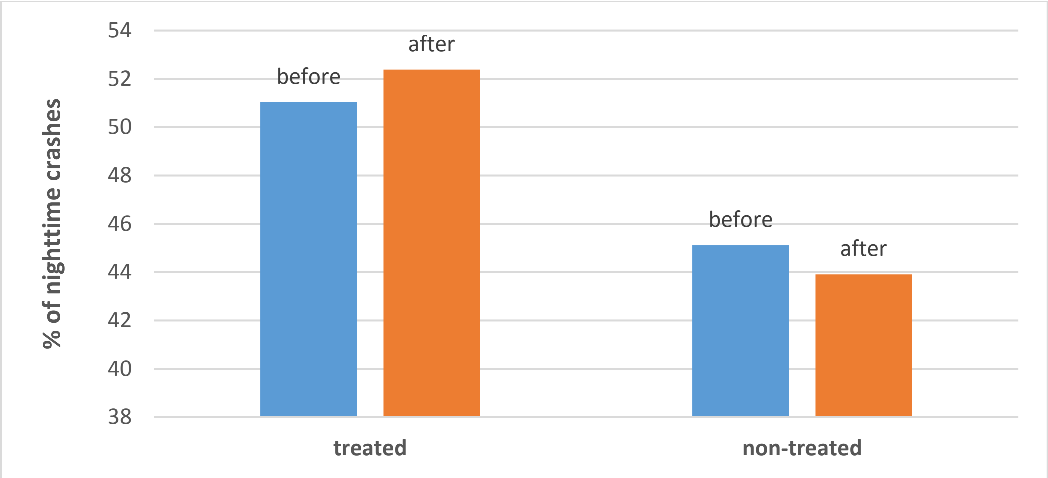

Figure 5.1: Percent of Nighttime Crashes for Treated and Non-Treated Sites in the Before and After Period

Figure 5.1 shows that the nighttime crashes during the after period are more than before the speed limit change for all treated sites. On the contrary, nighttime crashes for non-treated sites during the after period are less than the before period.

5.2.2 Vehicle Body Type

Different vehicle types involved in a crash such as automobile, van, pickup trucks and SUVs, and large trucks and trailers are considered for treated sites and non-treated sites. A query was made between the VEHICLES folder with the option of various vehicle types and the ACCIDENT_CANSYS folder for identified sections affected by speed limit change and without change. The detailed number of crashes for vehicle types are included in Appendix C and summary results are given in Tables 5.9 and 5.10.

Table 5.9: Percent of Vehicle Types Involved in Crashes for Treated Sites in the Before Period and After Period

Vehicle Type	Treated Sites Before Period	Treated Sites After Period
1-Auto	47.10%	49.70%
2-Van	6.90%	5.80%
3-SUV	34.10%	30.69%
4-Large Truck	11.60%	13.70%

Table 5.10: Percent of Vehicle Types Involved in Crashes for Non-Treated Sites in the Before Period and After Period

Vehicle Type	Non-Treated Sites Before Period	Non-Treated Sites After Period
1-Auto	52.08%	52.84%
2-Van	6.70%	5.44%
3-SUV	34.92%	34.40%
4-Large Truck	6.28%	7.30%

In order to present the percentage of vehicle types involved in crashes for both treated sites and non-treated sites more clearly, Figures 5.2 and 5.3 depict results for the sections affected by speed limit change and sections without speed limit change during before-and-after periods.

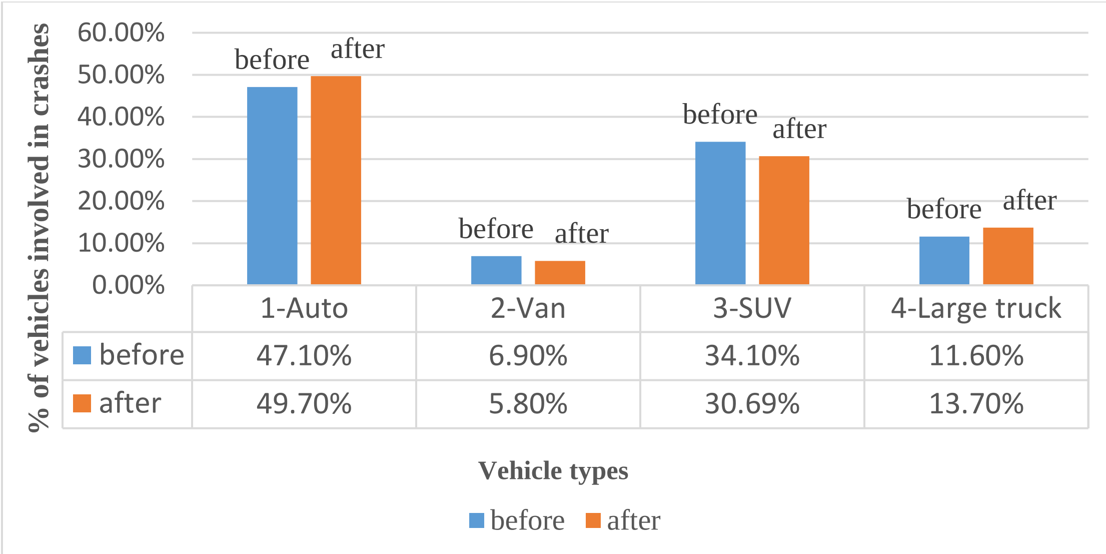

Figure 5.2: Percent of Vehicle Types Involved in Crashes for Treated Sites in the Before and After Period

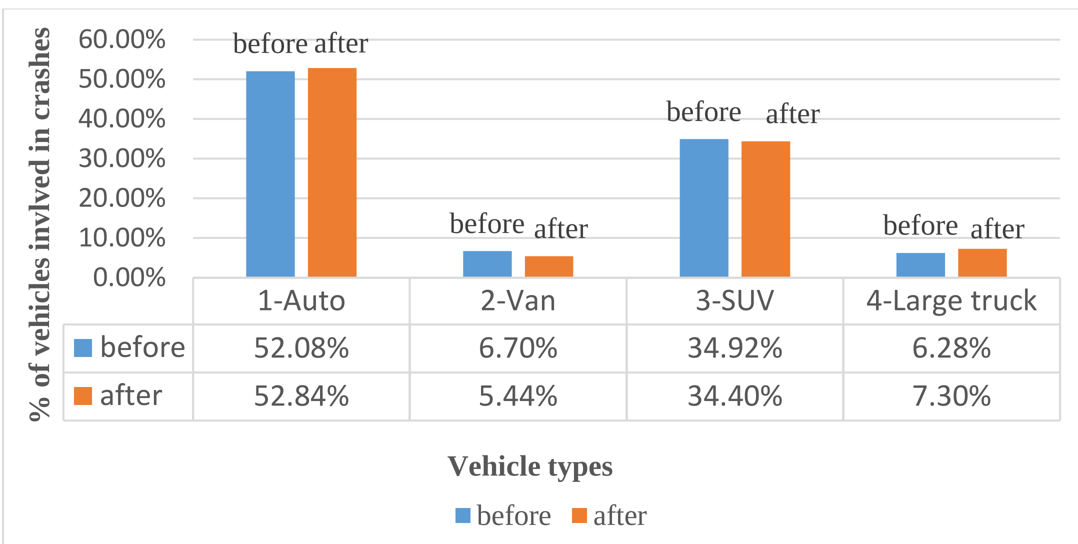

Figure 5.3: Percent of Vehicle Types Involved in Crashes for Non-Treated Sites in the Before and After Period

Figure 5.2 shows that the percentage of auto vehicles and large trucks involved in crashes has increased by more than 2 percent during the period after speed limit change compared to before speed limit change for all treated sites. However, Figure 5.3 shows that the percentage increase of large trucks and auto vehicles involved in crashes for non-treated sites is less than treated sites in the after period compared to the before period.

5.2.3 Alcohol Involvement of Driver

In this section, two conditions are considered for a driver involved in a crash. (1) If the driver has consumed alcohol, and (2) If the driver has not consumed any alcohol. For this purpose, a query was made between the ACCIDENT_SUMMARY folder with the option of alcohol involvement parameter, the OCUPANTS folder for the driver involved in crash, and ACCIDENT_CANSYS folder for identified sections. The following tables represent the number of drivers involved in crashes based on alcohol involvement for both treated and non-treated sections during the 3 years before and 3 years after speed limit change.

Table 5.11: Number of Drivers Involved in Crashes Based on Alcohol Involvement for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Alcohol involvement		Total number of drivers	% of alcoholic drivers involved in crashes
		Yes	No		
2008	Treated sites	109	4,033	4,142	2.63
	Non-treated sites	168	3,231	3,399	4.94
2009	Treated sites	90	3,708	3,798	2.37
	Non-treated sites	129	2,767	2,896	4.45
2010	Treated sites	94	4,211	4,305	2.18
	Non-treated	131	3,550	3,681	3.56
Total	**Treated sites**	293	11,952	12,245	2.39
Total	**Non-treated sites**	428	9,548	9,976	4.29

Table 5.12: Number of Drivers Involved in Crashes Based on Alcohol Involvement for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Alcohol involvement		Total number of drivers	% of alcoholic drivers involved in crashes
		Yes	No		
2012	Treated sites	87	3,093	3,180	2.74
	Non-treated sites	63	2,045	2,108	2.99
2013	Treated sites	77	3,478	3,555	2.17
	Non-treated sites	60	2,156	2,216	2.71
2014	Treated sites	65	3,195	3,260	1.99
	Non-treated	76	2,344	2,420	3.14
Total	**Treated sites**	229	9,766	9,995	2.29
Total	**Non-treated sites**	199	6,545	6,744	2.95

Tables 5.11 and 5.12 show that the number of drivers involved in crashes based on alcohol consumption has decreased for both treated sites and non-treated sites during the after period

compared to the before period. Percentage of alcoholic drivers involved in crashes for treated sites during the before period is about 2.39 percent but during the after period is 2.29 percent, which is 0.1 percent less than the before period. Similarly, the percentage of alcoholic drivers involved in crashes for non-treated sites in the before period is 4.29 percent but in the after period is 2.95 percent, which is 1.34 percent less than the before period.

5.2.4 Weather Conditions

There are 13 types of weather conditions in the KCARS database, such as no adverse weather condition, rain, mist, drizzle, sleet, hail, snow, fog, smoke, strong wind, blowing dust and sand, freezing rain, mist, drizzle, rain and fog, rain and wind, sleet and fog, and snow and wind. To make it much easier, in this study, it was decided to consider two types for weather conditions: no adverse weather conditions and adverse weather conditions, which includes all other conditions mentioned earlier. For this purpose, a query was needed to be made with the ACCIDENT_CANSYS and ACCIDENT folders from the KCARS database. In the ACCIDENT folder, there are the weather condition options, and in the ACCIDENT_CANSYS, there is information for sites characteristics affected or not affected by speed limit change. Tables 5.13 and 5.14 present the number of crashes for both treated and non-treated sites during the before and after periods based on weather condition.

Table 5.13: Number of Crashes Based on Weather Condition for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Weather condition		Total crashes	% of adverse weather crashes
		Adverse weather condition	No adverse weather condition		
2008	Treated sites	1,339	1,877	3,216	41.64
	Non-treated sites	912	1,074	1,986	45.92
2009	Treated sites	1,134	1,875	3,009	37.69
	Non-treated sites	652	1,027	1,679	38.83
2010	Treated sites	1,159	2,025	3,184	36.40
	Non-treated sites	709	1,309	2,018	35.13
Total	**Treated sites**	3,632	5,777	9,409	38.60
Total	**Non-treated sites**	2,273	3,410	5,683	40.00

Table 5.14: Number of Crashes Based on Weather Condition for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Weather condition		Total crashes	% of adverse weather crashes
		Adverse weather condition	No adverse weather condition		
2012	Treated sites	861	1,983	2,844	30.27
	Non-treated sites	293	1,197	1,490	19.66
2013	Treated sites	1,113	2,018	3,131	35.55
	Non-treated sites	437	1,163	1,600	27.31
2014	Treated sites	939	1,959	2,898	32.40
	Non-treated sites	367	1,349	1,716	21.39
Total	**Treated sites**	2,913	5,960	8,873	32.83
Total	**Non-treated sites**	1,097	3,709	4,806	22.83

Results from Tables 5.13 and 5.14 show that the percentage of adverse weather crashes has decreased for treated sites by around 6 percent and for non-treated sites around 18 percent, which is much more than that of the treated sites.

5.2.5 Day of the Week

All seven days of the week are available in the KCARS database located in the ACCIDENT folder. In order to get the number of crashes for the sections affected by speed limit change and without change, it was decided to consider two different sets of days as weekdays and weekends. A query was made between the ACCIDENT_CANSYS folder with identified sections and the ACCIDENT folder for the days of the week. Tables 5.15 and 5.16 present this information.

Table 5.15: Number of Crashes Based on Day of Crash for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Day of accident		Total crashes	% of weekend crashes
		Weekdays	Weekends		
2008	Treated sites	2,350	866	3,216	26.93
	Non-treated sites	1,417	569	1,986	28.65
2009	Treated sites	2,013	996	3,009	33.10
	Non-treated sites	1,035	644	1,679	38.36
2010	Treated sites	2,075	1,109	3,184	34.83
	Non-treated sites	1,187	831	2,018	41.18
Total	**Treated sites**	6,438	2,971	9,409	31.58
Total	**Non-treated sites**	3,639	2,044	5,683	35.97

Table 5.16: Number of Crashes Based on Day of Crash for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Day of accident		Total crashes	% of weekend crashes
		Weekdays	Weekends		
2012	Treated sites	2,066	778	2,844	27.36
	Non-treated sites	1,129	361	1,490	24.23
2013	Treated sites	2,160	971	3,131	31.01
	Non-treated sites	1,132	468	1,600	29.25
2014	Treated sites	2,047	851	2,898	29.37
	Non-treated sites	1,255	461	1,716	26.86
Total	**Treated sites**	6,273	2,600	8,873	29.30
Total	**Non-treated sites**	3,516	1,290	4,806	26.84

Tables 5.15 and 5.16 show that the percentage of weekend crashes has decreased during the period after speed limit change compared to the before period for all treated sites by around 2 percent. Similarly, weekend crashes for non-treated sites have decreased by around 9 percent, which is nearly 7 percent more than treated sites.

5.2.6 Driver Gender

In the KCARS database, there are three different gender types: female, male, and unknown. In this study, two groups for gender types are considered as male and others (female and unknowns). For this purpose, a query was made between the sections affected/not affected by speed limit change from the ACCIDENT_CANSYS folder and the OCCUPANTS folder by selecting gender type and driver selection as number one. Tables 5.17 and 5.18 depict the number of drivers involved in crashes according to gender type for the sections affected by speed limit change and without change.

Table 5.17: Number of Drivers Involved in Crashes Based on Gender Type for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Gender type		Total number of drivers	% of male drivers	% of other drivers
		Male	Others			
2008	Treated sites	2,723	1,419	4,142	65.74	34.26
	Non-treated sites	2,493	906	3,399	73.35	26.65
2009	Treated sites	2,469	1,329	3,798	65.01	34.99
	Non-treated sites	2,105	791	2,896	72.69	27.31
2010	Treated sites	2,757	1,548	4,305	64.04	35.96
	Non-treated sites	2,529	1,152	3,681	68.70	31.30
Total	**Treated sites**	7,949	4,296	12,245	64.92	35.08
Total	**Non-treated sites**	7,127	2,849	9,976	71.44	28.56

Table 5.18: Number of Drivers Involved in Crashes Based on Gender Type for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Gender type		Total number of drivers	% of male drivers	% of other drivers
		Male	Others			
2012	Treated sites	2,108	1,072	3,180	66.29	33.71
	Non-treated sites	1,233	875	2,108	58.49	41.51
2013	Treated sites	2,298	1,257	3,555	64.64	35.36
	Non-treated sites	1,351	865	2,216	60.97	39.03
2014	Treated sites	2,111	1,149	3,260	64.75	35.25
	Non-treated sites	1,464	956	2,420	60.50	39.50
Total	**Treated sites**	6,517	3,478	9,995	65.20	34.80
Total	**Non-treated sites**	4,048	2,696	6,744	60.02	39.98

Tables 5.17 and 5.18 show that male drivers involved in crashes during the period after speed limit change are 0.28 percent more than before speed limit change for treated sites. However, the percentage of male drivers involved in crashes for non-treated sites during the after period is 12 percent less than the before period.

5.2.7 Age of Driver

There are different ages for drivers involved in a crash and in this study, ages are divided into two groups, which is common in traffic safety analysis, classified as young drivers (from 15 to 24 years old) versus others, and old drivers (over 65 years old) versus others. For this purpose, a query was made from the KCARS database between the OCCUPANT folder with the option of age range, driver selection as number one, and the ACCIDENT_CANSYS folder with the identified sections affected/not affected by speed limit change. Tables 5.19 and 5.20 show the number of young drivers involved in crashes for treated and non-treated sites.

Table 5.19: Number of Young Drivers Involved in Crashes Versus Others for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Age group		Total number of drivers	% of young drivers	% of other drivers
		Young	Others			
2008	Treated sites	913	3,229	4,142	22.04	77.96
	Non-treated sites	780	2,629	3,409	22.88	77.12
2009	Treated sites	831	2,967	3,798	21.88	78.12
	Non-treated sites	688	2,556	3,244	21.21	78.79
2010	Treated sites	972	3,333	4,305	22.58	77.42
	Non-treated sites	736	2,587	3,323	22.15	77.85
Total	**Treated sites**	2,716	9,529	12,245	22.18	77.82
Total	**Non-treated sites**	2,204	7,772	9,976	22.09	77.91

Table 5.20: Number of Young Drivers Involved in Crashes Versus Others for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Age group		Total number of drivers	% of young drivers	% of other drivers
		Young	Others			
2012	Treated sites	676	2,504	3,180	21.26	78.74
	Non-treated sites	495	1,780	2,275	21.76	78.24
2013	Treated sites	770	2,785	3,555	21.66	78.34
	Non-treated sites	471	1,750	2,221	21.21	78.79
2014	Treated sites	710	2,550	3,260	21.78	78.22
	Non-treated sites	483	1,765	2,248	21.49	78.51
Total	**Treated sites**	2,156	7,839	9,995	21.57	78.43
Total	**Non-treated sites**	1,449	5,295	6,744	21.49	78.51

According to Tables 5.19 and 5.20, the percentage of young drivers involved in crashes has decreased by around 1 percent for both treated sites and non-treated sites in the after period compared to before period. Tables 5.21 and 5.22 show the percentage of old drivers involved in crashes during the before-and-after periods for both treated and non-treated sites.

Table 5.21: Number of Old Drivers Involved in Crashes Versus Others for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Age group		Total number of drivers	% of old drivers	% of other drivers
		Old	Others			
2008	Treated sites	282	3,860	4,142	6.81	93.19
	Non-treated sites	232	3,142	3,374	6.88	93.12
2009	Treated sites	268	3,530	3,798	7.06	92.94
	Non-treated sites	221	2,874	3,095	7.14	92.86
2010	Treated sites	299	4,006	4,305	6.95	93.05
	Non-treated sites	246	3,261	3,507	7.01	92.99
Total	**Treated sites**	849	11,396	12,245	6.93	93.07
Total	**Non-treated sites**	699	9,277	9,976	7.01	92.99

Table 5.22: Number of Old Drivers Involved in Crashes Versus Others for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Age group		Total number of drivers	% of old drivers	% of other drivers
		Old	Others			
2012	Treated sites	288	2,892	3,180	9.06	90.94
	Non-treated sites	195	1,949	2,144	9.10	90.90
2013	Treated sites	335	3,220	3,555	9.42	90.58
	Non-treated sites	227	2,171	2,398	9.47	90.53
2014	Treated sites	271	2,989	3,260	8.31	91.69
	Non-treated sites	184	2,018	2,202	8.36	91.64
Total	**Treated sites**	894	9,101	9,995	8.94	91.06
Total	**Non-treated sites**	606	6,138	6,744	8.99	91.01

Tables 5.21 and 5.22 show that the percentage of older drivers has increased by 2% for both treated sites and non-treated sites during the before-and-after periods. Overall, by comparing young drivers versus old drivers, it is understood that the percentage of old drivers has increased for both treated sites and non-treated sites, but the percentage of young drivers have decreased in the after period compared to the before period.

5.2.8 Type of Crash

Another crash characteristic is related to the accident class, which contains categories such as other non-collision, overturned, collision with pedestrian, collision with other motor vehicle, collision with parked motor vehicle, collision with railway train, collision with pedal cycle, collision with animal, collision with fixed object, collision with other object, and unknown, which are all available in the KCARS database. In this study, we decided to consider two groups, classified as (1) collision with fixed object and (2) collision with others. For this purpose, a query was made between the ACCIDENT_CANSYS folder with the option of an identified section and the ACCIDENTS folder with the option of an accident class selection. Results are tabulated in Tables 5.23 and 5.24.

Table 5.23: Number of Crashes Based on Crash Type for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Crash type		Total number of crashes	% of collision with fixed objects	% of collision with others
		Collision with fixed object	Collision with others			
2008	Treated sites	1,238	1,975	3,213	38.53	61.47
	Non-treated sites	679	1,308	1,987	34.17	65.83
2009	Treated sites	1,010	2,001	3,011	33.54	66.46
	Non-treated sites	387	1,292	1,679	23.05	76.95
2010	Treated sites	1,073	2,107	3,180	33.74	66.26
	Non-treated sites	496	1,518	2,014	24.63	75.37
Total	**Treated sites**	3,321	6,083	9,404	35.31	64.69
Total	**Non-treated sites**	1,562	4,118	5,680	27.50	72.50

Table 5.24: Number of Crashes Based on Crash Type for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Crash type		Total number of crashes	% of collision with fixed objects	% of collision with others
		Collision with fixed object	Collision with others			
2012	Treated sites	909	1,944	2,853	31.86	68.14
	Non-treated sites	318	1,169	1,487	21.39	78.61
2013	Treated sites	1,124	2,006	3,130	35.91	64.09
	Non-treated sites	432	1,170	1,602	26.97	73.03
2014	Treated sites	950	1,945	2,895	32.82	67.18
	Non-treated sites	405	1,310	1,715	23.62	76.38
Total	**Treated sites**	2,983	5,895	8,878	33.60	66.40
Total	**Non-treated sites**	1,155	3,649	4,804	24.04	75.96

Results from Tables 5.23 and 5.24 show the percentage of collision with fixed objects has decreased for both treated sites and non-treated sites by nearly 2 percent in the after period compared to the before period.

5.2.9 License Type of Driver

This section is related to license compliance, which gives information about the drivers' licenses. There are different categories for driver's license compliance in the KCARS database, classified as: (1) not licensed, (2) valid license, (3) suspended license, (4) revoked, (5) expired, (6) canceled/denied, (7) disqualified, (8) restricted, and (9) unknown. In this study, two types are considered as (1) valid license versus (2) others, and a query was made between the DRIVERS folder for license compliance type, the OCCUPANTS folder for driver seat position, and the ACCIDENT_CANSYS folder for the treated and non-treated sites selection. Tables 5.25 and 5.26 present this information.

Table 5.25: Number of Drivers Involved in Crashes Based on License Compliance Type for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Driver's license type		Total number of drivers	% of drivers with valid license	% of other drivers
		Valid license	Others			
2008	Treated sites	3,916	243	4,159	94.16	5.84
	Non-treated sites	3,262	161	3,423	95.30	4.70
2009	Treated sites	3,590	211	3,801	94.45	5.55
	Non-treated sites	2,779	124	2,903	95.73	4.27
2010	Treated sites	4,017	268	4,285	93.75	6.25
	Non-treated sites	3,474	176	3,650	95.18	4.82
Total	**Treated sites**	11,523	722	12,245	94.10	5.90
Total	**Non-treated sites**	9,515	461	9,976	95.38	4.62

Table 5.26: Number of Drivers Involved in Crashes Based on License Compliance Type for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Driver's license type		Total number of drivers	% of drivers with valid license	% of other drivers
		Valid license	Others			
2012	Treated sites	2,978	197	3,175	93.80	6.20
	Non-treated sites	1,943	156	2,099	92.57	7.43
2013	Treated sites	3,373	180	3,553	94.93	5.07
	Non-treated sites	2,057	161	2,218	92.74	7.26
2014	Treated sites	3,064	203	3,267	93.79	6.21
	Non-treated sites	2,233	194	2,427	92.01	7.99
Total	**Treated sites**	9,415	580	9,995	94.20	5.80
Total	**Non-treated sites**	6,233	511	6,744	92.42	7.58

Results from Tables 5.25 and 5.26 show that the percentage of drivers with valid licenses for treated sites has slightly increased in the after period compared to the before period. However, the percentage of drivers with valid license has decreased by nearly 3 percent for non-treated sites in the after period versus the before period.

5.2.10 Seatbelt Use by Driver

This section is related to the seatbelt use by drivers involved in crashes. There are different categories for seatbelt use in the KCARS database, such as (1) Lap belt only (L), (2) Shoulder and Lap (S), and (3) Shoulder only (X). In this study, these three categories are considered for drivers with seatbelt use versus drivers who did not use a seatbelt. For this purpose, a query was made between the OCCUPANTS folder for selecting the driver seat and safety equipment use (named as seatbelt use) and the ACCIDENT_CANSYS folder with the option of site selections for both treated sites and non-treated sites. Tables 5.27 and 5.28 represent results for use of seatbelts by drivers involved in crashes.

Table 5.27: Number of Drivers Involved in Crashes Based on Seatbelt Use for Treated Sites and Non-Treated Sites in the Before Period

Year	Roadway sections	Driver's seatbelt use		Total number of drivers	% of drivers with seatbelt use	% of drivers without seatbelt use
		Yes	No			
2008	Treated sites	3,603	539	4,142	86.99	13.01
	Non-treated sites	2,967	433	3,400	87.26	12.74
2009	Treated sites	3,288	510	3,798	86.57	13.43
	Non-treated sites	2,497	398	2,895	86.25	13.75
2010	Treated sites	3,757	548	4,305	87.27	12.73
	Non-treated sites	3,216	465	3,681	87.37	12.63
Total	**Treated sites**	10,648	1,597	12,245	86.96	13.04
Total	**Non-treated sites**	8,680	1,296	9,976	87.01	12.99

Table 5.28: Number of Drivers Involved in Crashes Based on Seatbelt Use for Treated Sites and Non-Treated Sites in the After Period

Year	Roadway sections	Driver's seatbelt use		Total number of drivers	% of drivers with seatbelt use	% of drivers without seatbelt use
		Yes	No			
2012	Treated sites	2,773	407	3,180	87.20	12.80
	Non-treated sites	1,813	295	2,108	86.01	13.99
2013	Treated sites	3,116	439	3,555	87.65	12.35
	Non-treated sites	1,894	322	2,216	85.47	14.53
2014	Treated sites	2,825	435	3,260	86.66	13.34
	Non-treated sites	2,094	326	2,420	86.53	13.47
Total	**Treated sites**	8,714	1,281	9,995	87.18	12.82
Total	**Non-treated sites**	5,801	943	6,744	86.02	13.98

Tables 5.27 and 5.28 clearly show that the percentage of drivers who did not use a seatbelt has slightly decreased for the sections affected by speed limit change, but it has increased by 1 percent for non-treated sites in the after period compared to the before period. It can also be interpreted that the percentage of drivers with seatbelt use for treated sites has increased and drivers appear to be more cautious after the speed limit change compared to the time that speed limit had remained unchanged. However, the difference seems very small.

Chapter 6: Summary and Conclusions

6.1 Summary

Speed limits are the peak legal trip speeds under acceptable conditions of good weather, free-flowing traffic, and good vision. Suitable speed limits are necessary to ensure reasonably safe and efficient trips. Posting suitable speed limits on roadways is very important. Incorrectly posted speed limits could bring about problems, such as reduced driver compliance rates and increased number of crashes, injuries, and fatalities. HB 2192, a bill allowing the Secretary of Transportation in Kansas to set a new speed limit on interstates, was signed by the Governor to become effective July 1, 2011.

The eligible freeway sections were estimated at around 800 miles and as a result of this bill, a task force was put together to look at eligible freeways and determine where to raise the speed limit from 70 mph to 75 mph. Supporters pointed out that drivers were already driving 5 to 10 mph above the posted speed limit and therefore it made sense to make it formal. It had also been mentioned that the increased speed limit would help the economic development of Kansas, by encouraging more traffic on I-70. On the other hand, opponents said drivers would not change their behavior and would still drive 5 to 10 mph above the posted speed limit, bringing actual speeds to even higher values. In this case, the primary concern was safety, as crash severities tend to increase with increased speeds, based on laws of physics. The key objective of this study was to evaluate safety impacts of freeway sections affected by speed limit change in Kansas. Sections where the speed limit changed from 70 mph to 75 mph, and other comparable sections where the speed limit remained at 70 mph without any change, were identified. Details of crashes by severity level for 3 years before (2008–2010) and 3 years after (2012–2014) the speed limit change were gathered by using the state crash database. In order to evaluate the safety situation, three methods as provided in the Highway Safety Manual (AASHTO, 2014) were utilized: (1) Empirical Bayes (EB) observational before-and-after study; (2) Before-and-after study with a comparison group; and (3) Cross-sectional method using Negative Binomial (NB) regression model. The evaluation was conducted to see if speed limit changes had caused an increase in total crashes or fatal and injury crashes. It was decided to utilize all three methods, since each method has its own pros and cons and researchers wanted to verify that the results are consistent and in the same direction. In regard to speed analysis, where data were obtained from permanent count stations, the t-test was applied to check whether significant increases in the 85th percentile speed were observed between before and after conditions. Since the sample size was excessively large, the Kolmogorov-Smirnov (K-S) test was also conducted to see if there was any difference between two sets of speed data distributions in the before period compared to the after period.

6.2 Conclusions

Based on the analysis of Kansas speed and crash databases, the following related conclusions are summarized in this section according to three safety-effectiveness evaluation methods, speed study, crash contributory causes, and crash characteristics for treated and non-treated sites during the periods before-and-after speed limit changes.

6.2.1 Conclusions Regarding Crash Data Analysis

According to the EB before-after study, overall CMF for the total treated sites was estimated and safety effectiveness represented a 16 percent increase in total crashes after speed limit increase, which was statistically significant at the 95 percent confidence level. However, results of the EB method did not show any statistically significant increase for fatal and injury crashes after the speed limit change. Furthermore, the before-and-after study with the comparison group method showed that raising the speed limit caused a 27 percent increase in the total number of crashes, and the treatment effect was statistically significant at the 95 percent confidence level. Number of fatal and injury crashes increased even more, around 35 percent, and this increase was also statistically significant at the 95 percent confidence level. Results of the cross-sectional method also showed that speed limit increase caused a 25 percent increase in total crashes and even caused a 62 percent increase in fatal and injury crashes, which is 37 percent more than the increase in total crashes. These increases were also statistically significant at the 95 percent confidence level.

CMF values for total crashes seems more stable (1.16, 1.27, and 1.25) irrespective of the method that was utilized; however, CMF for fatal crashes show a wide variation from 1.007 (not significant) to 1.62. One possibility is that the sample size of number of fatal and injury crashes is much smaller compared to total crashes, and hence more randomness is associated with that.

Among the three methods, the more reliable method could be considered as the before-and-after study with comparison group method, since it takes into consideration what happened on treated sections in comparison to the safety experience at non-treated sections. Hence, it could be concluded that fatal and injury crashes increased by 35% while total crashes increased by 27% after the speed limit increase was implemented.

6.2.2 Conclusions Regarding Speed Data Analysis

The study suggests considerable impact of speed limit change from 70 mph to 75 mph at the 85th percentile speed. According to one-tailed t-test results, speed limit change increased the 85th percentile speed by approximately 3 mph after speed limit change for most freeway sections affected by speed limit change. Moreover, posted speed limit increase caused drivers to speed up significantly at most of the places where ATRs exist for the sections influenced by speed limit change. ATR 3 (all months' speed data) and ATR 9 (1-month data) are the only traffic count stations that showed drivers' speeds had not been statistically greater than before the speed limit change and the reason may be that the sample size in the after period was much larger than in the before period, which may not help to easily compare the impact of speed limit change. Two-tailed t-test results also showed that 85th percentile speed was statistically different at all treated sections after speed limit change. Furthermore, the 85th percentile speed is still statistically different for non-treated sections where the speed limit did not change. The statistical significance of the change in speed for the before-and-after analysis according to two-tailed t-test was because the sample size for this research was so large that any change in 85th percentile speed would be significant. In this study, since the sample size for speed data was large, the K-S test was also applied to consider if the two sets of speed data were differently distributed or not. It was concluded that speed data for majority of treated sites during the after period was statistically different (higher) than the before period.

6.2.3 Conclusions Regarding Crash Contributory Causes and Characteristics

Total driver-related crash contributory causes have increased for both treated sites and non-treated sites during the after period compared to the before period. The more important thing to note is that the speeding-cause difference for non-treated sites was not considerable and not too much change was observed for the after period versus the before period. In addition, it can be interpreted that speeding as a driver CC for treated sites has reduced more than that of non-treated sites.

The percentage of nighttime crashes showed a nearly 1 percent increase in the after time period compared to the before time period, but for sections where the speed limit was not changed, nighttime crashes decreased by 1 percent. Furthermore, the percentage of automobiles and large trucks involved in crashes for the sections affected by speed limit change presented more of an increase than the sections without speed limit change, which means that large trucks were involved in more crashes when the speed limit increased, compared to when that the speed limit had remained at 70 mph. It is possible that trucks at 75 mph are leading to more speed differentials contributing to unsafe conditions. Moreover, the total number of drivers involved in crashes based on alcohol consumption, weather conditions, and weekend crashes decreased for both treated and non-treated sites during the after period compared to the before period. However, male drivers involved in crashes increased when the speed limit increased, but for non-treated sites, male drivers' crash involvement decreased by 11 percent. Additionally, young drivers involved in crashes decreased by 2 percent for both treated and non-treated sites, while older drivers' crash involvement increased by 2 percent for both sets of sites.

Collisions with fixed objects decreased by 1.6 percent at treated sites, while at non-treated sites they decreased by 3.4 percent. On the contrary, collisions with other vehicles, other objects, animal crashes, etc., showed an increase for both types of sites in the after period versus the before period.

Finally, the percentage of drivers who have used seatbelt while driving did increase by 0.22 percent when the speed limit changed from 70 mph to 75 mph but for the sections without speed limit change, the number of drivers with seatbelt use decreased by 0.99 percent. This means drivers became more cautious about seatbelt use after the speed limit changed compared to the time where the speed limit had not changed at all.

This study provides important insights on the safety experience and other related factors associated with the increased speed limits on selected freeway sections in Kansas in the summer of 2011. By considering all applicable methodologies, it could be summarized that safety got worse after the speed limits increased from 70 mph to 75 mph.

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Appendix A: Speed Analysis

Table A.1: Speed Frequency Distribution for F10VD5 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	69	0.089	0.089	2,932	124,631
45	50	47.5	138	0.178	0.267	6,555	311,362
50	55	52.5	469	0.605	0.872	24,622	1,292,681
55	60	57.5	1,761	2.272	3.144	101,257	5,822,306
60	65	62.5	7,051	9.099	12.24	440,687	27,542,968
65	70	67.5	19,655	25.363	37.60	1,326,712	89,553,093
70	75	72.5	31,569	40.736	78.34	2,288,752	165,934,556
75	80	77.5	14,178	18.295	96.63	1,098,795	85,156,612
80	85	82.5	2,031	2.621	99.25	167,557	13,823,493
85	90	87.5	418	0.539	99.79	36,575	3,200,312
90	95	92.5	157	0.203	100	14,522	1,343,331
Total			77,496	100		5,508,970	394,105,350

Table A.2: Speed Frequency Distribution for F10VD5 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	250	0.06	0.06	10,625	451,563
45	50	47.5	709	0.18	0.24	33,678	1,599,681
50	55	52.5	2,398	0.60	0.85	125,895	6,609,488
55	60	57.5	7,784	1.96	2.81	447,580	25,735,850
60	65	62.5	30,577	7.70	10.50	1,911,063	119,441,406
65	70	67.5	60,881	15.33	25.83	4,109,468	277,389,056
70	75	72.5	108,227	27.25	53.08	7,846,458	568,868,169
75	80	77.5	136,246	34.30	87.38	10,559,065	818,327,538
80	85	82.5	43,082	10.85	98.23	3,554,265	293,226,863
85	90	87.5	5,941	1.50	99.73	519,838	45,485,781
90	95	92.5	1,082	0.27	100	100,085	9,257,863
Total			397,177	100		29,218,018	2,166,393,256

Table A.3: Speed Frequency Distribution for CXJUQ3 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	1,525	0.10	0.108	64,812	2,754,531
45	50	47.5	3,247	0.23	0.338	154,232	7,326,043
50	55	52.5	8,911	0.63	0.97	467,827	24,560,943
55	60	57.5	40,453	2.86	3.83	2,326,047	133,747,731
60	65	62.5	221,408	15.70	19.54	13,838,000	864,875,000
65	70	67.5	545,310	38.67	58.22	36,808,425	2,484,568,687
70	75	72.5	427,029	30.28	88.50	30,959,602	2,244,571,181
75	80	77.5	135,414	9.60	98.11	10,494,585	813,330,337
80	85	82.5	21,803	1.54	99.65	1,798,747	148,396,668
85	90	87.5	3,623	0.25	99.91	317,012	27,738,593
90	95	92.5	1,189	0.084	100	109,982	10,173,381
Total			1,409,912	100		97,339,275	6,762,043,100

Table A.4: Speed Frequency Distribution for CXJUQ3 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	5,648	0.11	0.11	240,040	10,201,700
45	50	47.5	14,085	0.27	0.38	669,038	31,779,281
50	55	52.5	42,223	0.81	1.19	2,216,708	116,377,144
55	60	57.5	192,673	3.69	4.87	11,078,698	637,025,106
60	65	62.5	919,344	17.59	22.47	57,459,000	3,591,187,500
65	70	67.5	2,005,742	38.38	60.84	135,387,585	9,138,661,988
70	75	72.5	1,472,048	28.17	89.01	106,723,480	7,737,452,300
75	80	77.5	466,425	8.92	97.93	36,147,938	2,801,465,156
80	85	82.5	88,672	1.70	99.63	7,315,440	603,523,800
85	90	87.5	14,840	0.28	99.92	1,298,500	113,618,750
90	95	92.5	4,524	0.09	100	418,470	38,708,475
Total			5,226,224	100		358,954,895	24,820,001,200

Table A.5: Speed Frequency Distribution for CXSRG1 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	703	0.22	0.22	29,877	1,269,793
45	50	47.5	1,628	0.51	0.73	77,330	3,673,175
50	55	52.5	4,465	1.41	2.14	234,412	12,306,656
55	60	57.5	10,388	3.29	5.43	597,310	34,345,325
60	65	62.5	32,701	10.36	15.79	2,043,812	127,738,281
65	70	67.5	85,512	27.10	42.89	5,772,060	389,614,050
70	75	72.5	128,296	40.66	83.55	9,301,460	674,355,850
75	80	77.5	45,489	14.41	97.96	3,525,397	273,218,306
80	85	82.5	5,268	1.67	99.63	434,610	35,855,325
85	90	87.5	742	0.23	99.86	64,925	5,680,937
90	95	92.5	295	0.094	100	27,287	2,524,093
Total			315,487	100		22,108,483	1,560,581,794

Table A.6: Speed Frequency Distribution for CXSRG1 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	2,099	0.16	0.16	89,208	3,791,319
45	50	47.5	6,382	0.50	0.67	303,145	14,399,388
50	55	52.5	25,242	1.98	2.65	1,325,205	69,573,263
55	60	57.5	65,996	5.19	7.84	3,794,770	218,199,275
60	65	62.5	152,209	11.96	19.80	9,513,063	594,566,406
65	70	67.5	316,943	24.91	44.70	21,393,653	1,444,071,544
70	75	72.5	488,217	38.36	83.07	35,395,733	2,566,190,606
75	80	77.5	181,717	14.28	97.35	14,083,068	1,091,437,731
80	85	82.5	28,597	2.25	99.59	2359,253	194,638,331
85	90	87.5	3,867	0.30	99.90	338,363	29,606,719
90	95	92.5	1,297	0.10	100	119,973	11,097,456
Total			1,272,566	100		88,715,430	6,237,572,038

Table A.7: Speed Frequency Distribution for E7PK42 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	310	0.11	0.11	13,175	559,937
45	50	47.5	349	0.12	0.23	16,577	787,431
50	55	52.5	773	0.27	0.506	40,582	2,130,581
55	60	57.5	3,492	1.23	1.74	200,790	11,545,425
60	65	62.5	24,830	8.78	10.52	1,551,875	96,992,187
65	70	67.5	57,388	20.29	30.81	3,873,690	261,474,075
70	75	72.5	122,702	43.39	74.21	8,895,895	644,952,387
75	80	77.5	65,554	23.18	97.39	5,080,435	393,733,712
80	85	82.5	6,319	2.23	99.63	521,317	43,008,693
85	90	87.5	874	0.30	99.94	76,475	6,691,562
90	95	92.5	169	0.06	100	15,632	1,446,006
Total			282,760	100		20,286,445	1,463,322,000

Table A.8: Speed Frequency Distribution for E7PK42 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	872	0.14	0.14	37,060	1,575,050
45	50	47.5	1,285	0.21	0.36	61,038	2,899,281
50	55	52.5	2,181	0.36	0.72	114,503	6,011,381
55	60	57.5	7,881	1.31	2.03	453,158	26,056,556
60	65	62.5	50,615	8.41	10.44	3,163,438	197,714,844
65	70	67.5	85,860	14.27	24.72	5,795,550	391,199,625
70	75	72.5	171,951	28.58	53.30	12,466,448	903,817,444
75	80	77.5	201,689	33.53	86.83	15,630,898	1,211,394,556
80	85	82.5	70,223	11.67	98.50	5,793,398	477,955,294
85	90	87.5	7,601	1.26	99.76	665,088	58,195,156
90	95	92.5	1,430	0.24	100	132,275	12,235,438
Total			601,588	100		44,312,850	3,289,054,625

Table A.9: Speed Frequency Distribution for A0OOS8 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	213	0.026	0.026	9,053	384,731
45	50	47.5	1122	0.14	0.16	53,295	2,531,513
50	55	52.5	6548	0.80	0.97	343,770	18,047,925
55	60	57.5	36,766	4.50	5.47	2,114,045	121,557,588
60	65	62.5	176,459	21.62	27.09	11,028,688	689,292,969
65	70	67.5	377,582	46.26	73.34	25,486,785	1,720,357,988
70	75	72.5	189,978	23.27	96.61	13,773,405	998,571,863
75	80	77.5	24,257	2.97	99.59	1,879,918	145,693,606
80	85	82.5	2,719	0.33	99.92	224,318	18,506,194
85	90	87.5	448	0.05	99.97	39,200	3,430,000
90	95	92.5	212	0.03	100	19,610	1,813,925
Total			816,304	100		54,972,085	3,720,188,300

Table A.10: Speed Frequency Distribution for A0OOS8 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	3,084	0.12	0.12	131,070	5,570,475
45	50	47.5	7,318	0.28	0.40	347,605	16,511,238
50	55	52.5	27,426	1.04	1.43	1,439,865	75,592,913
55	60	57.5	133,720	5.05	6.48	7,688,900	442,111,750
60	65	62.5	570,210	21.54	28.03	35,638,125	2,227,382,813
65	70	67.5	1,220,209	46.10	74.13	82,364,108	5,559,577,256
70	75	72.5	606,698	22.92	97.05	43,985,605	3,188,956,363
75	80	77.5	65,829	2.49	99.54	5,101,748	395,385,431
80	85	82.5	9,369	0.35	99.89	772,943	63,767,756
85	90	87.5	1,850	0.07	99.96	16,1875	14,164,063
90	95	92.5	1,120	0.04	100	103,600	9,583,000
Total			2,646,833	100		177,735,443	11,998,603,056

Table A.11: Speed Frequency Distribution for CB1U73 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	411	0.047	0.047	17,468	742,369
45	50	47.5	667	0.08	0.12	31,683	1,504,919
50	55	52.5	1594	0.18	0.31	83,685	4,393,463
55	60	57.5	7,193	0.83	1.14	413,598	23,781,856
60	65	62.5	46,500	5.36	6.49	2,906,250	181,640,625
65	70	67.5	126,266	14.55	21.04	8,522,955	575,299,463
70	75	72.5	371,500	42.80	63.84	26,933,750	1,952,696,875
75	80	77.5	269,681	31.07	94.91	20,900,278	1,619,771,506
80	85	82.5	37,444	4.31	99.22	3,089,130	254,853,225
85	90	87.5	5461	0.63	99.85	477,838	41,810,781
90	95	92.5	1306	0.15	100	120,805	11,174,463
Total			868,023	100		63,497,438	4,667,669,544

Table A.12: Speed Frequency Distribution for CB1U73 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	1,227	0.11	0.11	52,148	2,216,269
45	50	47.5	2,743	0.24	0.35	130,293	6,188,894
50	55	52.5	8,583	0.76	1.11	450,608	23,656,894
55	60	57.5	34,150	3.03	4.14	1,963,625	112,908,438
60	65	62.5	128,324	11.38	15.52	8,020,250	501,265,625
65	70	67.5	170794	15.15	30.67	11,528,595	778,180,163
70	75	72.5	210,038	18.63	49.30	15,227,755	1,104,012,238
75	80	77.5	371,605	32.96	82.25	28,799,388	2,231,952,531
80	85	82.5	173,589	15.39	97.65	14,321,093	1,181,490,131
85	90	87.5	22,086	1.96	99.61	1,932,525	169,095,938
90	95	92.5	4,432	0.39	100	409,960	37,921,300
Total			1,127,571	100		82,836,238	6,148,888,419

Table A.13: Speed Frequency Distribution for CO1AY7 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	51	0.012	0.012	2,168	92,119
45	50	47.5	234	0.05	0.07	11,115	527,963
50	55	52.5	951	0.22	0.29	49,928	2,621,194
55	60	57.5	5,412	1.27	1.56	311,190	17,893,425
60	65	62.5	37,492	8.78	10.33	2,343,250	146,453,125
65	70	67.5	83,319	19.51	29.84	5,624,033	379,622,194
70	75	72.5	175,773	41.15	70.99	12,743,543	923,906,831
75	80	77.5	109,682	25.68	96.67	8,500,355	658,777,513
80	85	82.5	12,101	2.83	99.50	998,333	82,362,431
85	90	87.5	1785	0.42	99.92	156,188	13,666,406
90	95	92.5	332	0.08	100	30,710	2,840,675
Total			427,132	100		30,770,810	2,228,763,875

Table A.14: Speed Frequency Distribution for CO1AY7 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	107	0.01	0.01	4,548	193,269
45	50	47.5	505	0.04	0.05	23,988	1,139,406
50	55	52.5	2,439	0.20	0.25	128,048	6,722,494
55	60	57.5	14,626	1.20	1.45	840,995	48,357,213
60	65	62.5	108,958	8.96	10.41	6,809,875	425,617,188
65	70	67.5	184,087	15.14	25.55	12,425,873	838,746,394
70	75	72.5	263,972	21.70	47.25	19,137,970	1,387,502,825
75	80	77.5	458,548	37.70	84.95	35,537,470	2,754,153,925
80	85	82.5	167,866	13.80	98.75	13,848,945	1,142,537,963
85	90	87.5	13,227	1.09	99.84	1,157,363	101,269,219
90	95	92.5	1,952	0.16	100	180,560	16,701,800
Total			1,216,287	100		90,095,633	6,722,941,694

Table A.15: Speed Frequency Distribution for CTGTW8 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	1,547	0.229	0.229	65,748	2,794,269
45	50	47.5	8,017	1.18	1.41	380,808	18,088,356
50	55	52.5	39,197	5.79	7.21	2,057,843	108,036,731
55	60	57.5	134,489	19.88	27.09	7,733,118	444,654,256
60	65	62.5	231,966	34.29	61.37	14,497,875	906,117,188
65	70	67.5	194,114	28.69	90.06	13,102,695	884,431,913
70	75	72.5	58,500	8.65	98.71	4,241,250	307,490,625
75	80	77.5	7,251	1.07	99.78	561,953	43,551,319
80	85	82.5	1,079	0.16	99.94	89,018	7,343,944
85	90	87.5	274	0.04	99.98	23,975	2,097,813
90	95	92.5	117	0.02	100	10,823	1,001,081
Total			676,551	100		42,765,103	2,725,607,494

Table A.16: Speed Frequency Distribution for CTGTW8 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	6,980	0.30	0.30	296,650	12,607,625
45	50	47.5	26,500	1.14	1.44	1,258,750	59,790,625
50	55	52.5	125,185	5.38	6.82	6,572,213	345,041,156
55	60	57.5	419,389	18.03	24.85	24,114,868	1,386,604,881
60	65	62.5	788,201	33.88	58.72	49,262,563	3,078,910,156
65	70	67.5	706,134	30.35	89.07	47,664,045	3,217,323,038
70	75	72.5	219,076	9.42	98.49	15,883,010	1,151,518,225
75	80	77.5	29,593	1.27	99.76	2,293,458	177,742,956
80	85	82.5	4,142	0.18	99.94	341,715	28,191,488
85	90	87.5	1,029	0.04	99.98	90,038	7,878,281
90	95	92.5	363	0.02	100	33,578	3,105,919
Total			2,326,592	100		147,810,885	9,468,714,350

Table A.17: Speed Frequency Distribution for 4LGSU7ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	55	0.02	0.02	2,337	99,343
45	50	47.5	164	0.07	0.09	7,790	370,025
50	55	52.5	791	0.34	0.43	41,527	2,180,193
55	60	57.5	4,126	1.78	2.215	237,245	13,641,587
60	65	62.5	25,307	10.91	13.13	1,581,687	98,855,468
65	70	67.5	51,937	22.40	35.53	3,505,747	236,637,956
70	75	72.5	95,404	41.15	76.69	6,916,790	501,467,275
75	80	77.5	47,539	20.50	97.19	3,684,272	285,531,118
80	85	82.5	5,407	2.33	99.53	446,077	36,801,393
85	90	87.5	771	0.33	99.86	67,462	5,902,968
90	95	92.5	316	0.13	100	29,230	2,703,775
Total			231,817	100		16,520,168	1,184,191,106

Table A.18: Speed Frequency Distribution for 4LGSU7 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	362	0.10	0.10	15,385	653,863
45	50	47.5	804	0.21	0.31	38,190	1,814,025
50	55	52.5	1,914	0.51	0.82	100,485	5,275,463
55	60	57.5	6,893	1.84	2.66	396,348	22,789,981
60	65	62.5	35,246	9.38	12.04	2,202,875	137,679,688
65	70	67.5	53,193	14.16	26.21	3,590,528	242,360,606
70	75	72.5	77,448	20.62	46.83	5,614,980	407,086,050
75	80	77.5	127,766	34.02	80.85	9,901,865	767,394,538
80	85	82.5	60,321	16.06	96.91	4,976,483	410,559,806
85	90	87.5	9,274	2.47	99.38	811,475	71,004,063
90	95	92.5	2,343	0.62	100	216,728	20,047,294
Total			375,564	100		27,865,340	2,086,665,375

Table A.19: Speed Frequency Distribution for 7FGNB7 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	89	0.03	0.033	3,783	160,756
45	50	47.5	254	0.09	0.13	12,065	573,088
50	55	52.5	919	0.34	0.46	48,248	2,532,994
55	60	57.5	4,793	1.75	2.22	275,598	15,846,856
60	65	62.5	28,961	10.60	12.82	1,810,063	113,128,906
65	70	67.5	56,933	20.84	33.66	3,842,978	259,400,981
70	75	72.5	110,630	40.50	74.16	8,020,675	581,498,938
75	80	77.5	62,356	22.83	96.99	4,832,590	374,525,725
80	85	82.5	7,231	2.65	99.63	596,558	49,215,994
85	90	87.5	745	0.27	99.91	65,188	5,703,906
90	95	92.5	255	0.09	100	23,588	2,181,844
Total			273,166	100		19,531,330	1,404,769,988

Table A.20: Speed Frequency Distribution for 7FGNB ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	922	0.30	0.30	39,185	1,665,363
45	50	47.5	1,526	0.49	0.79	72,485	3,443,038
50	55	52.5	2,088	0.67	1.46	109,620	5,755,050
55	60	57.5	5,076	1.63	3.09	291,870	16,782,525
60	65	62.5	28,440	9.15	12.24	1,777,500	111,093,750
65	70	67.5	36,298	11.67	23.91	2,450,115	165,382,763
70	75	72.5	59,501	19.14	43.05	4,313,823	312,752,131
75	80	77.5	117,259	37.71	80.76	9,087,573	704,286,869
80	85	82.5	53,473	17.20	97.96	4,411,523	363,950,606
85	90	87.5	5,352	1.72	99.68	468,300	40,976,250
90	95	92.5	1,017	0.33	100	94,073	8,701,706
Total			310,952	100		23,116,065	1,734,790,050

Table A.21: Speed Frequency Distribution for 9Q9OK1 ATR Before Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	3,769	0.08	0.08	160,183	6,807,756
45	50	47.5	14,667	0.33	0.42	696,683	33,092,419
50	55	52.5	78,003	1.77	2.19	4,095,158	214,995,769
55	60	57.5	578,655	13.12	15.30	33,272,663	1,913,178,094
60	65	62.5	2,068,379	46.89	62.19	129,273,688	8,079,605,469
65	70	67.5	1,275,981	28.93	91.12	86,128,718	5,813,688,431
70	75	72.5	329,616	7.47	98.59	23,897,160	1,732,544,100
75	80	77.5	49,290	1.12	99.71	3,819,975	296,048,063
80	85	82.5	8,879	0.20	99.91	732,518	60,432,694
85	90	87.5	2,389	0.05	99.97	209,038	18,290,781
90	95	92.5	1,506	0.03	100	139,305	12,885,713
Total			4,411,134	100		282,425,085	18,181,569,288

Table A.22: Speed Frequency Distribution for 9Q9OK1 ATR After Speed Limit Change

Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	11,565	0.13	0.13	491,513	20,889,281
45	50	47.5	27,834	0.32	0.45	1,322,115	62,800,463
50	55	52.5	139,970	1.59	2.03	7,348,425	385,792,313
55	60	57.5	1,089,752	12.36	14.40	62,660,740	3,602,992,550
60	65	62.5	3,943,771	44.74	59.14	246,485,688	15,405,355,469
65	70	67.5	2,704,209	30.68	89.82	182,534,108	12,321,052,256
70	75	72.5	746,178	8.47	98.28	54,097,905	3,922,098,113
75	80	77.5	117,427	1.33	99.62	9,100,593	705,295,919
80	85	82.5	23,490	0.27	99.88	1,937,925	159,878,813
85	90	87.5	6,240	0.07	99.95	546,000	47,775,000
90	95	92.5	3,953	0.04	100	365,653	33,822,856
Total			8,814,389	100		566,890,663	36,667,753,031

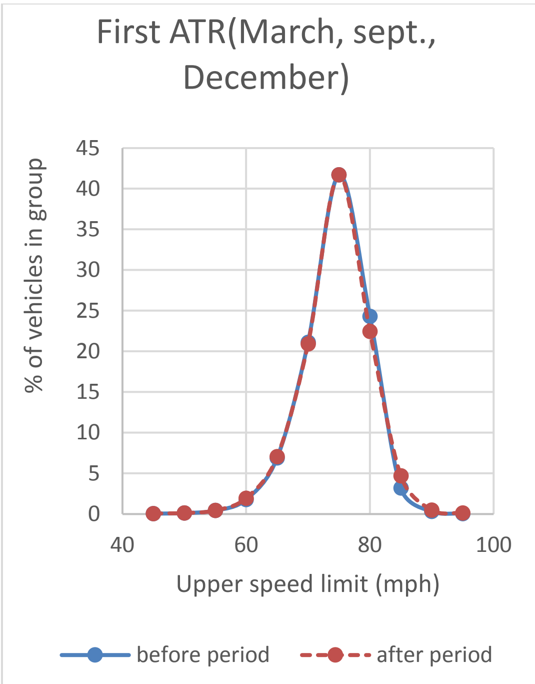
Table A.23: Speed Frequency Distribution for 91TFY5 ATR Before Speed Limit Change

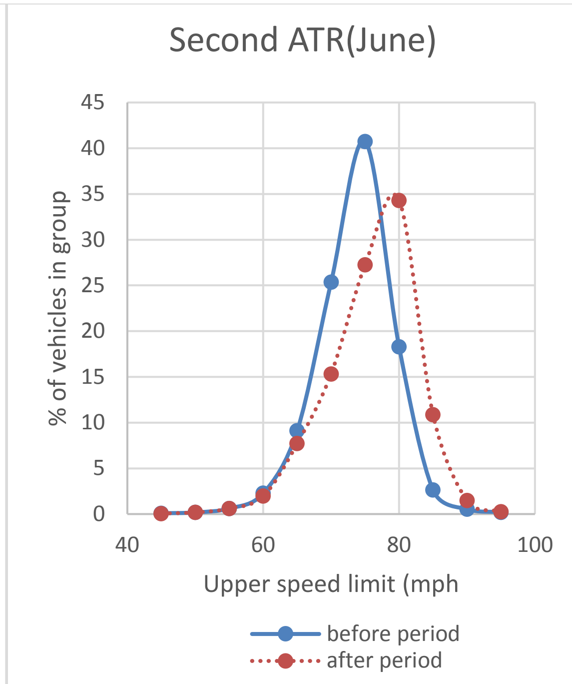
Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	61	0.042	0.042	2,593	110,181
45	50	47.5	222	0.15	0.20	10,545	500,888
50	55	52.5	838	0.58	0.78	43,995	2,309,738
55	60	57.5	3,362	2.33	3.11	193,315	11,115,613
60	65	62.5	14,833	10.27	13.38	927,063	57,941,406
65	70	67.5	35,793	24.79	38.17	2,416,028	163,081,856
70	75	72.5	61,966	42.92	81.09	4,492,535	325,708,788
75	80	77.5	24,809	17.18	98.28	1,922,698	149,009,056
80	85	82.5	2,221	1.54	99.82	183,233	15,116,681
85	90	87.5	179	0.12	99.94	15,663	1,370,469
90	95	92.5	84	0.06	100	7,770	718,725
Total			144,368	100		10,215,435	726,983,400

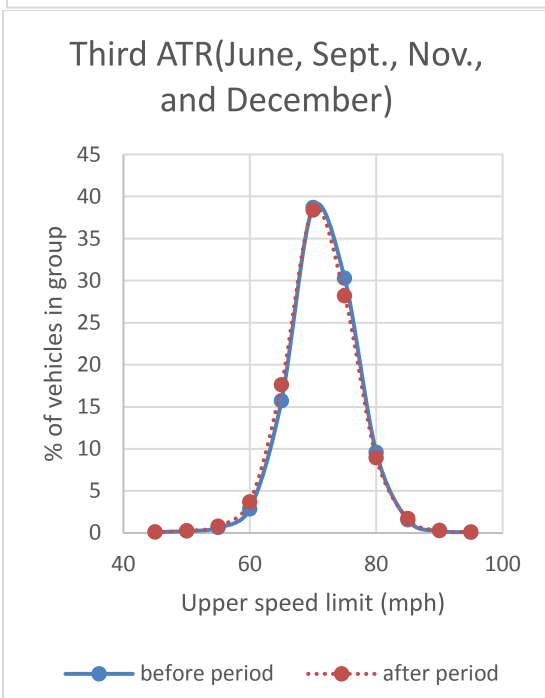
Table A.24: Speed Frequency Distribution for 91TFY5 ATR After Speed Limit Change

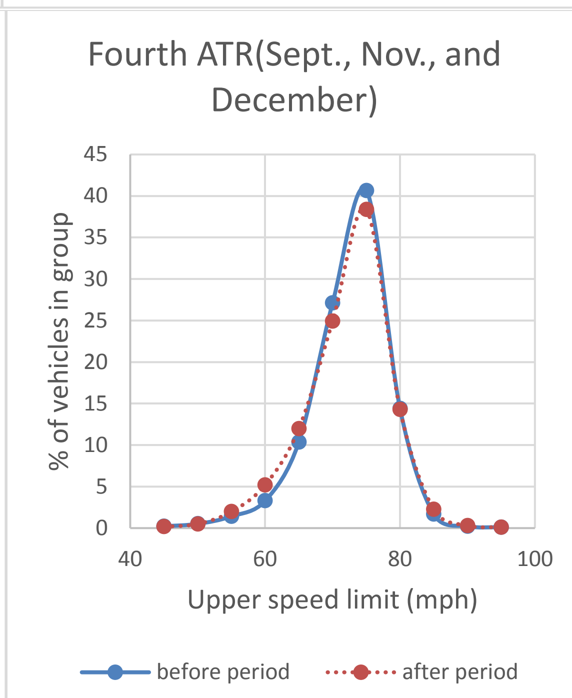
Speed Group							
Lower Limit (mph)	Upper limit (mph)	Middle speed (S) (mph)	Number of vehicles in group (N)	Vehicles in group (%)	Cumulative vehicle (%)	NS	NS^2
40	45	42.5	271	0.12	0.12	11,518	489,494
45	50	47.5	727	0.33	0.45	34,533	1,640,294
50	55	52.5	1,995	0.90	1.35	104,738	5,498,719
55	60	57.5	6,630	2.98	4.33	381,225	21,920,438
60	65	62.5	24,608	11.08	15.41	1,538,000	96,125,000
65	70	67.5	53,685	24.17	39.58	3,623,738	244,602,281
70	75	72.5	95,772	43.11	82.69	6,943,470	503,401,575
75	80	77.5	35,268	15.88	98.57	2,733,270	211,828,425
80	85	82.5	2,818	1.27	99.84	232,485	19,180,013
85	90	87.5	260	0.12	99.95	22,750	1,990,625
90	95	92.5	98	0.04	100	9,065	838,513
Total			222,132	100		15,634,790	1,107,515,375

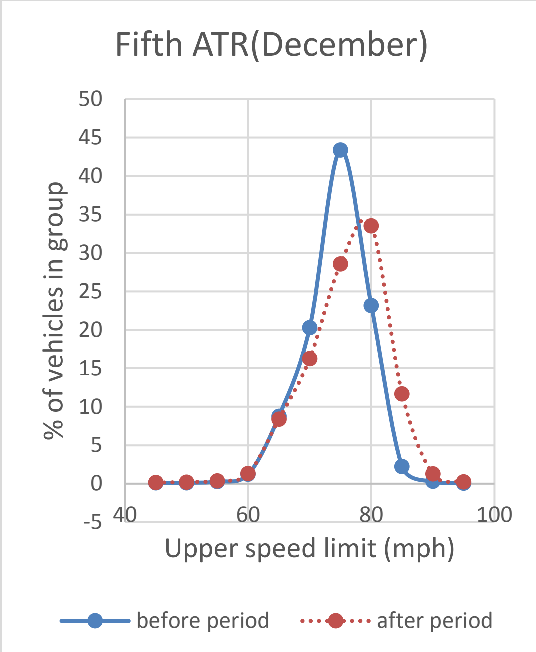
Appendix B: Speed Data Distributions in the Before and After Periods

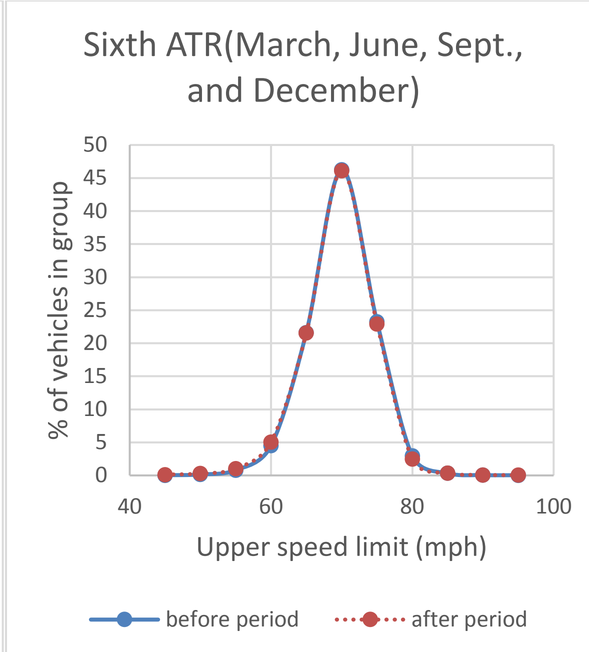


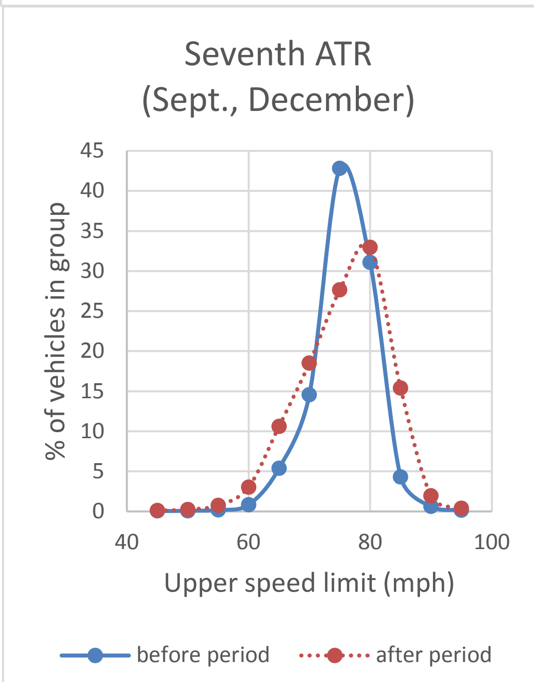


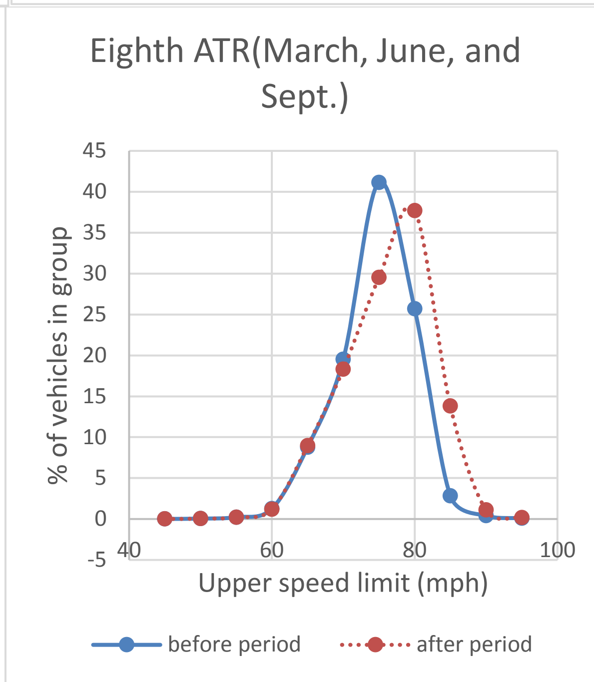


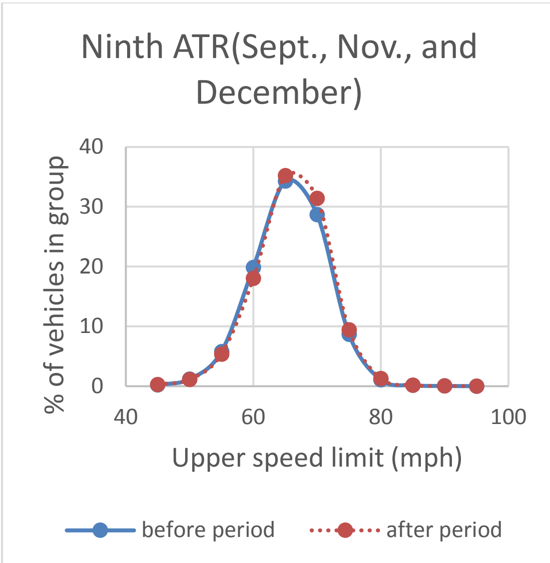


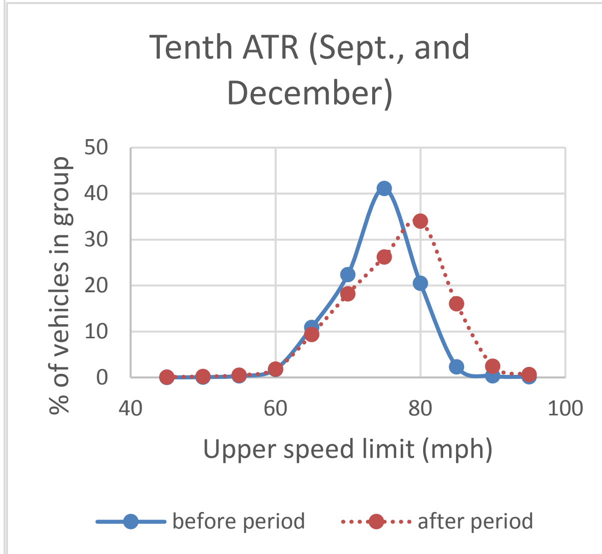

Fifth ATR(December)
% of vehicles in group
Upper speed limit (mph)
before period
after period

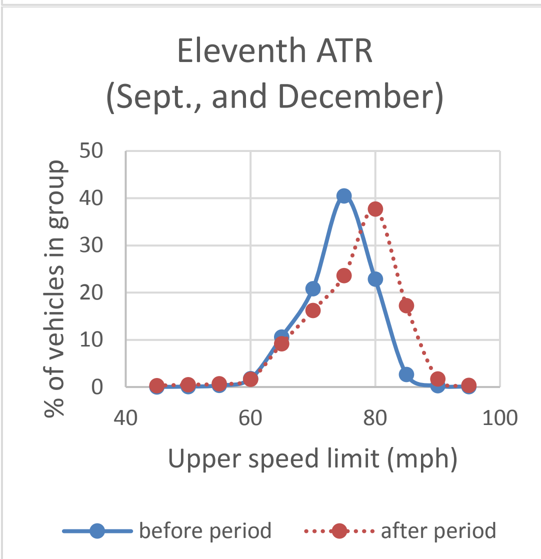

Sixth ATR(March, June, Sept., and December)
% of vehicles in group
Upper speed limit (mph)
before period
after period

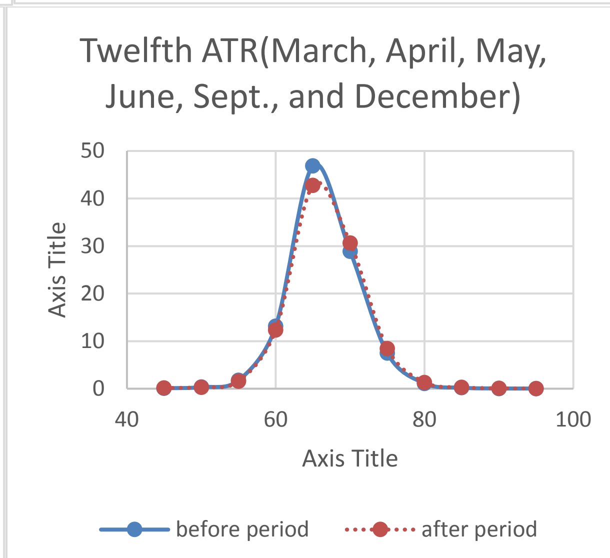

Seventh ATR (Sept., December)
% of vehicles in group
Upper speed limit (mph)
before period
after period

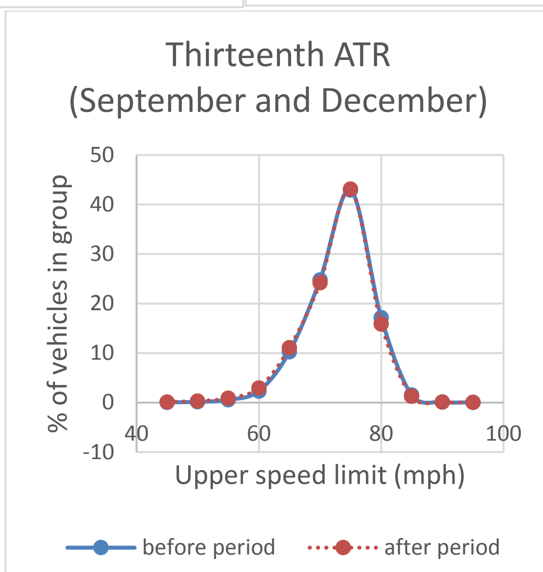

Eighth ATR(March, June, and Sept.)
% of vehicles in group
Upper speed limit (mph)
before period
after period


Ninth ATR(Sept., Nov., and December)
40
30
20
10
0
% of vehicles in group
40
60
80
100
Upper speed limit (mph)
before period
after period


Tenth ATR (Sept., and December)
50
40
30
20
10
0
% of vehicles in group
40
60
80
100
Upper speed limit (mph)
before period
after period


Eleventh ATR (Sept., and December)
50
40
30
20
10
0
% of vehicles in group
40
60
80
100
Upper speed limit (mph)
before period
after period


Twelfth ATR(March, April, May, June, Sept., and December)
50
40
30
20
10
0
Axis Title
40
60
80
100
Axis Title
before period
after period


Thirteenth ATR (September and December)
50
40
30
20
10
0
-10
% of vehicles in group
40
60
80
100
Upper speed limit (mph)
before period
after period

Appendix C: Light Condition, Type of Vehicles Involved in Crashes

Table C.1: Daytime Crashes versus Nighttime Crashes for Treated Sites in the Before Time

ID	Daytime crashes					Nighttime crashes					% of nighttime crashes
	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	
1	88	79	52	219	4.75	63	86	73	222	4.63	50.34
2	68	62	53	183	3.97	76	57	48	181	3.77	49.73
3	65	70	72	207	4.49	98	86	97	281	5.86	57.58
4	43	59	37	139	3.02	34	38	34	106	2.21	43.27
5	47	54	55	156	3.39	40	56	66	162	3.38	50.94
6	16	15	19	50	1.09	27	18	31	76	1.58	60.32
7	20	11	9	40	0.87	16	15	12	43	0.90	51.81
8	54	52	78	184	3.99	74	39	81	194	4.04	51.32
9	10	4	7	21	0.46	12	4	6	22	0.46	51.16
10	21	33	16	70	1.52	25	28	15	68	1.42	49.28
11	38	22	16	76	1.65	37	33	32	102	2.13	57.30
12	1	0	1	2	0.04	1	0	1	2	0.04	50.00
13	25	33	23	81	1.76	20	35	47	102	2.13	55.74
14	22	17	15	54	1.17	23	28	29	80	1.67	59.70
15	44	33	21	98	2.13	69	43	75	187	3.90	65.61
16	21	14	30	65	1.41	30	51	43	124	2.58	65.61
17	13	17	34	64	1.39	28	37	27	92	1.92	58.97
18	6	11	3	20	0.43	2	7	12	21	0.44	51.22
19	32	46	39	117	2.54	50	55	43	148	3.08	55.85
20	28	20	35	83	1.80	45	56	39	140	2.92	62.78
21	74	43	48	165	3.58	71	50	56	177	3.69	51.75
22	10	8	11	29	0.63	9	18	7	34	0.71	53.97
23	59	42	33	134	2.91	49	61	68	178	3.71	57.05
24	49	57	71	177	3.84	42	60	60	162	3.38	47.79
25	140	110	145	395	8.58	92	85	106	283	5.90	41.74
26	91	92	118	301	6.53	81	72	70	223	4.65	42.56
27	217	189	280	686	14.89	144	98	108	350	7.29	33.78
28	39	28	30	97	2.11	40	42	38	120	2.50	55.30
29	63	41	33	137	2.97	44	46	48	138	2.88	50.18
30	38	29	31	98	2.13	36	50	49	135	2.81	57.94
31	36	39	27	102	2.21	46	29	36	111	2.31	52.11
32	34	27	29	90	1.95	56	50	54	160	3.33	64.00
33	0	0	0	0	0.00	2	2	0	4	0.08	100.00
34	22	18	12	52	1.13	18	11	21	50	1.04	49.02
35	12	29	32	73	1.58	18	39	37	94	1.96	56.29
36	18	19	22	59	1.28	18	28	30	76	1.58	56.30
37	20	11	10	41	0.89	15	16	25	56	1.17	57.73
38	2	3	4	9	0.20	6	7	6	19	0.40	67.86
39	15	10	7	32	0.69	25	29	22	76	1.58	70.37
Total				**4,606**	**100**				**4,799**	**100**	**51.03**

Table C.2: Daytime Crashes versus Nighttime Crashes for Treated Sites in the After Time

ID	Daytime crashes					Nighttime crashes					% of nighttime crashes
	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	
1	67	90	57	214	5.05	69	66	54	189	4.06	46.90
2	64	90	80	234	5.52	60	81	57	198	4.25	45.83
3	81	103	84	268	6.33	90	92	90	272	5.84	50.37
4	29	35	32	96	2.27	26	30	35	91	1.95	48.66
5	35	53	42	130	3.07	49	44	49	142	3.05	52.21
6	9	22	26	57	1.35	20	30	28	78	1.67	57.78
7	12	15	13	40	0.94	13	17	19	49	1.05	55.06
8	30	75	53	158	3.73	59	74	44	177	3.80	52.84
9	4	9	12	25	0.59	5	15	10	30	0.64	54.55
10	30	32	40	102	2.41	27	21	28	76	1.63	42.70
11	34	24	31	89	2.10	44	39	31	114	2.45	56.16
12	5	4	5	14	0.33	5	4	5	14	0.30	50.00
13	29	29	34	92	2.17	36	37	21	94	2.02	50.54
14	25	26	25	76	1.79	39	42	36	117	2.51	60.62
15	29	37	33	99	2.34	58	52	57	167	3.58	62.78
16	28	32	24	84	1.98	44	49	37	130	2.79	60.75
17	26	45	16	87	2.05	27	29	36	92	1.97	51.40
18	12	11	12	35	0.83	17	13	14	44	0.94	55.70
19	39	58	42	139	3.28	62	57	52	171	3.67	55.16
20	33	34	40	107	2.53	46	34	50	130	2.79	54.85
21	77	77	78	232	5.48	68	61	79	208	4.46	47.27
22	12	17	16	45	1.06	21	19	20	60	1.29	57.14
23	40	76	65	181	4.27	51	67	73	191	4.10	51.34
24	49	54	59	162	3.82	58	59	45	162	3.48	50.00
25	88	98	104	290	6.85	86	103	71	260	5.58	47.27
26	133	81	67	281	6.63	92	82	63	237	5.09	45.75
27	9	13	16	38	0.90	11	17	8	36	0.77	48.65
28	17	18	19	54	1.27	18	19	16	53	1.14	49.53
29	41	42	84	167	3.94	52	56	49	157	3.37	48.46
30	37	43	48	128	3.02	43	62	55	160	3.43	55.56
31	48	43	44	135	3.19	44	43	41	128	2.75	48.67
32	18	20	24	62	1.46	42	37	48	127	2.73	67.20
33	4	3	5	12	0.28	5	4	4	13	0.28	52.00
34	9	13	11	33	0.78	18	21	24	63	1.35	65.63
35	13	16	22	51	1.20	41	29	41	111	2.38	68.52
36	30	27	21	78	1.84	25	15	16	56	1.20	41.79
37	25	26	29	80	1.89	60	68	53	181	3.88	69.35
38	8	12	7	27	0.64	18	7	9	34	0.73	55.74
39	9	16	9	34	0.80	16	20	11	47	1.01	58.02
Total				**4,226**	**100**				**4,649**	**100**	**52.38**

Table C.3: Daytime Crashes versus Nighttime Crashes for Non-Treated Sites in the Before Time

ID	Daytime crashes					Nighttime crashes					% of nighttime crashes
	2008	**2009**	**2010**	**Total**	**% Total**	**2008**	**2009**	**2010**	**Total**	**% Total**	
1	53	57	56	166	5.34	34	53	64	151	5.91	47.63
2	52	61	76	189	6.08	39	56	54	149	5.83	44.08
3	228	201	291	720	23.15	133	84	97	314	12.28	30.37
4	41	30	32	103	3.31	38	40	36	114	4.46	52.53
5	82	91	109	282	9.07	51	43	53	147	5.75	34.27
6	102	67	87	256	8.23	59	41	69	169	6.61	39.76
7	18	23	27	68	2.19	16	25	18	59	2.31	46.46
8	129	83	125	337	10.84	68	75	86	229	8.96	40.46
9	16	13	10	39	1.25	26	10	17	53	2.07	57.61
10	42	40	42	124	3.99	40	31	54	125	4.89	50.20
11	0	0	0	0	0.00	1	0	0	1	0.04	100.00
12	8	4	4	16	0.51	4	9	6	19	0.74	54.29
13	17	12	22	51	1.64	13	10	24	47	1.84	47.96
14	22	25	36	83	2.67	20	35	35	90	3.52	52.02
15	3	4	5	12	0.39	4	6	2	12	0.47	50.00
16	10	5	1	16	0.51	5	10	8	23	0.90	58.97
17	8	8	3	19	0.61	19	21	22	62	2.42	76.54
18	23	13	25	61	1.96	23	27	27	77	3.01	55.80
19	48	18	15	81	2.60	40	31	31	102	3.99	55.74
20	10	20	9	39	1.25	10	11	18	39	1.53	50.00
21	35	46	42	123	3.95	42	55	42	139	5.44	53.05
22	23	34	23	80	2.57	25	33	39	97	3.79	54.80
23	17	11	14	42	1.35	11	22	15	48	1.88	53.33
24	16	16	7	39	1.25	24	23	22	69	2.70	63.89
25	17	15	15	47	1.51	23	19	25	67	2.62	58.77
26	7	13	7	27	0.87	21	24	3	48	1.88	64.00
27	37	29	24	90	2.89	45	26	36	107	4.18	54.31
Total				**3,117**	**100**				**2,564**	**100**	**45.12**

Table C.4: Daytime Crashes versus Nighttime Crashes for Non-Treated Sites in the After Time

ID	Daytime crashes					Nighttime crashes					% of nighttime crashes
	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	
1	29	36	34	99	3.67	33	26	29	88	4.17	47.06
2	25	30	34	89	3.30	24	24	25	73	3.46	45.06
3	232	185	174	591	21.93	98	103	144	345	16.35	36.86
4	20	29	33	82	3.04	18	24	16	58	2.75	41.43
5	97	72	97	266	9.87	49	40	37	126	5.97	32.14
6	77	80	83	240	8.91	60	42	53	155	7.35	39.24
7	21	16	25	62	2.30	18	18	13	49	2.32	44.14
8	116	126	155	397	14.73	78	65	62	205	9.72	34.05
9	16	12	23	51	1.89	20	8	13	41	1.94	44.57
10	34	36	45	115	4.27	30	42	42	114	5.40	49.78
11	1	0	0	1	0.04	0	1	0	1	0.05	50.00
12	3	2	2	7	0.26	5	4	5	14	0.66	66.67
13	14	12	13	39	1.45	15	16	16	47	2.23	54.65
14	17	24	21	62	2.30	25	29	27	81	3.84	56.64
15	3	4	6	13	0.48	2	1	2	5	0.24	27.78
16	8	12	9	29	1.08	6	5	12	23	1.09	44.23
17	10	8	15	33	1.22	22	13	26	61	2.89	64.89
18	15	25	15	55	2.04	12	18	16	46	2.18	45.54
19	16	31	31	78	2.89	18	22	22	62	2.94	44.29
20	12	16	4	32	1.19	14	9	9	32	1.52	50.00
21	31	29	50	110	4.08	33	47	36	116	5.50	51.33
22	12	19	21	52	1.93	20	23	29	72	3.41	58.06
23	13	17	23	53	1.97	19	22	28	69	3.27	56.56
24	5	17	9	31	1.15	17	17	19	53	2.51	63.10
25	10	14	8	32	1.19	24	15	20	59	2.80	64.84
26	2	5	7	14	0.52	10	6	9	25	1.18	64.10
27	21	24	17	62	2.30	29	33	28	90	4.27	59.21
Total				**2,692**	**100**				**2,107**	**100**	**43.91**

Table C.5: Number of Vehicles Involved in Crashes Before Speed Limit Change for Treated Sites

ID	Automobile (01)					Van (04)					Pickup Truck and SUV (5-6)					Large Truck(Trailer) (10-12)					Total veh.
	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	
1	75	93	74	242	4.34	8	8	1	17	2.06	66	74	53	193	4.78	30	19	22	71	5.15	523
2	74	62	61	197	3.53	12	9	6	27	3.27	64	47	48	159	3.94	15	16	10	41	2.98	424
3	77	85	87	249	4.46	12	10	13	35	4.24	63	57	74	194	4.80	25	23	33	81	5.88	559
4	38	45	46	129	2.31	3	5	2	10	1.21	33	49	23	105	2.60	11	7	7	25	1.81	269
5	45	64	64	173	3.10	12	11	10	33	4.00	40	47	51	138	3.42	15	16	21	52	3.77	396
6	17	18	22	57	1.02	7	0	4	11	1.33	18	13	23	54	1.34	9	6	5	20	1.45	142
7	10	12	18	40	0.72	2	2	2	6	0.73	17	10	7	34	0.84	12	5	8	25	1.81	105
8	59	41	109	209	3.75	12	13	15	40	4.85	54	52	62	168	4.16	22	9	36	67	4.86	484
9	6	4	10	20	0.36	0	0	0	0	0.00	16	5	5	26	0.64	2	0	1	3	0.22	49
10	15	20	12	47	0.84	4	5	2	11	1.33	22	23	12	57	1.41	13	18	6	37	2.69	152
11	25	25	18	68	1.22	7	4	2	13	1.58	23	28	22	73	1.81	30	13	11	54	3.92	208
12	1	0	1	2	0.04	0	0	0	0	0.00	1	0	1	2	0.05	0	0	1	1	0.07	5
13	20	33	19	72	1.29	5	10	4	19	2.30	20	22	27	69	1.71	7	15	28	50	3.63	210
14	14	20	20	54	0.97	7	3	2	12	1.45	13	17	13	43	1.06	19	11	12	42	3.05	151
15	70	36	53	159	2.85	10	6	7	23	2.79	36	35	39	110	2.72	18	13	12	43	3.12	335
16	18	29	37	84	1.51	8	2	5	15	1.82	15	26	23	64	1.58	16	13	14	43	3.12	206
17	16	14	23	53	0.95	5	10	10	25	3.03	17	23	23	63	1.56	11	12	14	37	2.69	178
18	2	10	4	16	0.29	1	0	1	2	0.24	1	4	8	13	0.32	4	6	4	14	1.02	45
19	30	48	41	119	2.13	5	5	6	16	1.94	40	36	34	110	2.72	21	26	11	58	4.21	303
20	39	38	44	121	2.17	6	3	7	16	1.94	27	28	26	81	2.01	10	15	6	31	2.25	249

Table C.5: Number of Vehicles Involved in Crashes Before Speed Limit Change for Treated Sites (Continued)

ID	Automobile (01)					Van (04)					Pickup Truck and SUV (5-6)					Large Truck(Trailer) (10-12)					Total veh.
	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	
21	75	44	73	192	3.44	12	4	6	22	2.67	77	52	44	173	4.28	16	10	10	36	2.61	423
22	7	18	8	33	0.59	1	3	1	5	0.61	12	9	11	32	0.79	1	1	3	5	0.36	75
23	64	58	55	177	3.17	10	4	14	28	3.39	51	46	40	137	3.39	13	10	11	34	2.47	376
24	53	68	82	203	3.64	3	7	9	19	2.30	48	53	71	172	4.26	6	12	15	33	2.39	427
25	151	140	174	465	8.34	22	9	17	48	5.82	98	72	90	260	6.44	31	15	47	93	6.75	866
26	125	118	148	391	7.01	17	8	12	37	4.48	63	64	77	204	5.05	24	19	27	70	5.08	702
27	319	218	359	896	16.07	37	41	57	135	16.36	150	144	225	519	12.85	26	36	46	108	7.84	1658
28	74	62	61	197	3.53	12	9	6	27	3.27	64	47	48	159	3.94	15	16	10	41	2.98	424
29	54	53	56	163	2.92	12	10	7	29	3.52	46	32	26	104	2.57	18	8	11	37	2.69	333
30	29	37	45	111	1.99	11	15	10	36	4.36	30	29	33	92	2.28	14	7	9	30	2.18	269
31	54	45	34	133	2.38	9	6	9	24	2.91	34	33	34	101	2.50	14	8	3	25	1.81	283
32	44	43	44	131	2.35	7	7	9	23	2.79	38	22	25	85	2.10	8	6	11	25	1.81	264
33	0	2	0	2	0.04	1	0	0	1	0.12	1	0	0	1	0.02	0	0	0	0	0.00	4
34	20	13	21	54	0.97	5	2	2	9	1.09	16	13	8	37	0.92	1	1	3	5	0.36	105
35	21	33	43	97	1.74	4	2	7	13	1.58	4	29	21	54	1.34	1	5	2	8	0.58	172
36	24	32	44	100	1.79	2	3	4	9	1.09	15	17	29	61	1.51	5	3	2	10	0.73	180
37	19	14	16	49	0.88	6	3	5	14	1.70	16	15	15	46	1.14	2	0	5	7	0.51	116
38	4	7	5	16	0.29	2	0	0	2	0.24	3	4	4	11	0.27	2	0	3	5	0.36	34
39	17	23	16	56	1.00	8	3	2	13	1.58	14	11	10	35	0.87	4	4	3	11	0.80	115
Total				**5,577**	**100**				**825**	**100**				**4,039**	**100**				**1,378**	**100**	**11,839**
% Total				**47.1%**					**6.9%**					**34.1%**					**11.6%**		**100**

Table C.6: Number of Vehicles Involved in Crashes After Speed Limit Change for Treated Sites

ID	Automobile (01)					Van (04)					Pickup Truck and SUV (5-6)					Large Truck(Trailer) (10-12)					Total veh.
	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	
1	75	79	68	222	4.64	7	15	2	24	4.23	44	58	39	141	4.77	24	35	28	87	6.59	474
2	72	103	76	251	5.24	7	8	4	19	3.35	47	70	60	177	5.99	17	18	25	60	4.54	507
3	90	107	101	298	6.23	13	19	12	44	7.76	61	69	57	187	6.33	25	27	17	69	5.22	598
4	24	29	36	89	1.86	5	5	2	12	2.12	17	17	21	55	1.86	8	10	9	27	2.04	183
5	39	56	44	139	2.90	5	5	5	15	2.65	19	20	30	69	2.33	17	18	17	52	3.94	275
6	8	24	22	54	1.13	4	2	4	10	1.76	6	15	17	38	1.29	4	6	9	19	1.44	121
7	8	10	16	34	0.71	2	5	0	7	1.23	3	8	7	18	0.61	6	4	2	12	0.91	71
8	42	69	48	159	3.32	13	8	9	30	5.29	26	59	39	124	4.19	16	27	20	63	4.77	376
9	2	14	6	22	0.46	0	1	1	2	0.35	0	9	8	17	0.58	0	2	1	3	0.23	44
10	10	21	24	55	1.15	7	1	4	12	2.12	21	19	21	61	2.06	17	15	21	53	4.01	181
11	28	31	30	89	1.86	7	2	1	10	1.76	26	18	20	64	2.17	22	10	10	42	3.18	205
12	1	0	1	2	0.04	0	0	0	0	0.00	1	0	1	2	0.07	0	0	1	1	0.08	5
13	20	21	16	57	1.19	4	3	4	11	1.94	23	29	21	73	2.47	16	15	13	44	3.33	185
14	21	27	26	74	1.55	12	4	2	18	3.17	19	17	20	56	1.89	12	19	9	40	3.03	188
15	39	31	52	122	2.55	8	7	4	19	3.35	31	35	30	96	3.25	12	18	13	43	3.26	280
16	36	31	28	95	1.98	6	6	2	14	2.47	17	23	18	58	1.96	7	21	14	42	3.18	209
17	18	32	28	78	1.63	4	3	4	11	1.94	18	27	12	57	1.93	9	24	7	40	3.03	186
18	12	7	9	28	0.58	0	1	1	2	0.35	6	4	2	12	0.41	5	9	4	18	1.36	60
19	54	57	48	159	3.32	8	6	11	25	4.41	36	45	30	111	3.76	15	22	16	53	4.01	348
20	45	38	49	132	2.76	4	4	4	12	2.12	22	18	31	71	2.40	5	9	14	28	2.12	243

Table C.6: Number of Vehicles Involved in Crashes After Speed Limit Change for Treated Sites (Continued)

ID	Automobile (01)					Van (04)					Pickup Truck and SUV (5-6)					Large Truck(Trailer) (10-12)					Total veh.
	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	
21	111	86	110	307	6.41	8	12	10	30	5.29	48	49	48	145	4.91	21	15	15	51	3.86	533
22	20	16	14	50	1.04	1	1	0	2	0.35	5	10	14	29	0.98	1	6	7	14	1.06	95
23	46	99	82	227	4.74	6	16	7	29	5.11	38	54	55	147	4.97	7	17	15	39	2.95	442
24	64	71	70	205	4.28	8	7	6	21	3.70	39	46	42	127	4.30	17	15	10	42	3.18	395
25	120	146	132	398	8.31	10	12	8	30	5.29	56	53	51	160	5.41	34	29	15	78	5.90	666
26	166	118	85	369	7.71	18	14	6	38	6.70	83	62	47	192	6.50	38	22	29	89	6.74	688
27	6	17	11	34	0.71	1	1	0	2	0.35	7	10	6	23	0.78	0	2	5	7	0.53	66
28	18	18	18	54	1.13	2	2	2	6	1.06	11	12	15	38	1.29	5	4	1	10	0.76	108
29	56	57	77	190	3.97	8	3	6	17	3.00	38	39	50	127	4.30	9	13	24	46	3.48	380
30	44	57	63	164	3.43	6	8	5	19	3.35	26	39	32	97	3.28	7	11	19	37	2.80	317
31	56	49	56	161	3.36	4	4	4	12	2.12	41	31	27	99	3.35	7	18	12	37	2.80	309
32	28	28	40	96	2.01	5	4	5	14	2.47	17	17	19	53	1.79	3	5	4	12	0.91	175
33	1	0	0	1	0.02	0	0	0	0	0.00	0	0	1	1	0.03	0	0	0	0	0.00	2
34	9	18	12	39	0.81	2	1	2	5	0.88	5	3	9	17	0.58	2	4	3	9	0.68	70
35	27	22	30	79	1.65	3	3	3	9	1.59	11	11	20	42	1.42	6	4	10	20	1.51	150
36	29	19	18	66	1.38	5	4	1	10	1.76	15	12	14	41	1.39	6	5	3	14	1.06	131
37	49	47	39	135	2.82	9	4	7	20	3.53	29	35	37	101	3.42	2	3	2	7	0.53	263
38	11	7	7	25	0.52	1	1	0	2	0.35	4	3	3	10	0.34	2	3	0	5	0.38	42
39	5	17	6	28	0.58	3	1	0	4	0.71	6	10	4	20	0.68	1	6	1	8	0.61	60
Total				**4,787**	**100**				**567**	**100**				**2,956**	**100**				**1,321**	**100**	**9,631**
% Total				**49.7%**					**5.8%**					**30.69%**					**13.7%**		**100**

Table C.7: Number of Vehicles Involved in Crashes Before Speed Limit Change for Non-Treated Sites

ID	Automobile (01)					Van(04)					Pickup Truck and SUV (5-6)					Large Truck(Trailer)(10-12)					Total veh.
	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	2008	2009	2010	Total	% Total	
1	45	64	64	173	4.22	12	11	10	33	6.25	40	47	51	138	5.01	15	16	21	52	10.51	396
2	53	68	82	203	4.95	3	7	9	19	3.60	48	53	71	172	6.25	6	12	15	33	6.67	427
3	319	218	359	896	21.83	37	41	57	135	25.57	150	144	225	519	18.86	26	36	46	108	21.82	1658
4	74	62	61	197	4.80	12	9	6	27	5.11	64	47	48	159	5.78	15	16	10	41	8.28	424
5	109	115	150	374	9.11	12	14	13	39	7.39	74	63	91	228	8.28	14	13	12	39	7.88	680
6	111	81	140	332	8.09	13	8	16	37	7.01	97	42	82	221	8.03	19	10	15	44	8.89	634
7	28	40	36	104	2.53	2	6	4	12	2.27	13	15	15	43	1.56	1	1	5	7	1.41	166
8	163	133	186	482	11.74	19	9	16	44	8.33	99	73	89	261	9.48	8	10	12	30	6.06	817
9	32	11	15	58	1.41	6	4	3	13	2.46	13	13	18	44	1.60	2	5	0	7	1.41	122
10	47	47	65	159	3.87	6	6	8	20	3.79	37	38	40	115	4.18	11	1	7	19	3.84	313
11	0	0	0	0	0.00	0	0	0	0	0.00	1	0	0	1	0.04	0	0	0	0	0.00	1
12	9	9	7	25	0.61	0	0	1	1	0.19	5	7	3	15	0.55	1	0	0	1	0.20	42
13	17	17	30	64	1.56	2	0	3	5	0.95	13	8	27	48	1.74	1	1	1	3	0.61	120
14	28	35	53	116	2.83	2	2	5	9	1.70	22	35	32	89	3.23	4	0	3	7	1.41	221
15	5	7	5	17	0.41	0	2	0	2	0.38	1	3	4	8	0.29	0	1	0	1	0.20	28
16	9	11	6	26	0.63	3	1	0	4	0.76	8	6	3	17	0.62	1	0	1	2	0.40	49
17	11	13	7	31	0.76	5	2	0	7	1.33	10	12	18	40	1.45	1	2	0	3	0.61	81
18	15	25	28	68	1.66	5	3	2	10	1.89	28	16	27	71	2.58	6	4	4	14	2.83	163
19	65	34	31	130	3.17	7	4	2	13	2.46	37	17	16	70	2.54	4	2	5	11	2.22	224
20	12	25	15	52	1.27	2	2	2	6	1.14	7	9	10	26	0.94	0	0	1	1	0.20	85
21	57	71	53	181	4.41	2	6	6	14	2.65	28	44	46	118	4.29	7	5	2	14	2.83	327
22	33	45	42	120	2.92	3	7	8	18	3.41	22	29	23	74	2.69	5	7	5	17	3.43	229
23	22	15	16	53	1.29	2	2	4	8	1.52	12	18	22	52	1.89	2	0	2	4	0.81	117
24	17	23	16	56	1.36	8	3	2	13	2.46	14	11	10	35	1.27	4	4	3	11	2.22	115
25	22	17	17	56	1.36	5	4	5	14	2.65	16	17	13	46	1.67	3	2	8	13	2.63	129
26	13	15	6	34	0.83	2	3	1	6	1.14	11	25	7	43	1.56	4	2	1	7	1.41	90
27	42	24	31	97	2.36	8	6	5	19	3.60	40	30	29	99	3.60	3	1	2	6	1.21	221
Total				**4,104**	**100**				**528**	**100**				**2,752**	**100**				**495**	**100**	**7,879**
% Total				**52.08%**					**6.70%**					**34.92%**					**6.28%**		**100**

Table C.8: Number of Vehicles Involved in Crashes After Speed Limit Change for Non-Treated Sites

ID	Automobile (01)					Van (04)					Pickup Truck and SUV (5-6)					Large Truck(Trailer)(10-12)					Total veh.
	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	2012	2013	2014	Total	% Total	
1	39	56	44	139	4.87	5	5	5	15	5.10	19	20	30	69	3.72	17	18	17	52	13.20	275
2	64	71	70	205	7.19	8	7	6	21	7.14	39	46	42	127	6.84	17	15	10	42	10.66	395
3	6	17	11	34	1.19	1	1	0	2	0.68	7	10	6	23	1.24	0	2	5	7	1.78	66
4	18	18	18	54	1.89	2	2	2	6	2.04	11	12	15	38	2.05	5	4	1	10	2.54	108
5	138	111	124	373	13.08	11	13	7	31	10.54	85	58	69	212	11.42	24	10	22	56	14.21	672
6	124	83	111	318	11.15	12	11	5	28	9.52	63	78	65	206	11.09	17	14	8	39	9.90	591
7	40	27	32	99	3.47	2	2	2	6	2.04	12	19	10	41	2.21	0	1	0	1	0.25	147
8	187	167	205	559	19.60	18	13	11	42	14.29	96	89	110	295	15.89	7	4	14	25	6.35	921
9	21	14	23	58	2.03	3	1	3	7	2.38	18	7	19	44	2.37	2	3	3	8	2.03	117
10	41	51	51	143	5.01	3	4	5	12	4.08	29	32	45	106	5.71	8	9	10	27	6.85	288
11	0	1	0	1	0.04	0	0	0	0	0.00	0	0	0	0	0.00	1	0	0	1	0.25	2
12	5	3	3	11	0.39	1	1	0	2	0.68	3	1	5	9	0.48	0	0	0	0	0.00	22
13	19	18	15	52	1.82	5	0	2	7	2.38	8	16	16	40	2.15	2	3	1	6	1.52	105
14	26	41	27	94	3.30	3	6	6	15	5.10	21	17	16	54	2.91	4	2	4	10	2.54	173
15	2	0	5	7	0.25	1	1	1	3	1.02	3	2	4	9	0.48	0	0	0	0	0.00	19
16	8	9	15	32	1.12	0	2	3	5	1.70	8	10	9	27	1.45	1	3	2	6	1.52	70
17	16	8	23	47	1.65	3	2	4	9	3.06	12	7	13	32	1.72	2	5	4	11	2.79	99
18	20	19	17	56	1.96	2	1	0	3	1.02	8	25	16	49	2.64	6	6	5	17	4.31	125
19	21	29	29	79	2.77	2	4	4	10	3.40	15	23	34	72	3.88	2	5	3	10	2.54	171
20	13	16	8	37	1.30	2	1	1	4	1.36	11	9	6	26	1.40	1	3	0	4	1.02	71
21	34	44	58	136	4.77	6	6	8	20	6.80	29	33	37	99	5.33	5	5	2	12	3.05	267
22	21	31	25	77	2.70	1	5	6	12	4.08	13	20	26	59	3.18	3	2	3	8	2.03	156
23	22	24	32	78	2.73	3	1	2	6	2.04	12	24	27	63	3.39	1	0	1	2	0.51	149
24	7	9	13	29	1.02	0	1	3	4	1.36	9	8	6	23	1.24	0	4	5	9	2.28	65
25	15	13	11	39	1.37	4	6	3	13	4.42	12	9	12	33	1.78	7	5	4	16	4.06	101
26	2	8	6	16	0.56	2	1	2	5	1.70	7	4	10	21	1.13	2	1	2	5	1.27	47
27	31	27	21	79	2.77	3	1	2	6	2.04	21	34	25	80	4.31	2	7	1	10	2.54	175
Total				**2,852**	**100**				**294**	**100**				**1,857**	**100**				**394**	**100**	**5,397**
% Total				**52.84%**					**5.44%**					**34.40%**					**7.30%**		**100**

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