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The 70-MPH speed limit: speed adaptation, spillover and surrogate measures of safety

Victor Kenneth Lund
Iowa State University

The 70-MPH speed limit: Speed adaptation, spillover and surrogate measures of safety

by

Victor Kenneth Lund

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Reginald Souleyrette, Major Professor
Thomas Maze
Thomas Stout
Alicia Carriquiry

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Disclaimer

This report was used in partial fulfillment of the requirements for the degree of Master of Science of the student researcher. The length of the after period used in this analysis is less than recommended by the 70-mph Steering committee. Additionally, at least 1,100 crashes were added to the Iowa Department of Transportation crash database after the download was completed for this research. As such, a thorough analysis could not be performed due to limited time constraints on behalf of the student. The data analysis included herein is not intended to be representative of an exhaustive before and after study of the safety effects due to the increase of the rural interstate speed limit from 65-mph to 70-mph in Iowa and should therefore be considered preliminary. Future analysis completed on data that become available later may alter the results as reported herein.

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Acknowledgments

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Abstract

On July 1, 2005, the speed limit on the rural interstates in Iowa was increased from 65-mph to 70-mph. This research first conducted a before and after study on the rural interstate and other facilities to study the effects on safety performance in Iowa due to this speed limit change. It explored the impact of the speed limit change on two effects known as the "speed adaptation" and "spillover effect." Research was also conducted on traffic citations issued on the rural interstate because citations may be a surrogate measure for highway safety. Finally, research was conducted on the recent increase in the retail price of gasoline and its effect on driver behavior. The rural interstates reported an increase in fatal crashes by 37.9 percent. No spillover effect in terms of crashes, speeds and volume were observed on other road types. Finally, no speed adaptation effect was observed in rural Iowa.

Key Words: speed limit, safety, spillover effect, speed adaptation, traffic citations

Chapter 1. General Introduction

1.0 Introduction

One of the essential components in providing safe roads is the speed limit. However, speed limit policy continues to be controversial. On July 1, 2005, the speed limit on the rural interstates in Iowa was increased from 65-mph to 70-mph. This change had been long considered by policy makers and the Iowa Department of Transportation (DOT) and was the subject of lively debate. Of concern was the impact the speed limit change on the rural interstate had on its safety performance and whether this change negatively affected other facilities (spillover) in terms of crashes and speeds. Additionally, the rural interstate speed limit introduced a 15-mph speed limit differential to rural primary highways that intersected and contained access with the rural interstate. This speed limit differential may have induced or augmented an effect known as the speed adaptation effect.

This research first examined crash performance on and off-system. It also explored the impact of the speed limit change on an effect known as the "spillover effect" to determine if increasing the speed limit on the rural interstates negatively affected other systems in terms of crashes or speeds. Because traffic citations reflect driver behavior, they may be a surrogate for highway safety. Research was then conducted on traffic citations issued before and after the speed limit change. If the recent increase in the retail price of gasoline did reduce the amount of travel, it may have partially masked any negative effects of the speed limit change. Research was conducted on the retail gasoline price and its corresponding effect on driver behavior in terms of the amount of travel. Finally, this research studied the speed adaptation effect in rural Iowa to determine if this effect exits and over what distance.

2.0 Thesis Organization

This thesis is divided into four chapters. This chapter provides a general introduction into the research topics. The second chapter reports on a before and after study of the safety effects of the rural interstate speed limit change. In addition to studying the rural interstates, other road types are also included in the analysis. These other road types include the urban interstates, rural expressways, rural other primary highways, and rural non-primary highways. Further study was conducted on rural interstate traffic citations and the effect of the retail gasoline price on driver behavior.

The third chapter reports on a study on the driver adaptation effect in rural Iowa. It examines whether the change in the rural interstate speed limit has produced an immediate effect in terms of higher speeds on rural county and state highways intersecting the rural interstates. This study attempts to determine if this effect exits in rural Iowa and if so, for what distance. And finally, the fourth chapter provides a general conclusion of the findings of this research. Additionally, recommendations for further research into this topic are also provided.

Chapter 2. Iowa's 70-mph Speed Limit: A Before and After Study

1.0 Introduction

One of the essential components of the highway system is the speed limit. Agent et al. (1998) states: "Appropriate speed limits are necessary to ensure a reasonable level of safe and efficient travel on highways and streets." However, speed limit policy continues to be controversial. The debate centers on finding a proper balance between safety and efficiency of the highway system.

The United States' economy is largely dependent on the transportation infrastructure and its ability to efficiently and reliably move people and goods. Efficiency of an uncongested transportation facility is primarily achieved by increasing the speed limit. This reduces travel time and reduces the time component of user costs. But this increase can adversely affect highway safety. Joksch (1993) suggests that as a highway's speed limit increases, so does the risk of a crash resulting in a fatality. Because of the seriousness of the risks, it is very important to closely monitor the after effects of policy decisions to increase speed limits in the context of highway safety.

The state of Iowa increased the speed limit on its rural interstates from 65-mph to 70-mph on July 1, 2005. This change in the rural interstate speed limit provides an opportunity to study the effects of the speed limit change on highway safety, and driver behavior. Because of the nature of the highway system, numerous factors are continuously interacting. One challenge in studying the safety effects due to speed limit changes is isolating these factors. Kockelman (2006) reported that these factors include demographic changes, changes in the level, pattern, distribution, scheduling and purpose of travel, infrastructure improvements, vehicle types and mix changes, seat belt, child restraint and young driver laws, alcohol laws, driver education and public safety campaigns, police enforcement, weather, and other secular trends. This report describes a preliminary before and after study on the safety effects of the rural interstate speed limit change.

2.0 Review of Literature

2.1 Determination of Speed Limits

When determining speed limit policy, decisions about posted speed limits should consider what most drivers would deem reasonable. Reasonable, as used in this context, refers to the speed at which drivers feel confident and safe in handling their vehicle. Najjar et al. (2000) states "Unrealistic posted speed limits generally reduce driver's compliance rate. In addition, the number of accidents, related injuries and fatality rates may increase in these situations." It would not be reasonable from a driver's perspective to post a 45-mph speed limit on an interstate because drivers know that traveling at higher speeds is reasonable due to previous experience and personal judgment. Thus, the imposition of an unreasonable speed limit may then produce a higher rate of non-compliance which may result in reducing the overall safety prompting there to be greater variation in speeds selected by drivers. In the past, speed limits have not necessarily reflected the design speeds of certain roadway functions, mainly interstates. This apparent disparity between safety and efficiency eventually led to the debate and relaxation of speed limit policy in the United States.

2.2 History of Speed Limits

2.2.1 National History

In the United States, speed limit laws date to 1901 and traditionally have been left to the state's authority to determine (Baum et al. 1989). The first federally regulated speed limit was enacted during World War II to conserve fuel and rubber for the war effort. It was at this time that a national speed limit was set at 35-mph. After the war ended, this national speed limit was repealed. Most states then established posted speed limits of 65 and 70-mph on the United States highways (Garber and Graham, 1990). Then, in response to the 1973 Arab oil embargo, Congress enacted the National Maximum Speed Limit (NMSL) of 55-mph. In addition to saving fuel, a reduction in the number of highway fatalities was observed after the NMSL was enacted. Nationwide, 54,052 fatalities in 1973 were followed by 45,196 fatalities in 1974. Soon after, Congress made the NMSL permanent. This law also required that states certify that they were enforcing the NMSL (National Highway Traffic Safety Administration, 1998). To enforce the NMSL, the United States Department of Transportation (DOT) would withhold federal highway funds from states not meeting the new speed limit requirements (Garber and Graham, 1990). Following in 1978, the Surface Transportation Assistance Act required that states report the percentage of drivers exceeding the NMSL (National Highway Traffic Safety Administration, 1998).

The Surface Transportation and Uniform Relocation Assistance Act (STURA Act) was passed by Congress in 1987. This act relaxed the 55-mph speed limit on the nation’s interstates and allowed the states to raise the speed limit to 65-mph on rural interstates. In 1987, thirty-eight states increased their rural interstate speed limit followed by two additional states in 1988 resulting in about 90 percent of the nation’s interstate highways posting a speed limit of 65-mph. Most recently, the National Highway System Designation Act (NHS Act) of 1995 repealed the NMSL, returning complete authority of establishing speed limits to the states. By the end of 1996, thirty-two states had again raised their speed limits on various roadways (National Highway Traffic Safety Administration, 1998).

2.2.2 Iowa History

The earliest recorded law relating to the speed limit in Iowa dates to 1929 in which a statewide speed limit of reasonable and proper was established. The war effort of World War II created the need to set the maximum speed limit at a 35-mph which helped to conserve rubber and gasoline. At the end of the war, the speed limit was returned to the previous law of reasonable and proper in 1945. In 1957, a nighttime speed limit of 60-mph was established. Soon after in 1959, the reasonable and proper speed limit was abolished. As a replacement of the reasonable and proper limit, each highway system was assigned a speed limit. Specifically, the interstate highways were assigned a 75-mph daytime and 65-mph nighttime speed limit, and primary highways were assigned a 70-mph daytime and 60-mph nighttime speed limit. No information was available on secondary roads (Crouch, 2006).

Because of the oil-embargo, the statewide speed limit was temporarily lowered to 55-mph in 1974 which was made permanent soon after in 1975. Following the passage of the STURA Act, Iowa increased its rural interstate speed limit to 65-mph in 1987, but retained the 55-mph speed limit for two-lane primary roads. Soon after the repeal of the NMSL in 1995, the speed limit of four lane divided highways were increased to 65-mph. Most recently, Iowa increased the speed limit on the rural interstate to 70-mph on July 1, 2005 (Crouch, 2006).

2.3 National Statistics Overview

Each year, approximately 40,000 to 45,000 highway fatalities occur in the United States. In 2005, the national fatality rate was reported as 1.45 fatalities per 100 million vehicle miles traveled (National Highway Traffic Safety Administration, 2005). By functional class, interstates experience the lowest number of fatal crashes among any roadway functional class as shown in Figure 1. However, crashes on the interstate have the potential to be more severe because of the high speeds (Joksch, 1993). Arterials exhibit the largest number of fatal crashes.

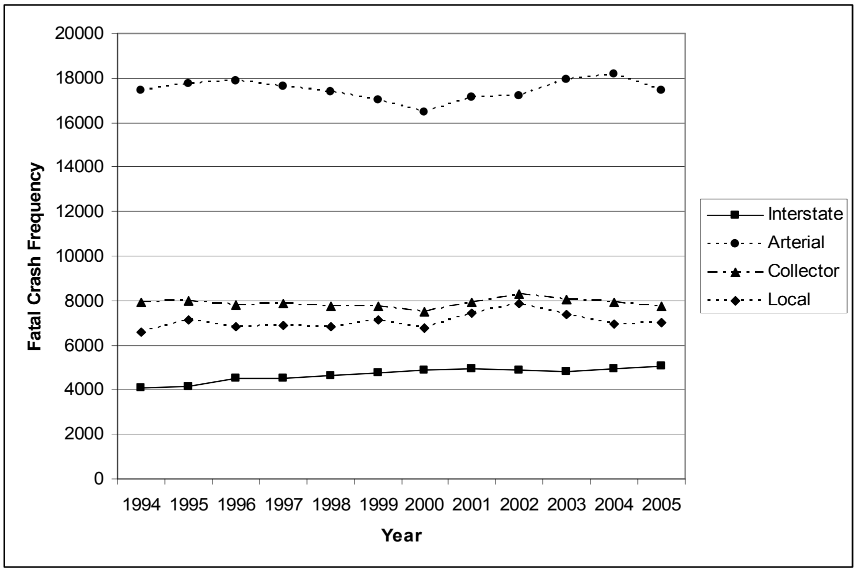

Figure 1. Nationwide Fatal Crash Frequency by Roadway Function Class
Source: FARS (Accessed 9/19/06)

The National Highway Traffic Safety Administration (2004, 2005) Annual Report on Traffic Safety Facts provides data on the nationwide fatality rate beginning in 1966 as shown in Figure 2. The three major congressional acts related to speed limit policy are placed on Figure 2 to illustrate their position in time relative to the national fatality rate. The referenced reports did not include the fatality rate from 1967 to 1969, therefore no numbers are reported in Figure 2 for these years.

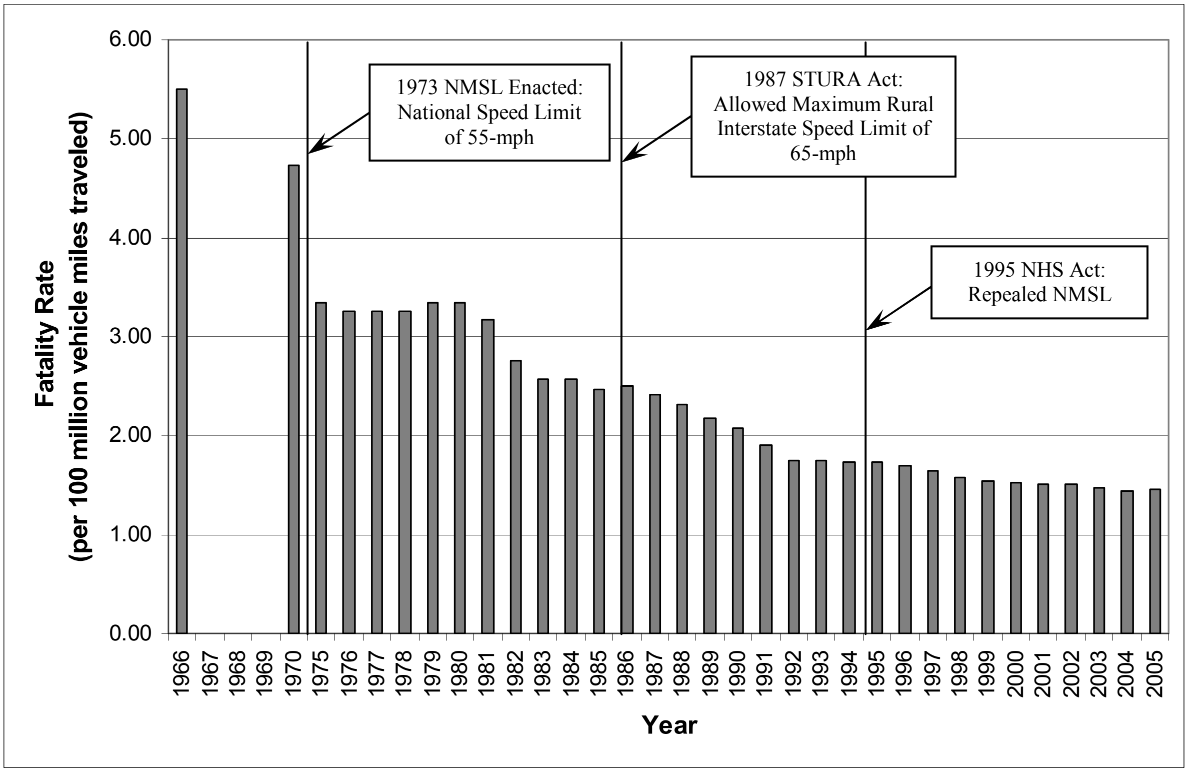

Figure 2. Nationwide Fatality Rate
Source: NHTSA 2004 and 2005 Annual Report

The fatality rate decreased dramatically from 1970 to 1975. Then the fatality rate increased slightly until 1979 after which the rate gradually decreased until 2004. In 2005, the fatality rate increased. A dramatic decrease in the fatality rate did occur after the NMSL was set at 55-mph. Following the 1987 STURA Act and 1995 NHS Act, the fatality rate continued to decrease. There was concern that fatalities would increase after the relaxation of the speed limit in 1987 and the complete repeal of the NMSL in 1995; but, this has not been observed. However, one may counterfactually hypothesize that the nationwide fatality rate would have been lower had the NMSL not been abolished. Although the acts of 1987 and 1995 coincide with continued decreases in the fatality rates, there are many other factors that contributed to improving highway safety, such as more stringent seat-belt laws, safety improvements in vehicles, public education programs, and better emergency response.

2.4 Research Methodology Controversy

Speed limit policy is a very controversial topic. Part of this controversy centers on the research methodology of speed limit safety studies. In an article supporting a possible safety benefit of the rural interstate 65-mph speed limit of the late 1980s, Lave and Elias (1994) hypothesized that the NMSL of 55-mph resulted in a misallocation of police resources. When the NMSL was made permanent in 1974, states were financially pressured to place their speed limits at 55-mph and to report the proportion of drivers exceeding the speed limit. This required additional enforcement by police departments thus reducing the amount of time spent patrolling other facilities such as the more dangerous county and state highways. Because of a resulting higher concentration of police patrols on the interstate, it was argued that this enforcement would also lower the interstate crash rate producing a rate much lower than it would have been if the enforcement had remained the same. Lave (1995), quotes a member of the International Association of Chiefs of Police as stating "[Federal financial sanctions] force the over-concentration of limited resources for the express purpose of attaining compliance rather than application of resources in a manner most effectively enhancing total highway safety…" Thus, Lave and Elias suggested that after the relaxation of the rural interstate speed limit allowing a 65-mph speed limit and the requirement to patrol the rural interstates, police departments could shift their resources to patrolling other facilities thereby enhancing highway safety.

Lave and Elias (1994) also hypothesized an overall safety benefit of the 65-mph rural interstate speed limit. The hypothesis stated that because rural interstates, state highways, and county roads were all posted at a 55-mph speed limit before the enactment of the STURA Act of 1987 allowing the speed limit to be increased to 65-mph on the rural interstates, drivers that chose to speed would chose to not drive on the interstate but instead drive on county and state highways which would lower their chance of being caught speeding due to the increased enforcement on the rural interstates. Additionally, drivers may have chose to drive on the county and state highways since they could provide a possible benefit of shortened travel times between destinations due to a more direct route to their destinations. When the rural intestate 65-mph speed limit was reinstated, the change could have produced a shift in traffic volumes from two-lane county and state highways to safer rural interstate facilities because drivers may have determined it would shorten travel time. In support of their hypothesis, Lave and Elias (1994) reported that states which raised their speed limits to 65-mph on rural interstates in 1987 had an overall drop in the statewide fatality rate of 6.15 percent for the years of 1987 and 1988. For states which did not raise their speed limit, they were reported to have an overall drop in the statewide fatality rate of only 2.62 percent for the same years.

Articles opposing the hypothesis' purported by Lave and Elias were written following the increase in speed limit during 1987 and 1995. Baum et al. (1989) and Baum et al. (1991) reported that states which increased their speed limit to 65-mph on rural interstates found there was an increase in fatalities on the rural interstates while there was no similar trend for states that did not raise speed limits on their rural interstates. In a comparison of the crash history for states which raised their rural interstate speed limit to at least 70-mph in 1995/1996 to those that did not, Farmer et al. (1997) reported that those states which raised the speed limit experienced a 16 percent increase in the number of fatalities on their interstate system following the change versus a 4 percent increase for those states that did not increase their interstate speed limits. In a later article, Farmer et al. (1999) quoted the Insurance

Institute for Highway Safety president as stating “It’s clear from this study that the current round of speed limit increases, like increases on rural interstates in the 1980s, is costing hundreds of lives per year”

As a rebuttal to the studies reporting that an increase in the speed limit increases the number of fatalities, it was argued by Lave and Elias (1994) that those studies only looked at the *number* of fatalities on those highways which were affected by the change. It was suggested that to study the safety effects of a speed limit change, it is necessary to assess the impact on the entire or statewide system by using fatality rates.

2.5 Summary of Speed Limit Safety Studies

An extensive review was conducted on several statewide studies that analyzed the safety effects of increasing interstate speed limits. These studies included analysis periods which covered the speed limit changes of the 1987 STURA Act and repeal of the NMSL in 1995. Table 1 summarizes some of the findings that were reported.

Most of the studies did report an increase in various crash severities after an increase in the speed limit on their respective interstate facilities. However, it was reported in Kansas, Oklahoma, and Utah that there was no adverse effects on safety due to the increase in the speed limit on their interstates. Each of these states increased their rural interstate speed limits to 70 or 75-mph.

Table 1. Summary of State Interstate Speed Limit Studies

State	Author(s)	Rural Interstate Speed Limit		Results
		Before	After	
Illinois	Sidhu, 1990	55	65	Fatal, injury and property damage crashes all experienced an increase in the after period for rural interstates. Only property damage crashes were found to have a statistically significant increase using a Chi-Squared test.
Illinois	Rock, 1995	55	65	A statistically significant increase in all crashes, fatalities, and injuries was found on interstates posted at 65mph for the after period by using a t-test. An ARIMA model calculated an additional 345 crashes, 15 fatalities, and 150 injuries resulted on rural highways due to the 65mph speed limit
Iowa	Ledolter and Chan, 1996	55	65	Found an 82% increase in fatal crashes on the rural interstates with a before period of 1983-1986 (56 fatal crashes) and an after period of 1988-1991 (102 fatal crashes). Increase was found to be statistically significant under a Poisson assumption.
Iowa	Raju et al., 1998	55	65	Using a Bayesian approach, an additional four fatal crashes occurred per quarter on the rural interstate due to the speed limit change.
Kansas	Najjar et al., 2000	65	70	There was no significant increase in the after period for all crash, fatal crash, and fatality rates.
Kentucky	Agent et al., 1998	Various	Various	55mph interstate segments had a fatal and injury crash rate of 0.39 crashes/161MVKM and 30 crashes/161MVKM, respectively. 65-mph interstate segments had a fatal and injury crash rate of 0.44 crashes/161MVKM and 23 crashes/161MVKM, respectively.
Michigan[1]	Binkowski et al., 1998	65	70	No spillover effect, in terms of vehicle speeds, was found on facilities located near interstates in which there was an increase in the speed limit. Crash data was not analyzed.
Minnesota	Minnesota DOT, 2007	65	70	A 70% increase (32% increase adjusted by vmt) in fatal crashes was observed on the rural interstates after the speed limit was increased. The study used a 5 year before and 5 year after period.
New Mexico	Gallaher et al., 1989	55	65	A statistically significant increase was found in fatal crashes, fatalities, and fatal single-vehicle crashes under the assumption of a Poisson distribution. No change was found for multi-vehicle fatal crashes.
North Carolina	Renski et al., 1998	65	70	Interstate facilities that had an increase in the speed limit of 10mph were found to have more risk of increase crash severity than those that only had an increase in the speed limit of 5mph.
Oklahoma[2]	Oklahoma DOT, 1998	65	75	No statistically significant increase in overall crash frequencies or crash rates were observed on the rural interstates. Additionally, no statistically significant change occurred in crash severity.
Texas	Brackett and Ball, 1990	55	65	A statistically significant increase was found in injury, property damage, total and serious crashes.
Utah[3]	Vernon et al., 2004	65	75	No increase in the total, fatal, injury crash rates were observed on rural interstates in the after period.
Washington State	Ossiander and Cummings, 2002	55	65	Found the fatal crash rate on rural interstates was 110% higher than it would have been had the speed limit change not been changed. The overall crash rate on all interstates showed little change.

1. Trucks remained at 55-mph
2. Non-turnpike rural interstates were posted at 70-mph
3. Small proportion of interstates increased to 70-mph

Kockelman (2006) suggested that in cases of an increase in a speed limit from a lower range (55-mph to 65-mph), there may be a greater change in the number of crashes in the after period versus a speed limit change from a higher range (65-mph to 75-mph). It was suggested that for speed limit changes encompassing higher ranges, drivers may already be cautious due to the already existing high speed environment. Figure 3 illustrates this hypothesized relationship between the differences of the range of the speed limit change to the probability of a fatality.

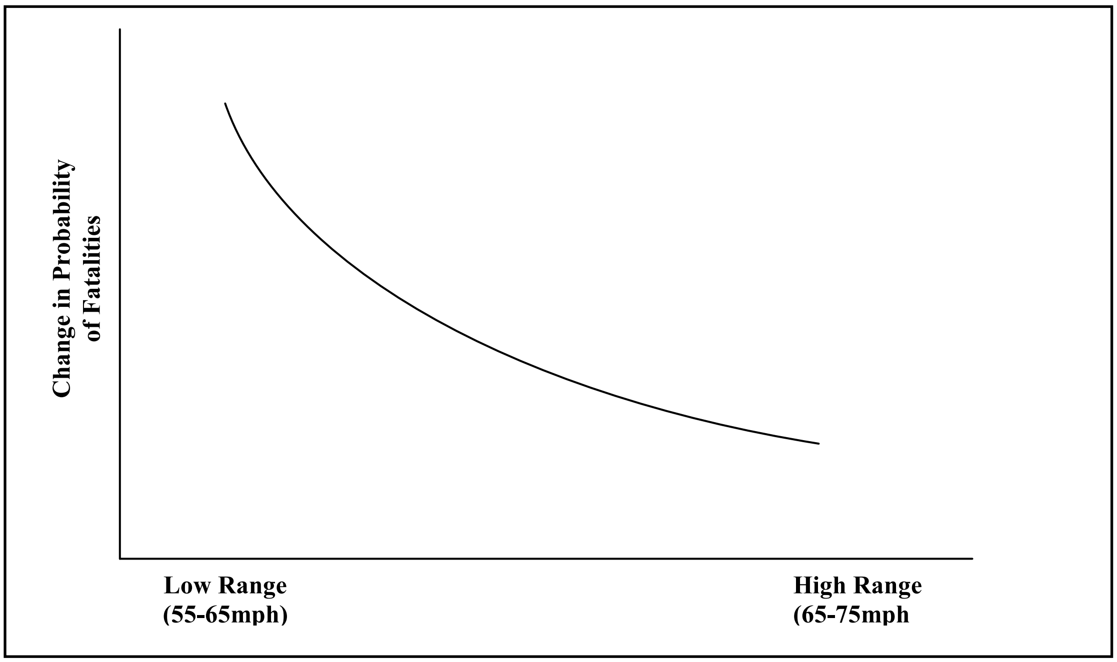

Figure 3. Hypothesized Relationship between the Relative Change in Speed Limit Ranges and Safety
Source: Kockelman, 2006

2.6 Spillover Effect

The transportation system can be considered an open system. A change in the operating conditions at one location of the transportation system may have an effect on other portions of the system as well. Changing a parameter at one location in the transportation system and the effect it has on other portions of that system has been named the "spillover effect" (Binkowski et al., 1998; Kockelman, 2006; Ledolter and Chan, 1996; Pant et al., 1992; Rock, 1995; Srinivasan, 2002). Kockelman (2006) provides a definition of the spillover effect with respect to vehicle speeds as "…the impact that a speed limit change on one road may have on parallel facilities." It was suggested that urban areas may also be more susceptible to spillover effects than rural areas because of networks that are much denser. Three areas in which the spillover effect may be active are vehicle speeds, traffic volumes and crashes.

Garber and Graham (1990), in a state-by-state study of the effects of the 65-mph speed limit on interstate highways, summarized two opposing hypotheses known as "traffic diversion" and "speed spillover". In the context of increasing the speed limit on rural interstates, traffic diversion hypothesizes that traffic would shift to the rural interstates thereby decreasing the fatalities on rural non-interstate highways. In the same context, speed spillover hypothesizes that fatalities would increase on rural non-interstate highways because of an increase in the speed limit on the rural interstates. Srinivasan (2002) summarized the speed spillover effect in such a way that if it were to exist "…it can lead to increase in average speeds on roads where the speed limit was not raised and are not designed to handle high-speed traffic." This effect is characterized by drivers that "…get in the habit of driving faster and do so even on roads that have not had their speed limits raised" and those who might "…fail to slow down upon exiting a rural interstate and continuing their journey on roads with lower speed limits" (Garber and Graham, 1990).

2.6.1 Speed Spillover Effect

A study conducted by Ledolter and Chan (1996) evaluated the impact of increasing the speed limit on rural interstates in Iowa from 55-mph to 65-mph. Rural interstates, urban interstates, rural primary, and rural secondary roads were examined in the study with only the rural interstates experiencing a change in the speed limit. The rural interstates recorded an increase in vehicle speeds from 59-mph in the before period to 66-mph in the after period. For the other road classes that did not have a change in the speed limit, the average vehicle speeds increased by 1-mph. The speed spillover effect in this case was concluded to be "small."

Binkowski et al. (1998) studied the effect on speeds and traffic volume due to the increase in the speed limit from 65-mph to 70-mph on rural freeways in Michigan. Part of the study tested for the presence of a speed spillover effect from road segments with an increased speed limit to those sections in which the speed limit remained the same. Roadway segments used as a control group included intercity, urban and recreational freeway, and rural two-lane highways. The posted speed limits for the control segments were 55 and 65-mph. Experimental segments included intercity and recreational routes. The posted speed limit for all experimental segments was 65-mph during the before period and 70-mph for the after period. The 50th and 85th percentile speeds were measured on the control and experimental segments during the before and after periods. The control segments experienced an increase in the 50th and 85th percentile speeds in the after period of 0.1 to 0.8-mph, while the largest decrease observed was 0.3-mph. It was concluded that the control segments experienced no speed spillover effect.

Brown et al. (1990) conducted a case study of Alabama's 65-mph rural interstate speed limit. A portion of the study tested if there was a spillover effect from roads that were posted at 65-mph to those posted at 55-mph. The first test studied segments of the interstate that retained the 55-mph speed limit. Sites were selected so that speed adaptation would not be a confounding factor. The second test studied segments of non-interstate roads with a speed limit of 55-mph that were proximal to interstates with a 65-mph speed limit and that had access to the 65-mph interstate. The study found that the speed spillover effect onto 55-mph interstate and 55-mph non-interstate roads from 65-mph rural interstates was about the same with an increase of about 1-mph.

Godwin (1992) studied the effect of the 65-mph speed limit on safety for the entire United States. He found evidence that there was a speed spillover effect from 65-mph interstates to 55-mph rural interstates, but stated "The effect of speed spill-over to non-Interstate roads in both 55-mph and 65-mph states is uncertain." McKnight and Klein (1990) compared states which increased the speed limit on their rural interstates to 65-mph to those states which retained the 55-mph speed limit. They determined that in states which increased the speed limit on rural interstates to 65-mph, the percentage of vehicles exceeding the speed limit on 65-mph and 55-mph roads were both found to be significant. Garber and Graham (1990) reviewed data from states which increased the speed limit on rural interstate highways to 65-mph. Preliminary results suggested that the 65-mph speed limit did have an effect on rural non-interstates in terms of traffic diversion and speed spillover, but speed spillover was determined to have a larger effect than traffic diversion.

In a continuation of their 1985 study of speed adaptation, Casey and Lund (1992) suggested that by increasing the speed limit on some roads, it affected vehicle speeds on other roads up to two hours of driving time away. This may indicate that a change in the speed limit at one location in the transportation network can have far reaching effects throughout the network.

2.6.2 Traffic Diversion Effect

Rock (1995) studied the impact of increasing the speed limit on rural interstate and limited access-highways from 55-mph to 65-mph in Illinois. Vehicle miles traveled (VMT) for rural interstates increased significantly above the trend of the four years prior to the speed limit change. For non-interstate rural highways, VMT decreased relative to both the trend of the previous four years prior the speed limit change and in absolute terms. It was concluded that "…some traffic was diverted from highways with a 55-mph speed limit to 65-mph highways.", and the 65-mph highways may have actually "generated new traffic." It was also suggested that a consequence of this traffic diversion was that it produced a speed spillover onto 55-mph highways.

In Alabama, Brown et al. (1990) calculated a ratio of the average daily traffic (ADT) observed on rural interstates to non-interstate principal arterials. Before the speed limit change, the ratios ranged from 1.03 to 1.26. Following the speed limit change, the ratio was calculated as 1.49. It was concluded that "…shifts to the interstates are occurring from the non-interstate categories…" And in a study of the highway safety effects due to the 65-mph speed limit in Indiana, McCarthy (1991) also suggested that there was a shift in traffic from "lower-speed roads" to the interstates.

2.6.3 Crash Spillover Effect

In Iowa, Ledolter and Chan (1996) found that rural interstates experienced an increase in the number of fatal crashes by 82.1 percent in the after period. Roads that did not have a change in the speed limit, urban interstates, rural primary and rural secondary roads, experienced a change in the number of fatal crashes by -18.2, 8.1 and 1.5 percent, respectively. A comparison between rural and urban interstates found that the increase in the speed limit had a large effect on rural interstates, but the effect on urban interstates was found to be "essentially zero." Major injury crashes on rural interstates increased while they decreased on urban interstates, rural primary and rural secondary roads. Further analysis estimated that the increase in the speed limit produced an additional two fatal crashes on rural interstates, six fatal crashes on rural primary roads and four fatal crashes on rural secondary roads per quarter. A more conservative estimate calculated additional fatal crashes occurred on rural interstates, primary and secondary roads per quarter year.

A crash model developed by Rock (1995) suggested that on rural highways in Illinois, an additional 345 crashes, 15 fatalities, and 150 injuries occurred because of the speed limit change. The study cited higher speeds, increase in speed variance, traffic diversion, traffic generation and speed spillover as possible factors in producing additional crashes and injuries.

In Alabama, Brown et al. (1990) found that interstates with a 55-mph speed limit, property damage only crashes (PDO) increased significantly in the after period, but there were no significant increase in fatal and injury crashes. Non-interstate roads with a speed limit of 55-mph and proximal to the 65-mph interstates did not experience any significant increase for any of the different crash severities.

Pant et al. (1992) studied the effects of increasing the rural interstate speed limit in Ohio from 55-mph to 65-mph. Three types of roads were studied. They were rural interstates posted at 65-mph, rural interstates posted at 55-mph, and rural non-interstates posted at 55-mph. For rural interstates with a 55-mph speed limit, mean fatality rates increased significantly in the after period. However, when adjusted for "normal" and "adverse" weather conditions, no significant difference was found. Injury and PDO crashes decreased in the after period. For non-interstate highways with a 55-mph speed limit, there was no significant difference in the mean fatal crash rates. Similar to the rural interstate segments posted at 55-mph, injury and PDO crashes decreased in the after period. It was concluded that there were no negative consequences from the spillover effect.

In a state by state comparison, McKnight and Klein (1990) reported that roads posted at 55-mph and 65-mph had a significant increase in fatal crashes from the before to after period. Garber and Graham (1990) provided preliminary results that indicated that the 65-mph speed limit was affecting the number of fatalities on rural non-interstates in addition to the rural interstates.

3.0 Methodology

This report analyzed the effects of the *rural interstate* speed limit change through a before and after study. Crash data were obtained for the period January 1, 2003 to December 31, 2006. This provided up to 30 months for the before period and up to 18 months for the after period, for crashes, vehicle speeds and traffic volume. The analysis period for crashes and traffic volume were the same, but was different for speeds.

Because the increase in the speed limit occurred only on the rural interstates, other road types were analyzed to test for any type of spillover effect. Six road types were analyzed. These included:

- *Rural Interstates*
- *Urban Interstates*
- *Rural Expressways*
- *Rural Other Primary Highways*
- *Rural Non-Primary Roads*
- *Primary Parallel Routes*

3.1 Rural and Urban Interstates

The primary objective of this research was to study the safety effects of increasing the speed limit on the *rural interstates* in Iowa. Figure 4 displays *rural* and *urban interstates* in Iowa. The *rural interstates* consist of 622 miles of roadway while *urban interstates* consist of 143 miles. *Urban interstate* segments were defined as any segment located within one of Iowa's metropolitan planning organizations (MPO) planning areas. Any segment located outside of an MPO planning area was deemed rural. The *urban interstate* segments were located within the urban areas of Sioux City, Council Bluffs, Des Moines, Waterloo, Cedar Rapids, Iowa City and Davenport.

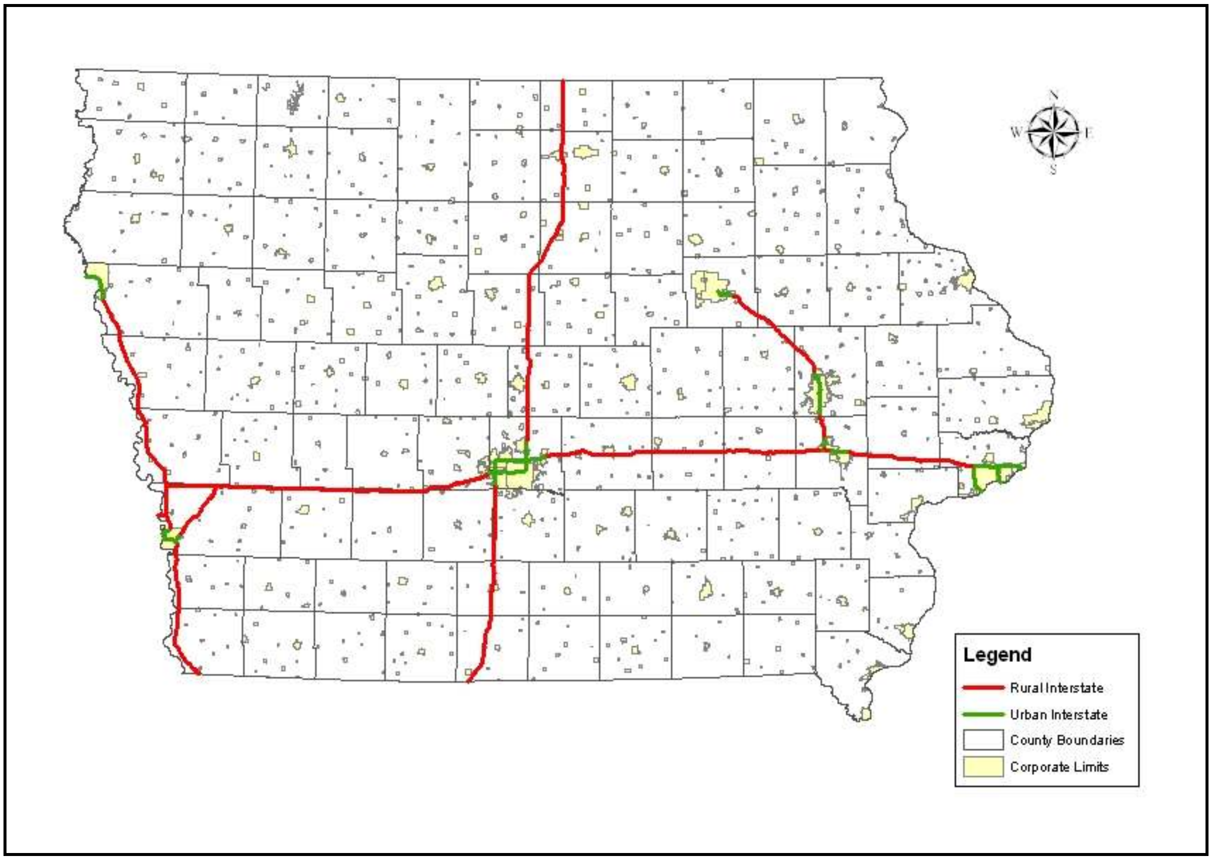

Figure 4. Iowa Rural and Urban Interstate

There are other ways *urban interstate* segments could be defined. For example, *urban interstates* could be defined as any segment in which the posted speed limit is less than that posted on the *rural interstate*. *Urban interstates* could also be defined as any segment that is located within the corporate limits of a city with a specified population. The issue with such definitions in Iowa is that portions of the interstate segments posted with a lower speed limit or located within corporate limits sometimes resemble *rural interstate* segments in terms of the number of access points and urban development. As demonstrated by these examples, any definition of *urban interstate* segments will ultimately consist of some subjective elements.

3.2 Rural Expressways

For this research, *rural expressways* consisted of four lanes, any type of median (hard surface without barrier, grass surface without barrier, hard surface with barrier, grass surface with barrier), under the jurisdiction of the Iowa DOT, and with at-grade intersections. Because of their similarity in design standards to the interstate system, any spillover effect to non-interstate facilities may first be expected thereon. Crash, volume and speed data were collected and analyzed for all Iowa expressways.

In Iowa, two-lane primary highways may become four-lane expressways for a short distance, thereafter reverting to a two-lane primary highway. For this study, any road segment which matched the definition of a *rural expressway* was defined as a *rural expressway*. This definition included many short and long segments. The *rural expressways* consist of 1,155 miles of roadway. Figure 5 displays the *rural expressway* road network as used for this study.

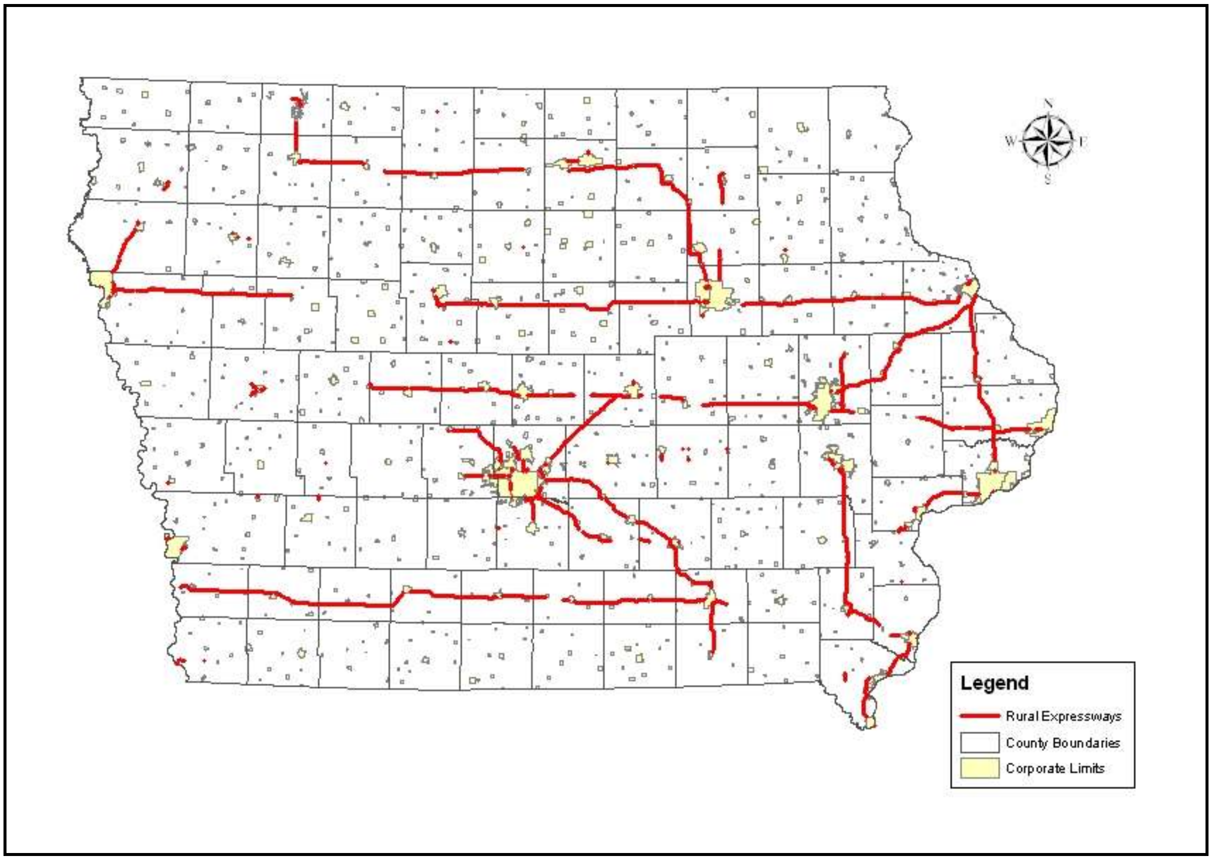

Figure 5. Iowa Rural Expressways

3.3 Rural Other Primary Highways

As with *rural expressways*, a spillover effect may also be observed on *rural other primary* highways. *Rural other primary* highways were defined as any road segment that is identified as part of the national or state highway system within Iowa, but is not considered an interstate or expressway highway. The *rural other primary* highways consist of 5,885 miles of roadway. Figure 6 displays the road network for the *rural other primary* highway system used for this study.

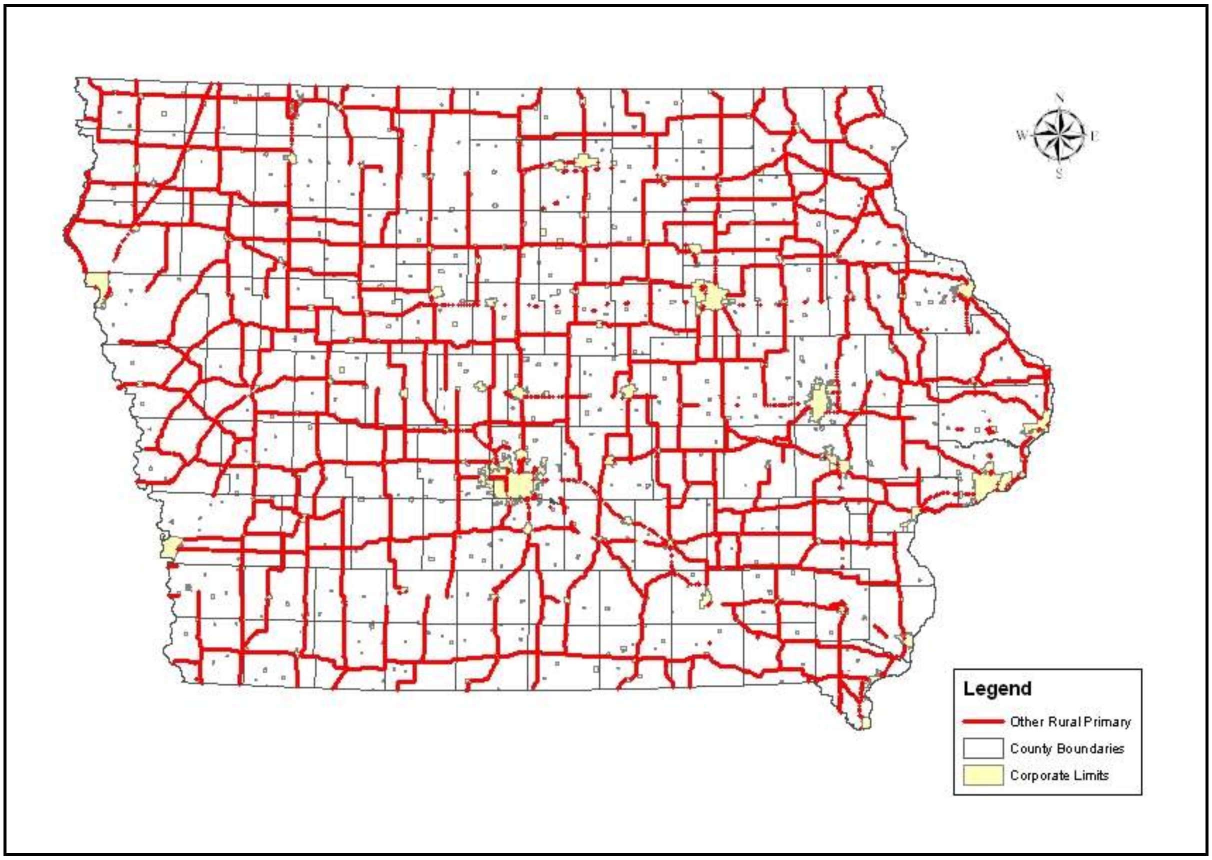

Figure 6. Iowa Rural Other Primary Highways

3.4 Rural Non-Primary Roads

The road classification within Iowa that consists of the largest amount of roadway miles is *rural non-primary* roads. *Rural non-primary* roads included all rural roads not defined as national or state highways, *rural expressways* or *rural interstates*. These roads are maintained by the various county agencies. The majority of these roads are aggregate surfaced (gravel) roads. *Rural non-primary* roads consist of 90,040 miles of roadway.

3.5 Primary Parallel Routes

This research also investigated the spillover effect on *primary parallel* routes to the interstate. *Primary parallel* routes consisted of any route that is part of the national or state highway system, considered to be within close proximity to the *rural interstates*, and offer a competing route to a *rural interstate*. The two *primary parallel* routes chosen for this study are US-65, and IA-92. Figure 7 displays the *primary parallel* routes used for this study.

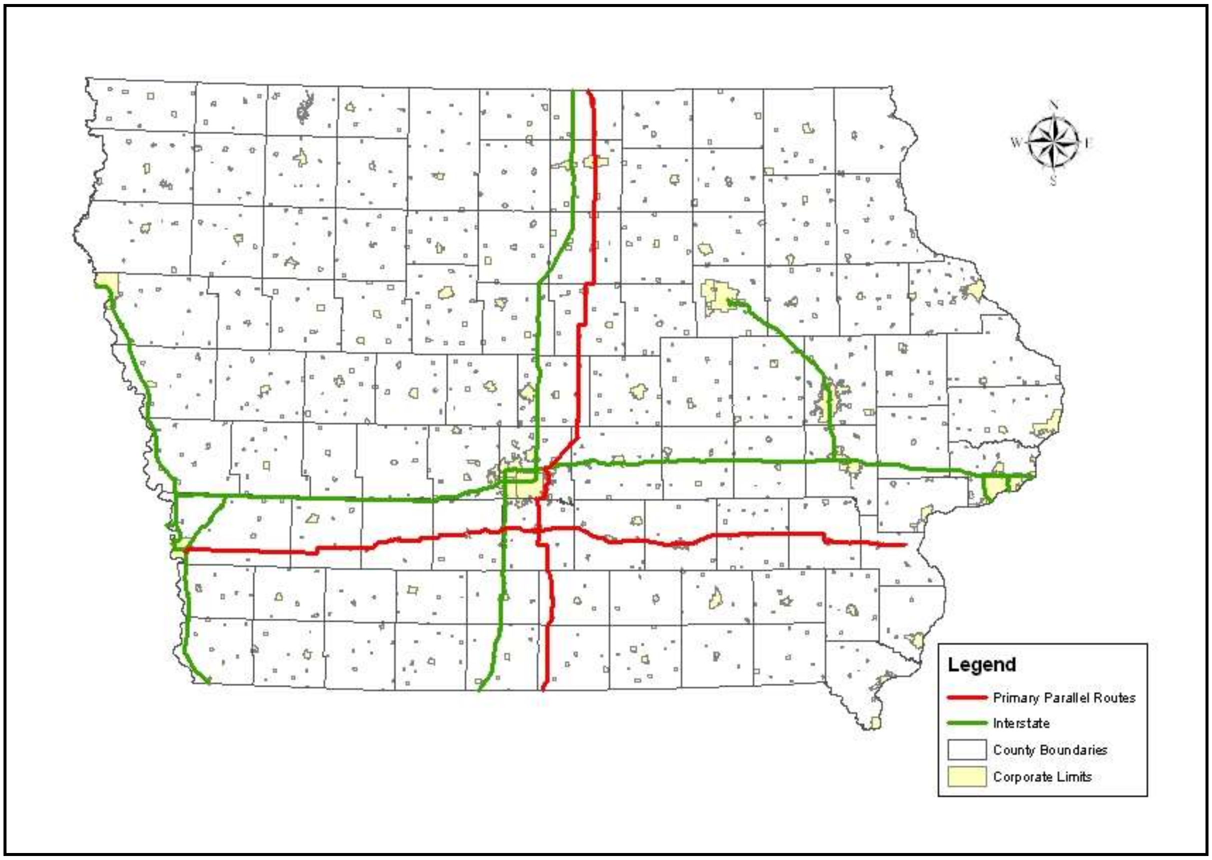

Figure 7. Parallel Routes

3.6 Rural Interstate Traffic Citations

With the passage of the 70-mph speed limit in Iowa, additional Iowa State Patrol enforcement was promised by the governor and legislature (Iowa Department of Public Safety, 2006). A change in the number of speeding citations could be considered as a surrogate for a change in the number of speed related crashes. Because the speed limit changed on the rural interstate, traffic citation data were only collected and studied for the rural interstate.

3.7 Effect of Retail Gasoline Price

The recent increase in the retail price of gasoline may have affected the travel behaviors of drivers in Iowa. Because of the higher prices, drivers may tend to drive less and attempt to conserve fuel by driving at lower speeds than they otherwise would have. Therefore, it is possible that the higher cost of gasoline may have indirectly “canceled” out some effects of the increase of the *rural interstate* speed limit. To determine if the cost of gasoline did have an effect on driver behavior and therefore offset some of the possible negative impacts of the speed limit change, the price of gasoline for the recent history in Iowa was collected. It was presumed that if drivers altered their behavior due to the higher cost of gasoline, this behavior would be most pronounced on a facility that consists of longer trips, namely *rural interstates*.

4.0 Data Analysis

4.1 Crash Data

The Iowa DOT maintains an extensive crash database. Crash data are submitted to the Iowa DOT from various police agencies such as the Iowa State Patrol, county sheriff offices, and city police departments and are usually submitted by these various police agencies at different times. For example, some police agencies may provide crash data on a weekly basis while others may only provide data once a month. When the crash data are submitted to the Iowa DOT, the data undergoes an editing process. The crash data used for this study were downloaded from the Iowa DOT database on April 2, 2007.

The crash severities for Iowa crash data are aggregated by fatal, major injury, minor injury, possible/unknown, and PDO. The severity of a crash is defined by the worst injury of the crash. The injury severities of those involved in a crash are estimated by an officer on the scene. In the officer's reporting guide, definitions are provided to aid the officer in identifying the severity of those involved in a crash. A crash is defined as fatal if any person involved in a crash died as a result of their injuries sustained from that crash within 30 days. A crash is defined as a major injury crash if any person's injuries sustained from that crash prevents that person from walking, driving or continuing with normal activities that they were capable of before the crash. Other indications of a major injury included severe lacerations, broken or distorted limbs, skull, chest, or abdominal injuries, unconsciousness, and unable to leave the crash scene without assistance. A crash is defined as a minor injury crash if any person's injuries are evident to those at the crash, but are not included in the definition of a fatal or major injury. Indications of a minor injury are lumps on a head, bruises, abrasions, and minor lacerations. A crash is defined as possible/unknown if a person involved in a crash reports or claims a personal injury sustained during that crash that is not included in the definition of fatal, major, and minor injuries. Indications of a possible/unknown crash are momentary unconsciousness, claim of injuries that are not evident, limping, complaint of any pain, nausea, and hysteria. A crash is also defined as a possible/unknown crash if a reporting officer does not know if any injuries were sustained from the crash. The final crash severity classification is property damage only (PDO). Crashes are defined as PDO crashes if the crash only resulted in the damage to the vehicle(s) involved in that crash. The reporting threshold of PDO crashes is $1,000 (Iowa Department of Transportation, 2001).

The crash data used for this study include a variety of information about each crash. Each crash is assigned a geographical coordinate which can be mapped using a geographical information system (GIS). Crashes determined to be within a specified distance of any facility of interest were assigned to that road type within ArcView GIS 3.3. The 2004 statewide road network most accurately reflects the geographical location of crashes that occurred during the analysis period of this research. A total of 3,261 out of 232,061 crashes (for the years of 2003 to 2006), or 1.4 percent, were not assigned a coordinate, thus they could not be located on a map and could not be used. Once the crash data were assigned to the appropriate road types, they were summarized by the number of crashes within the various severity levels on a monthly basis. The severity levels included in this analysis were fatal, fatal and major injury, and all crashes.

4.2 Speed and Volume Data

In conjunction with the crash data, speed and volume data were collected for each facility type from the Iowa DOT. The Iowa DOT maintains many permanent automatic traffic recorders (ATRs) throughout the state. Because of the existing structure of the ATR databases, it was necessary to create a computer program to extract the speed data. During discussions with the Iowa DOT, it was noted that the ATR database was changed during the summer of 2004. Because of this change, the analysis period for the speed data included August, 2004 to December, 2006. The speed data were summarized by the average, 85th percentile speeds, and the percent exceeding a given speed value threshold. Volume data were obtained from the monthly automatic traffic recorder reports provided on the Iowa DOT's website and included the same analysis period as crash data.

4.3 Rural and Urban Interstate Crashes

Only crashes located on the interstate mainline would be considered for the analysis. Crashes located on the interstate ramps were assumed to be unrelated to any effect of the speed limit change. Once the crashes were spatially assigned to the interstate, they were then aggregated by whether they occurred on a *rural* or *urban interstate* segment. *Rural interstate* crashes were additionally designated as daytime or nighttime.

The first step in spatially assigning crashes to the interstate was to select all interstate road segments from the 2004 statewide road network database. These selected road segments were placed into a mainline interstate road network. All other road segments not considered to be mainline interstate were selected and placed into a non-interstate mainline road network. The two road networks were then joined to the master crash database and a distance attribute was calculated for each road type.

Two additional fields were added to the master crash database: absolute difference in distance and LOC (level of confidence). Absolute difference between the two distance fields was created for interstate and non-interstate road segments. The LOC field was used to identify the confidence in which a facility was assigned to a crash. A value of 1 stated that a crash was assigned to the facility of interest (in this case the interstate) with a high degree of confidence. A value of 5 stated that a crash was assigned to another facility (in this case all non-interstate mainline roads) with a high degree of confidence. A crash with a LOC value of 3 was assigned to the facility of interest, but with a lower confidence than a value of 1. Some crashes are clearly located on a facility of interest. Other crashes are clearly located on other facilities. However, some crashes are “in-between” the two types of facilities. This iterative process was therefore implemented to provide a systematic approach to assigning these remaining “in-between” crashes to their respective facility type. A summary of the LOC values is found in Table 2.

Table 2. Road Segment Assignment Scheme

LOC	Assigned Facility
1	Facility of Interest
2	Facility of Interest
3	Facility of Interest
4	Other Facility
5	Other Facility

The crash assignment process consisted of a series of queries with various conditions. The distance values were reported in meters. The query conditions for assigning crashes to their respective road type and the order in which they were completed are:

First Query:

$D_{FI} \leq D_{OF}$ and $D_{FI} < 25$

LOC = 1

Second Query:

$D_{FI} > D_{OF}$ and $DiffDist > 50$

LOC = 5

Third Query:

$D_{FI} \leq D_{OF}$

LOC = 2

Fourth Query:

$D_{FI} > D_{OF}$ and $DiffDist > 5$

LOC = 4

Fifth Query:

All remaining crashes

LOC = 3

D_{FI} = Distance to facility of interest

D_{OF} = Distance to other facility

$DiffDist$ = Absolute difference between distance to facility of interest and other facility

The second step of the crash assignment process was to run a query that selected the crashes occurring on the facility of interest with the condition of LOC equals 1, 2 or 3. After the crash assignment process was completed, the crashes located on the interstate were defined as occurring either in a rural or urban area. An interstate crash located within 50 meters of any *rural interstate* segment as defined in section 3.1 was deemed rural. All other interstate crashes were deemed urban by default.

4.4 Other Road Types

All expressway road segments located outside of corporate limits were defined as "*rural expressways*." *Non-rural expressway* road segments were also selected using the 2004 statewide road network. Crashes were then assigned to their respective facility and analyzed by the same method as discussed in section 4.3.

All non-interstate, non-expressway primary road segments located outside corporate limits were selected and defined as "*rural other primary*" road segments, again using the 2004 statewide road network. Crashes not previously assigned to the *rural* or *urban interstates*, or *rural expressways* were then assigned to the closest *rural other primary* highway by the same method as discussed in section 4.3. All remaining crashes located outside of any corporate limit were defined as "*rural non-primary*" crashes. *Rural expressways*, *rural other primary*, and *rural non-primary* crashes were not analyzed for day/night safety performance.

Finally, to test if there was a shift in speeds or traffic volumes on *primary parallel* routes, ATRs from *primary parallel* routes and corresponding interstates were selected for a comparison analysis. For this purpose, IA-92 was paired with I-80 and US-65 was paired with I-35. Speed and traffic volume data were then compared. No crash data were analyzed in this step.

4.5 Daytime and Nighttime Rural Interstate Crashes

For this study, *rural interstate* crashes were defined as occurring during the day or night based upon official sunrise and sunset times obtained from the United States Naval Observatory. Rather than entering each segment location, approximations were developed for sunrise and sunset times. Since the sunrise and sunset times can only be obtained for one location, it was necessary to decide which location would be used for Iowa. Because of the longitudinal width of the state of Iowa, the sunrise and sunset times are different for the east and west ends of the state. The difference between the sunrise and sunset times were determined by selecting Davenport and Council Bluffs and obtaining their respective sunrise and sunset times for an arbitrary date of May 9, 2007. The sunrise and sunset times for Council Bluffs, Iowa were 6:12am and 8:29pm, respectively. The sunrise and sunset times for Davenport, Iowa were 5:50am and 8:08pm, respectively. The difference between the sunrise times is 22 minutes while the difference between sunset times is 21 minutes. Therefore, it was assumed that the sunrise and sunset times for a central location in Iowa would approximate the sunrise and sunset times for every location within the state. The central location selected was Ames, Iowa. The sunrise and sunset times were obtained for 2003 to 2006. To account for daylight savings time, the United States Naval Observatory noted that for days occurring during daylight savings time, one hour should be added to the times provided in the table.

Effective sunrise and sunset times defined for each day of the year were joined to the *rural interstate* crash database on the basis of the date. This join resulted in assigning the sunrise and sunset times for the day in which each crash occurred. To define crashes occurring during the daylight, a query was run with the conditions that the time of the crash must be less than the sunset time and greater than the sunrise time. All other crashes not selected were defined as occurring during the night by default.

4.6 Rural Interstate Traffic Citations

A manual defining the various types of traffic citations was provided by the Iowa State Patrol. A database consisting of all electronic traffic citations issued by the Iowa State Patrol was obtained through the Center for Transportation Research and Education (CTRE) at Iowa State University. The structure of the citation database allowed it to be queried and mapped in ArcView GIS 3.3. Citations were first assigned to the rural interstates with the method described in section 4.3. Speeding citations were then selected from the rural interstate traffic citation set.

Electronic traffic citations have only recently been put into use by the Iowa State Patrol. Over the last three years, the number of traffic citations has greatly increased as shown in Figure 8.

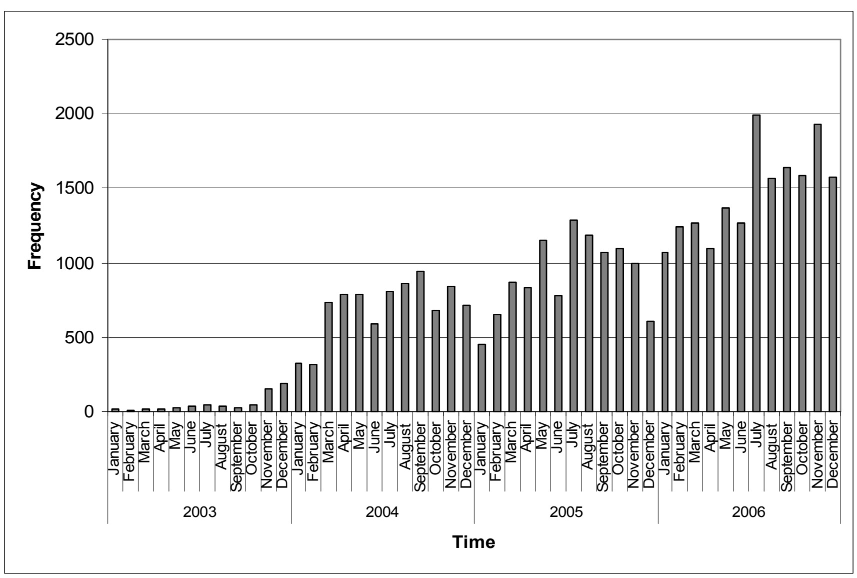

Figure 8. Market Penetration of Rural Interstate Electronic Speeding Citations

As shown in Figure 8, there were few citations in the database in 2003. Soon after in 2004, the number of electronic citations began to increase dramatically. According to the Iowa State Patrol, the current (July, 2007) utility of the electronic citation database is approximately 80 percent but should be at 100 percent by December, 2007. Because the number of paper traffic citations issued by the Iowa State Patrol was not known, the relative electronic share could not be determined. Therefore, the number of electronic speeding citations could not be compared before and after the change in the speed limit. However, the ratio between electronic speeding citations to the total number of electronic citations on the rural interstate was calculated and plotted for 2004 to 2006. An increase in the ratio of speeding citations to all other citations after the speed limit change could indicate an increase in the number of speeding related citations issued by the Iowa State Patrol.

4.7 Effect of the Retail Price of Gasoline

Data for the retail price of gasoline were obtained from United States Department of Energy (Energy Information Administration, 2007). The gasoline formulation selected for this analysis was regular grade gasoline, as sold through retail outlets. Prices were recorded on a monthly basis. Two charts were created that displayed the retail gasoline price plotted with the *rural interstate* ADT and average speed over time. The analysis period was selected as January, 2002 to December, 2006 coincident with the availability of ATR reports.

5.0 Results

For each of the road types that were analyzed, two crash charts are displayed for each crash severity. The first crash chart displays January, 2003 to December, 2006 crash data. The shaded boxes cover portions of the observed time period to allow similar months to be compared in the before and after time periods, as only 18 months of crash data are available after the speed limit change. For example, see Figure 9. A second chart displays only before and after periods over similar time periods to facilitate comparison. For example, see Figure 10.

5.1 Rural Interstates

Figures 9 through 14 display the *rural interstate* crash frequency before and after the speed limit change for fatal, fatal and major, and all crashes. Figure 9 displays the *rural interstate* fatal crash frequency. The two months with the largest fatal crash frequency are February, 2005 and November, 2005. The number of months not recording fatal crashes before the speed limit change was four while only one month did not record fatal crashes in the after period. Figure 10 displays the *rural interstate* fatal crash frequency for similar time periods before and after the speed limit change.

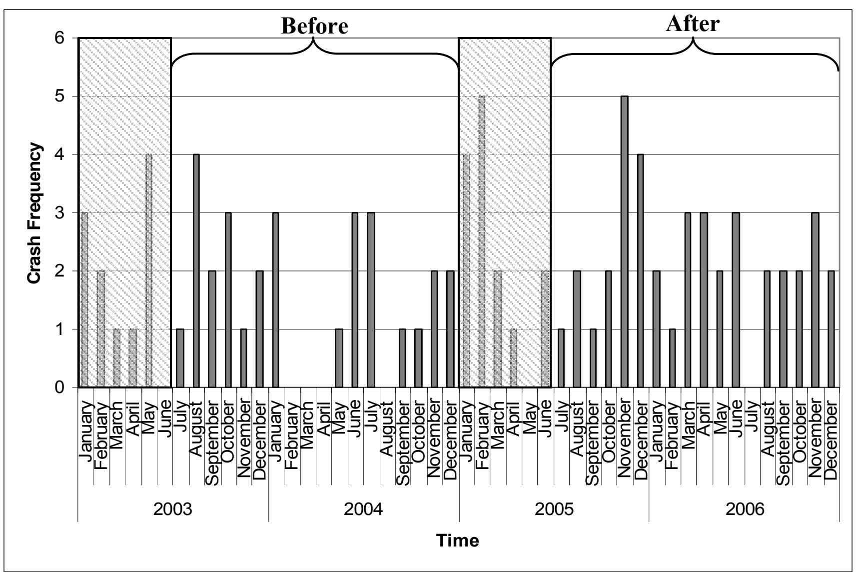

Figure 9. Rural Interstate Fatal Crash Frequency

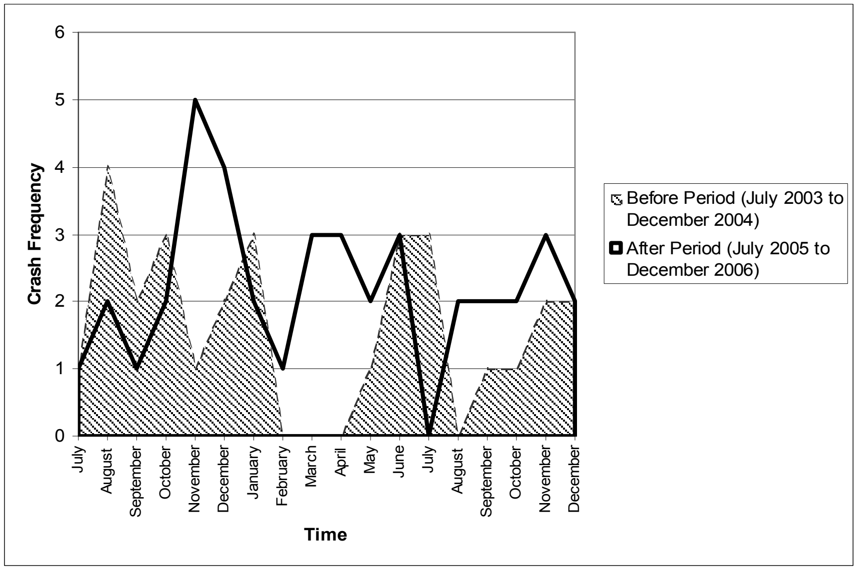

Figure 10. Rural Interstate Fatal Crash Frequency for Similar Periods

Figure 11 displays the *rural interstate* fatal and major injury crash frequency. During the before period, ten months recorded six or fewer fatal and major injury crashes. The after period recorded only six months of six or fewer fatal and major injury crashes. Figure 12 displays the *rural interstate* fatal and major injury crash frequency for similar periods before and after the *rural interstate* speed limit change.

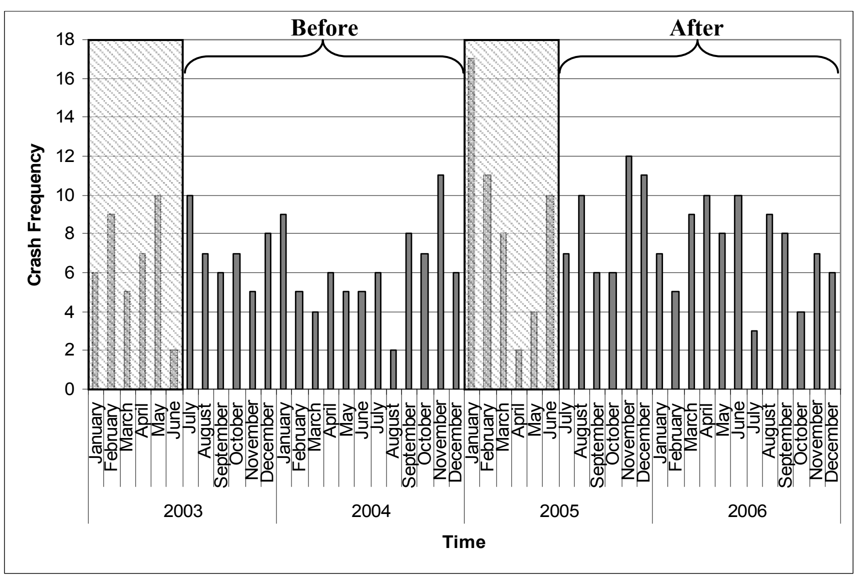

Figure 11. Rural Interstate Fatal and Major Injury Crash Frequency

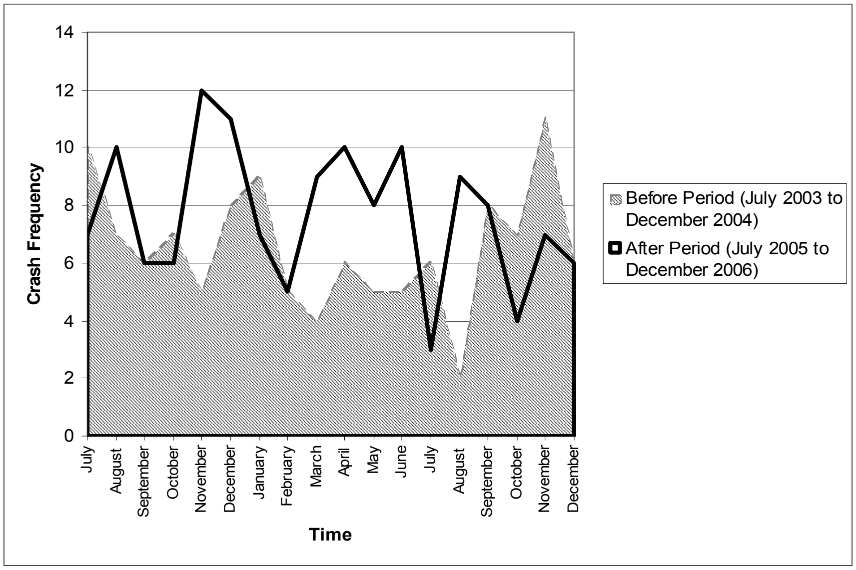

Figure 12. Rural Interstate Fatal and Major Injury Crash Frequency for Similar Periods

Figure 13 displays the crash frequency of all crashes recorded on the *rural interstates*. Figure 14 displays the crash frequency of all crashes on the *rural interstates* for similar before and after periods. With the exception of the first set of winter months, the crash frequency curves are observed to be very similar.

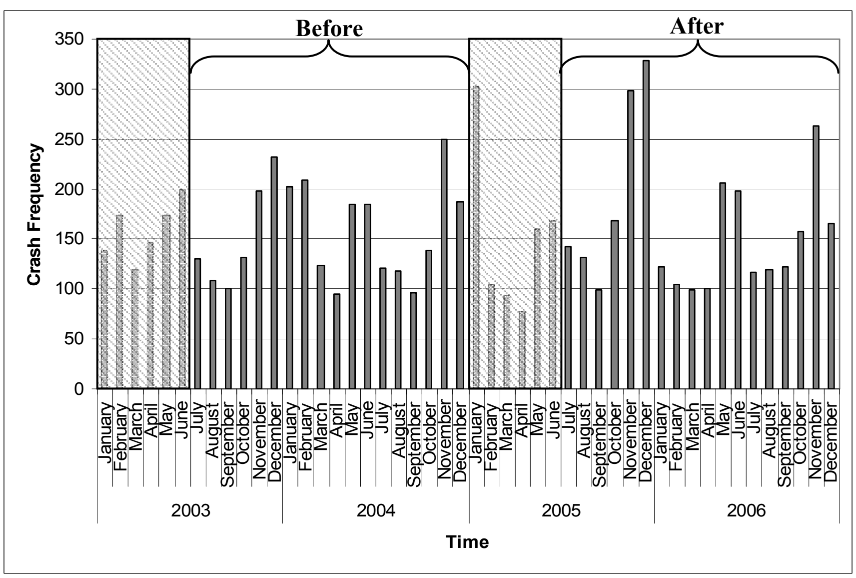

Figure 13. Rural Interstate All Crash Frequency

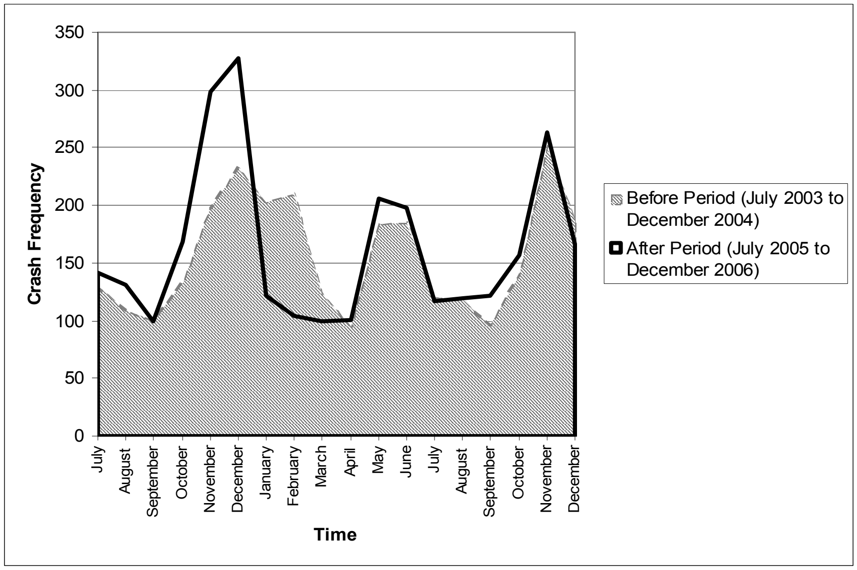

Figure 14. Rural Interstate All Crash Frequency for Similar Periods

Figure 15 displays the *rural interstate* average and 85th percentile speeds for the period of August, 2004 to December, 2006. The average and 85th percentile speeds are observed to be slowly increasing over time. Trend lines were placed through the after period data to provide a visual estimation of the trend change.

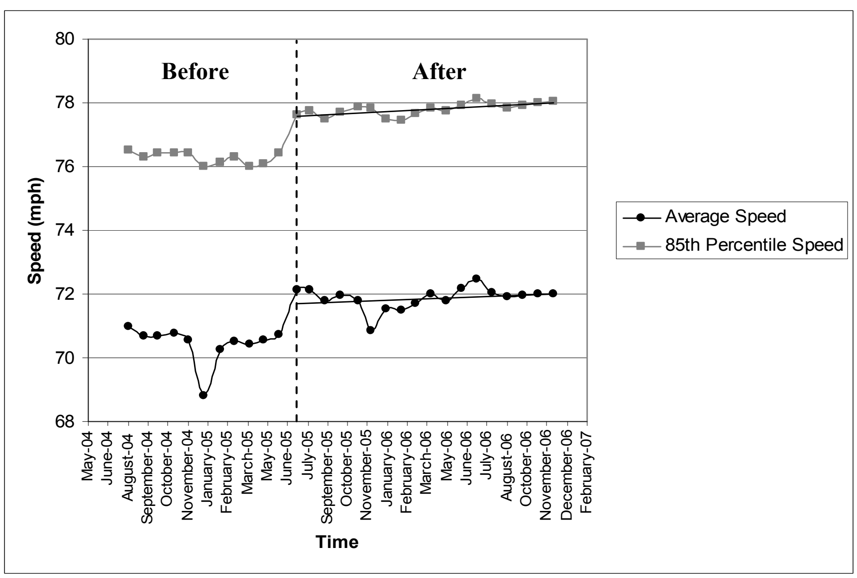

Figure 15. Rural Interstate Average and 85th Percentile Speeds

Figure 16 displays the percent of vehicles exceeding the speed limit by 10-mph on the *rural interstate* before and after the *rural interstate* speed limit change. After the speed limit change, the percent of those exceeding the speed limit by 10-mph is observed to be slowly increasing over time.

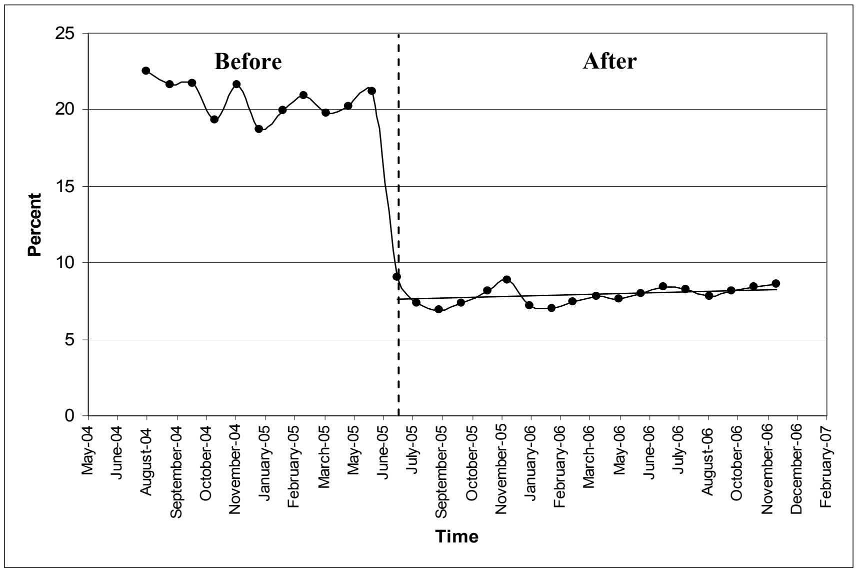

Figure 16. Percent of Vehicles Exceeding the Speed Limit by 10mph on the Rural Interstate

Figures 17 and 18 display the *rural interstate* average and 85th percentile speeds during the daytime and nighttime periods. Note the increasing trends in the after period.

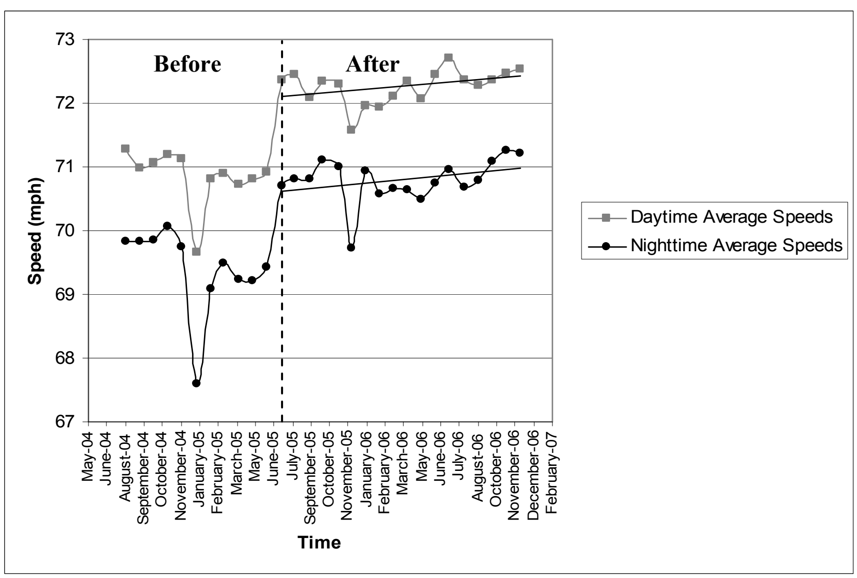

Figure 17. Rural Interstate Daytime and Nighttime Average Speeds

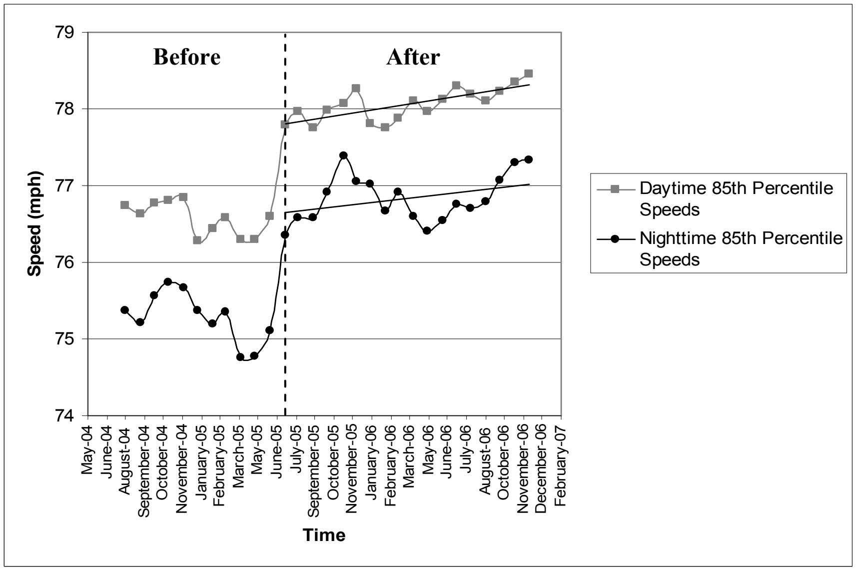

Figure 18. Rural Interstate Daytime and Nighttime 85th Percentile Speeds

Figure 19 displays the percent of vehicles exceeding the speed limit by 10-mph on the *rural interstate* during the daytime and nighttime periods. Percent exceeding is observed to be slowly increasing over time for both daytime and nighttime periods.

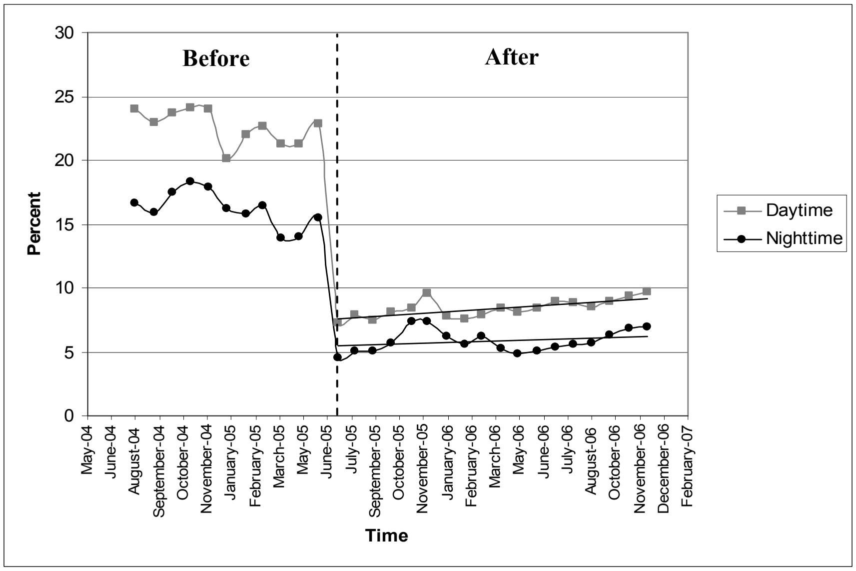

Figure 19. Percent of Daytime and Nighttime Vehicles Exceeding the Speed Limit by 10mph on the Rural Interstate

5.1.1 Rural Interstate Daytime Crashes

Figures 20 through 25 display the *rural interstate* daytime crash frequencies before and after the *rural interstate* speed limit change for fatal, fatal and major, and all crashes. Figure 20 displays the *rural interstate* daytime fatal crash frequency. There were seven months during the before period that did not report any fatal crashes. During the after period, there were six months that did not report any fatal crashes. Figure 21 displays the *rural interstate* daytime fatal crash frequency for similar before and after periods.

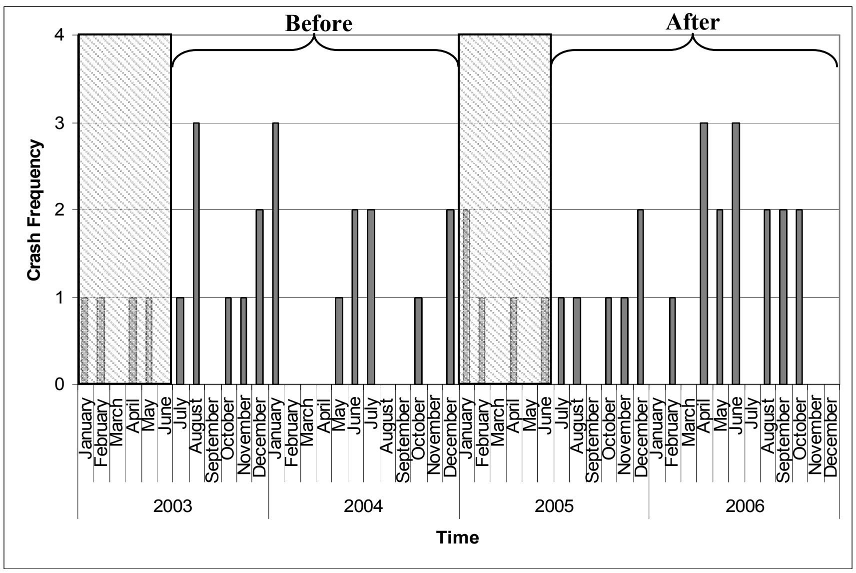

Figure 20. Rural Interstate Daytime Fatal Crash Frequency

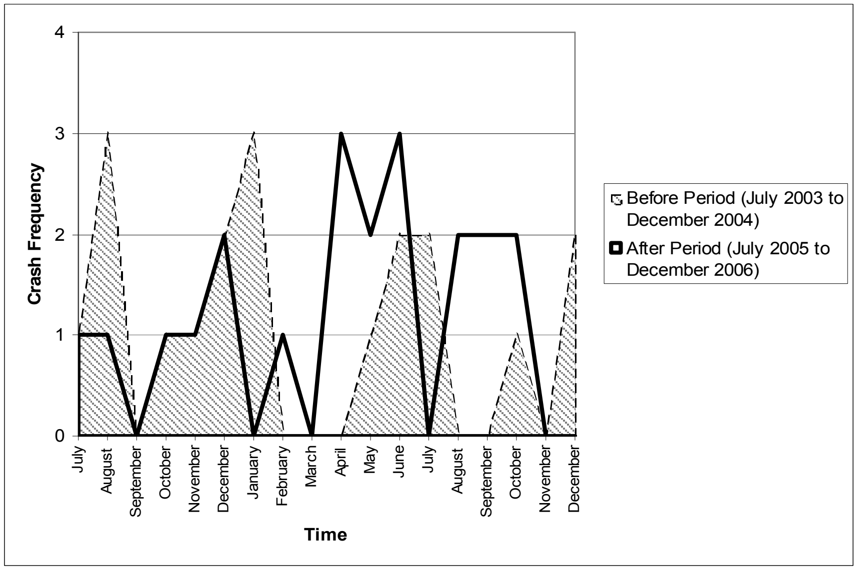

Figure 21. Rural Interstate Daytime Fatal Crash Frequency for Similar Periods

Figure 22 displays the *rural interstate* fatal and major injury crash frequency. Figure 23 displays the *rural interstate* fatal and major injury crash frequency for similar before and after periods.

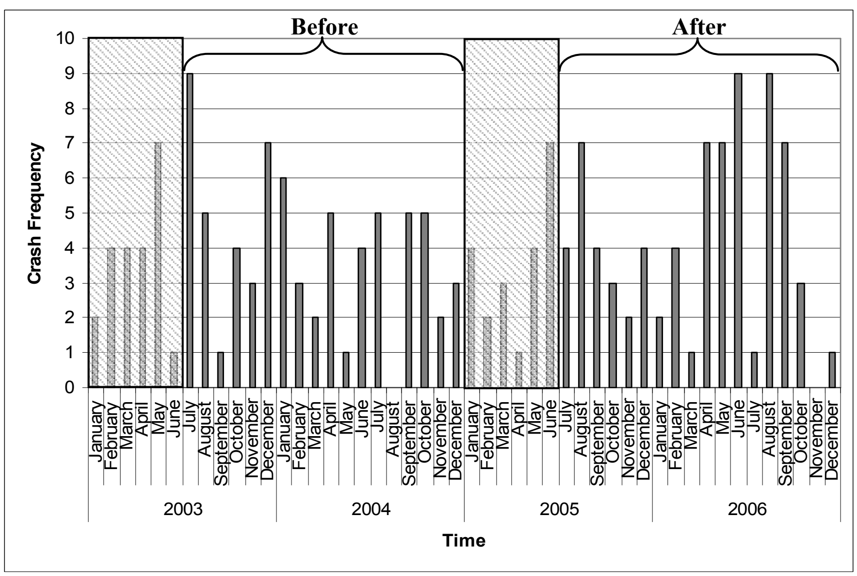

Figure 22. Rural Interstate Daytime Fatal and Major Injury Crash Frequency

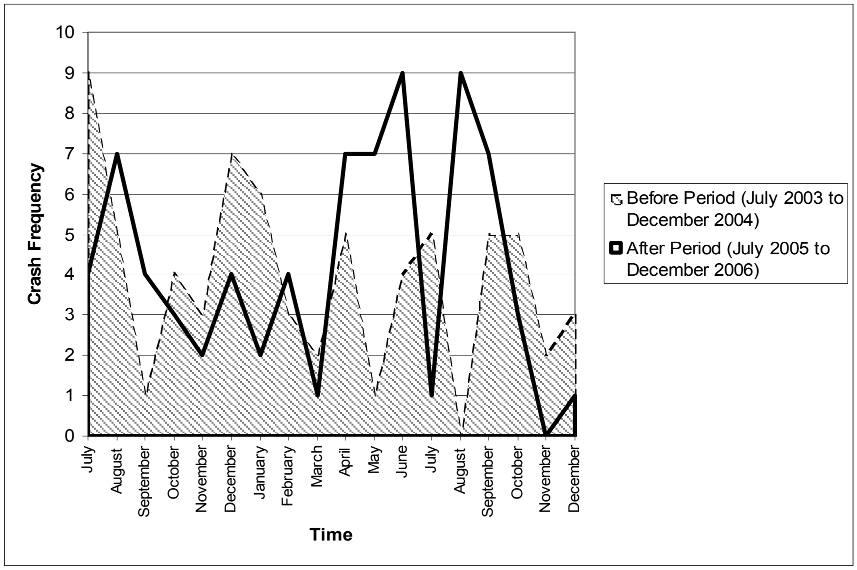

Figure 23. Rural Interstate Daytime Fatal and Major Injury Crash Frequency for Similar Periods

Figure 24 displays the crash frequency of all daytime crashes on the *rural interstates*, while Figure 25 displays the same for similar before and after periods. With the exception of the first set of winter months, the two frequency curves are observed to be very similar.

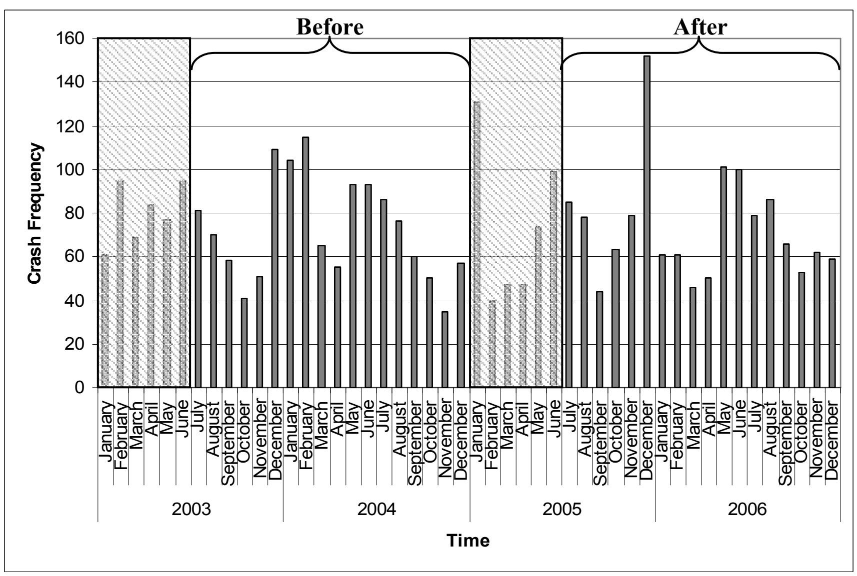

Figure 24. Rural Interstate Daytime All Crash Frequency

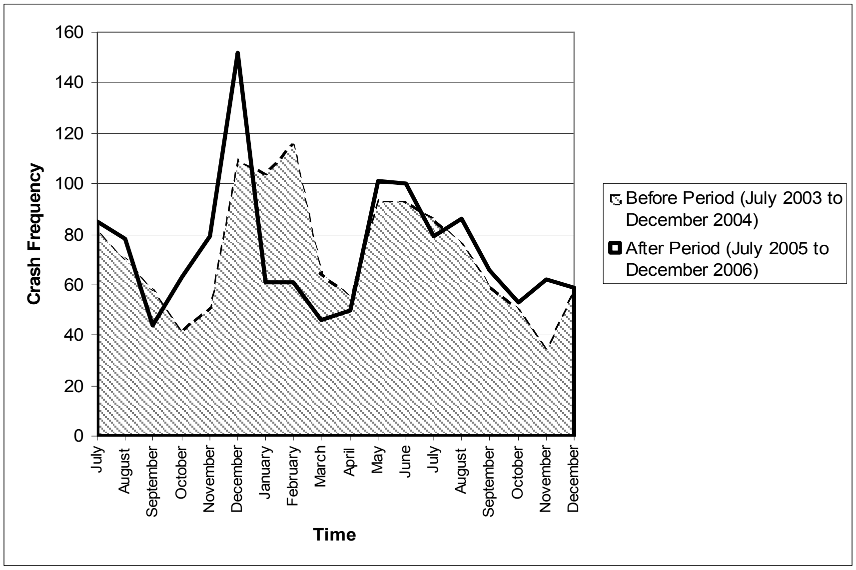

Figure 25. Rural Interstate Daytime All Crash Frequency for Similar Periods

Figure 26 displays a comparison of *rural interstate* daytime fatal and major injury crash frequencies and average speeds for the period of August, 2004 to December, 2006.

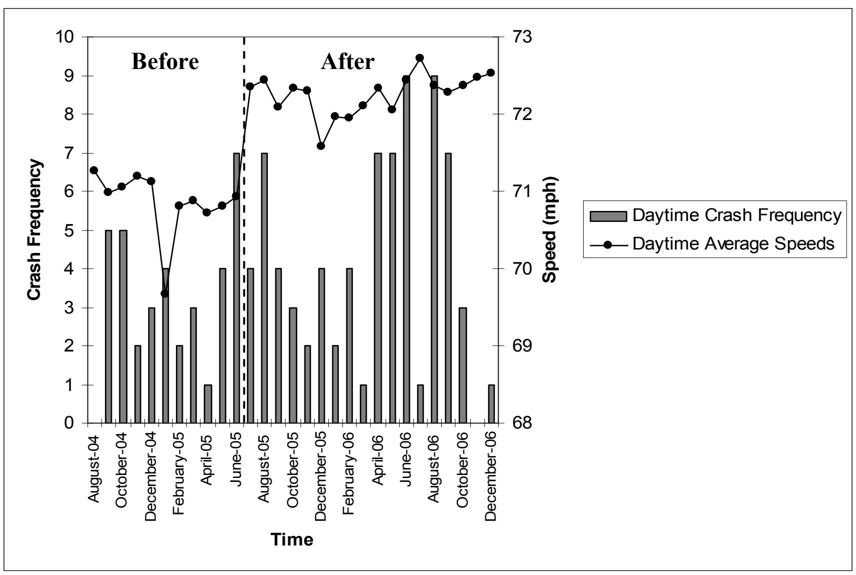

Figure 26. Rural Interstate Daytime Fatal and Major Injury Crash Frequency and Average Speeds

5.1.2 Nighttime Rural Interstate Crashes

Figures 27 through 32 display the *rural interstate* nighttime crash frequencies before and after the *rural interstate* speed limit change for fatal, fatal and major, and all crashes.

Figure 27 displays the *rural interstate* nighttime fatal crash frequency. The longest period of months not recording a fatal nighttime crash occurred during the before period. Figure 28 displays the *rural interstate* nighttime fatal crash frequency for similar before and after periods.

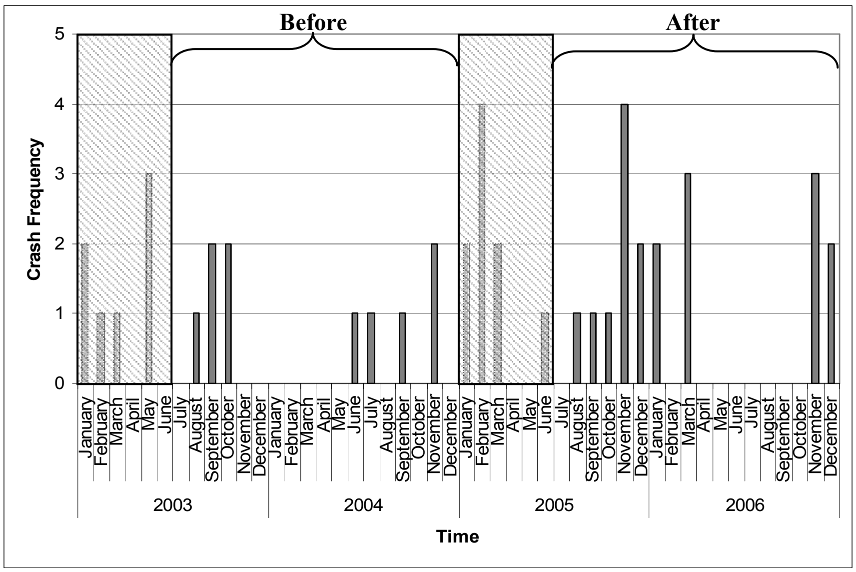

Figure 27. Rural Interstate Nighttime Fatal Crash Frequency

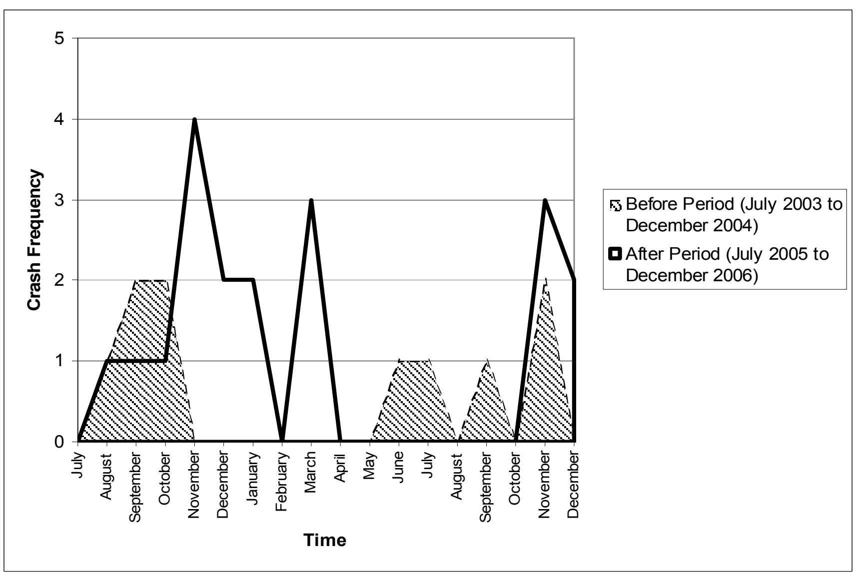

Figure 28. Rural Interstate Nighttime Fatal Crash Frequency for Similar Periods

Figure 29 displays the *rural interstate* nighttime fatal and major injury crash frequency. Figure 30 displays the *rural interstate* nighttime fatal and major injury crash frequency for similar before and after periods.

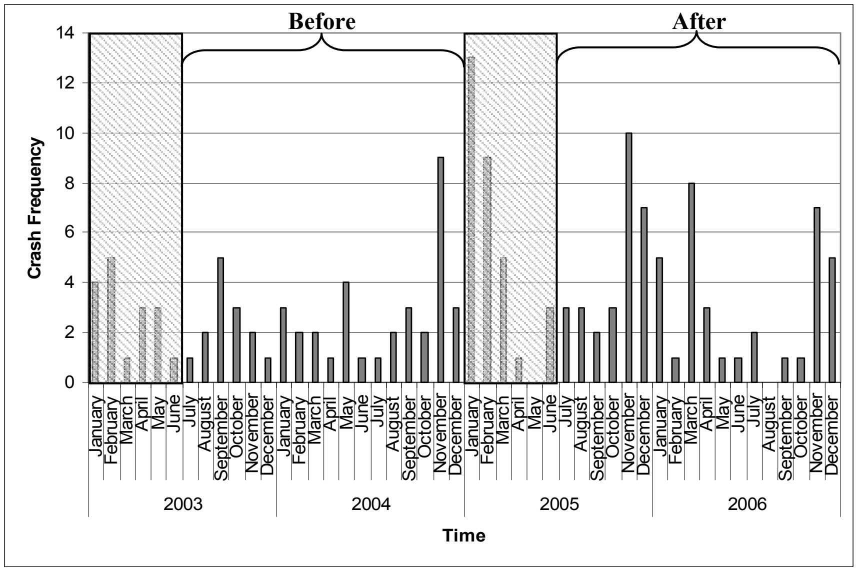

Figure 29. Rural Interstate Nighttime Fatal and Major Injury Crash Frequency

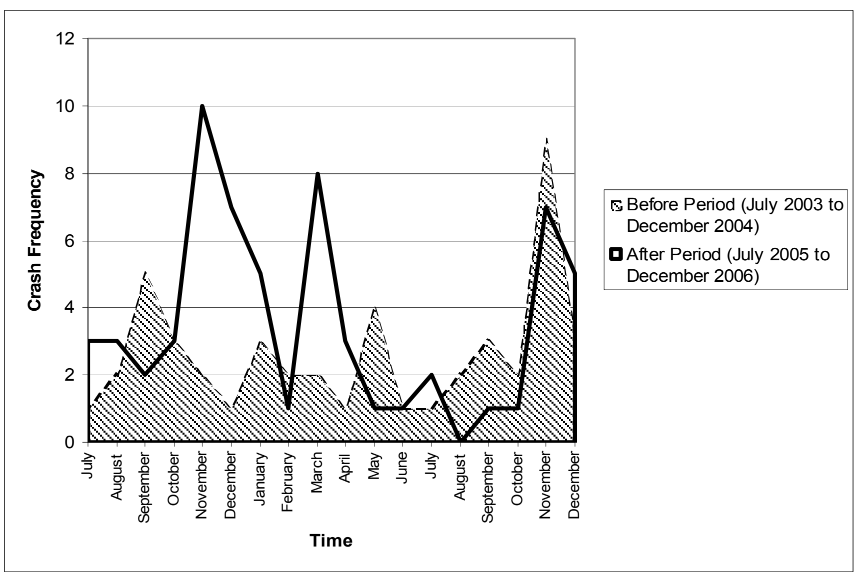

Figure 30. Rural Interstate Nighttime Fatal and Major Injury Crash Frequency for Similar Periods

Figure 31 displays the crash frequency for all nighttime crashes on the *rural interstate*. Figure 32 displays the crash frequency for all nighttime crashes on the *rural interstate* for similar before and after periods.

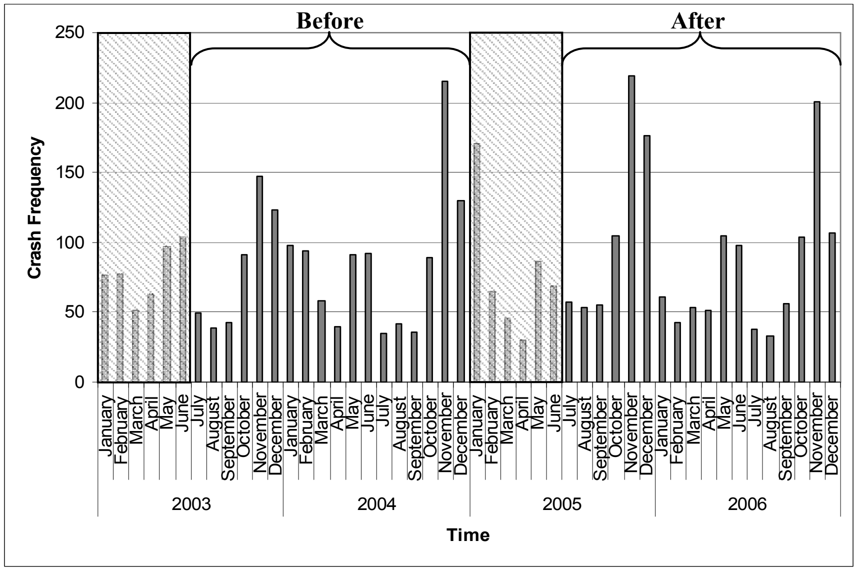

Figure 31. Rural Interstate Nighttime All Crash Frequency

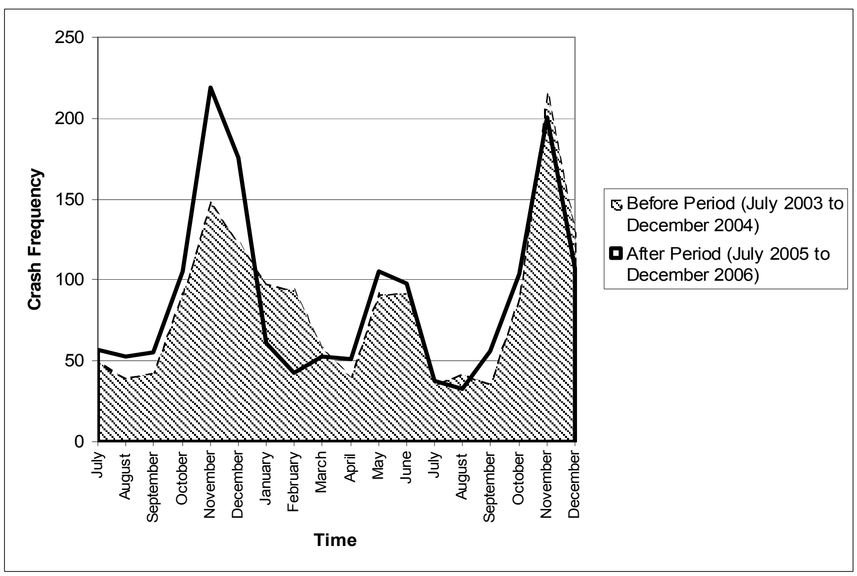

Figure 32. Rural Interstate Nighttime All Crash Frequency for Similar Periods

Figure 33 displays a comparison of the *rural interstate* fatal and major injury crash frequency and average speeds for the period of August, 2004 to December, 2006.

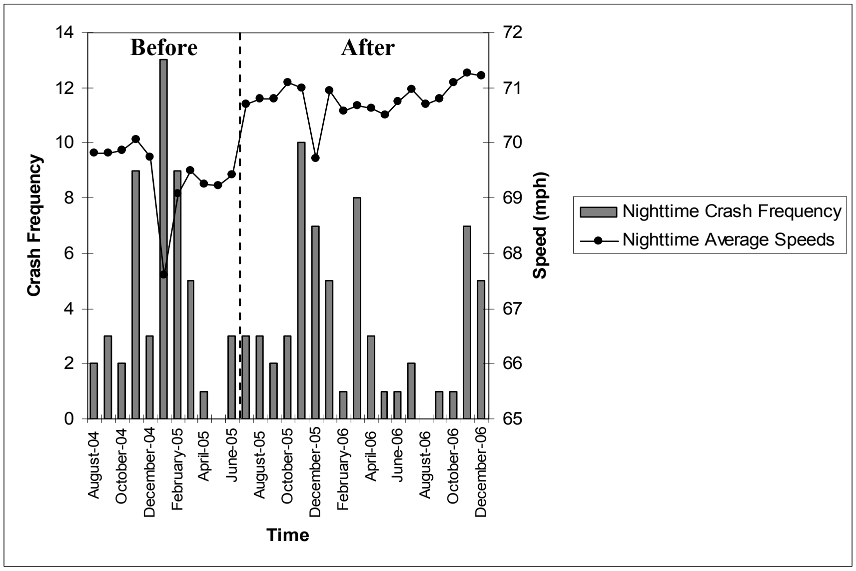

Figure 33. Rural Interstate Nighttime Fatal and Major Injury Crash Frequency and Average Speeds

5.2 Urban Interstates

Figures 34 through 39 display the *urban interstate* crash frequencies before and after the *rural interstate* speed limit change for fatal, fatal and major, and all crashes. Figure 34 displays the *urban interstate* fatal crash frequency. During the before period, there were eight months that did not record any fatal crashes, while during the after period there were seven months that did not record any fatal crashes. Figure 35 displays the *urban interstate* fatal crash frequency for similar before and after periods.

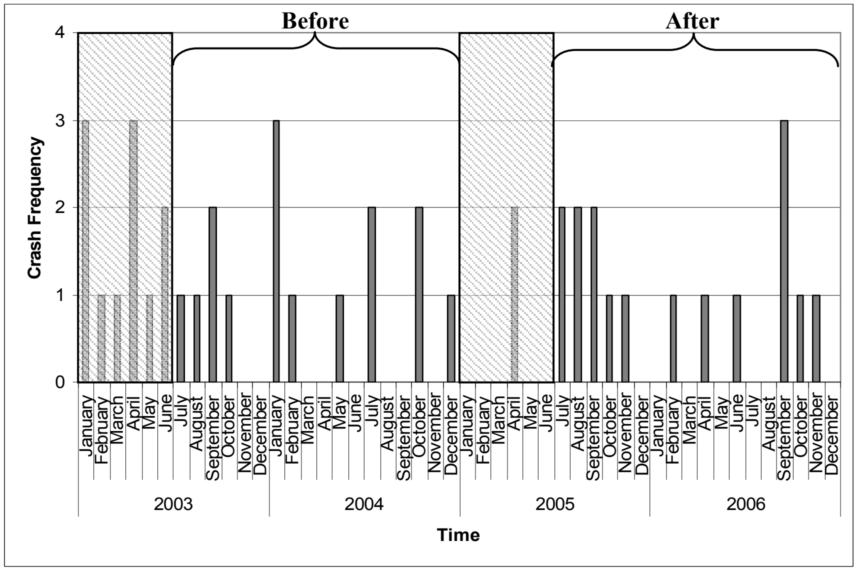

Figure 34. Urban Interstates Fatal Crash Frequency

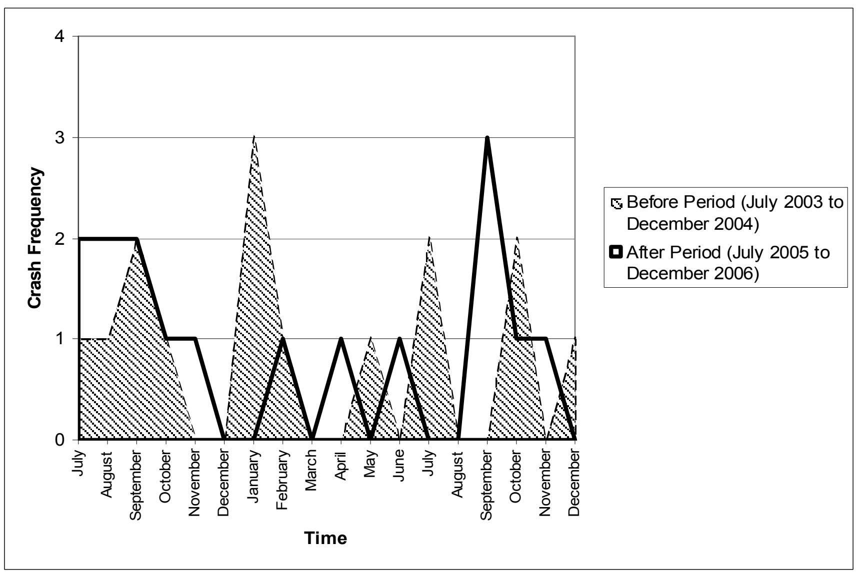

Figure 35. Urban Interstates Fatal Crash Frequency for Similar Periods

Figure 36 displays the *urban interstate* fatal and major injury crash frequency. Figure 37 displays the *urban interstate* fatal and major injury crash frequency for similar before and after periods.

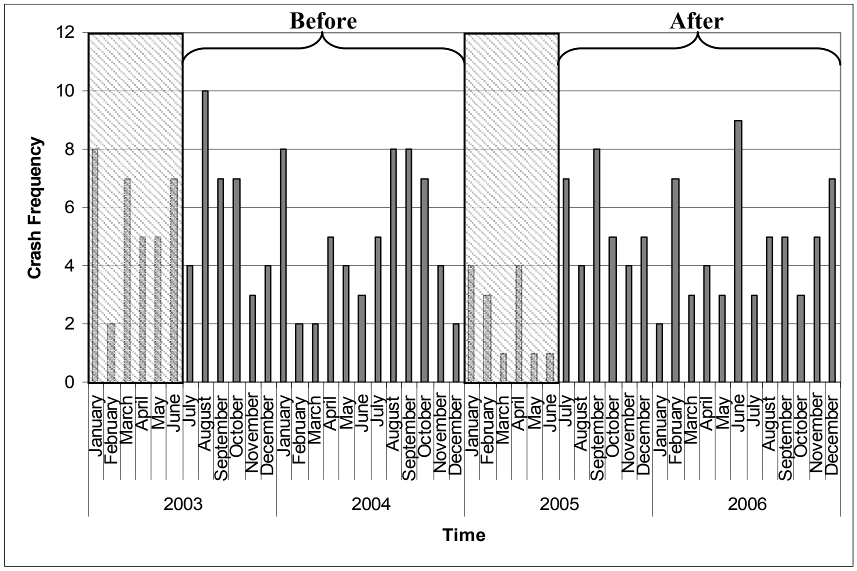

Figure 36. Urban Interstates Fatal and Major Injury Crash Frequency

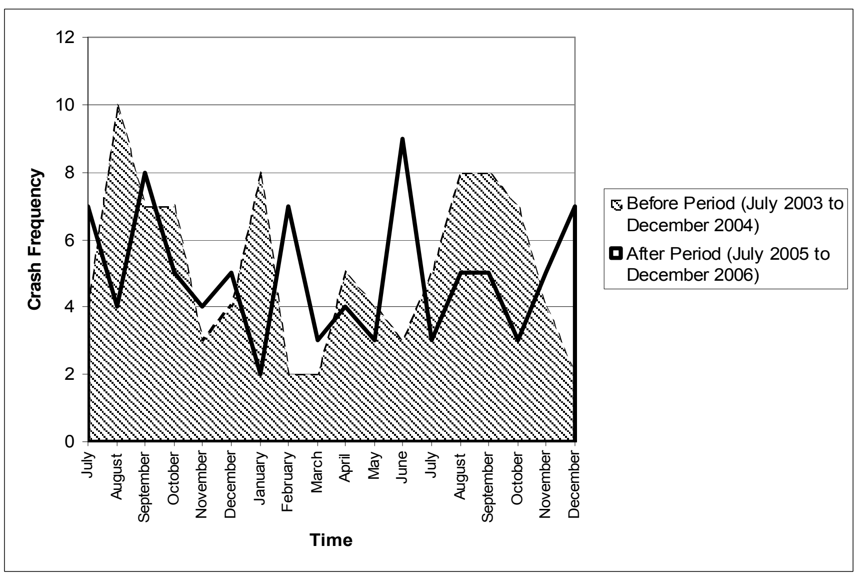

Figure 37. Urban Interstates Fatal and Major Injury Crash Frequency for Similar Periods

Figure 38 displays the crash frequency of all crashes on the *urban interstates*. Figure 39 displays the crash frequency of all crashes on the *urban interstates* for similar before and after periods.

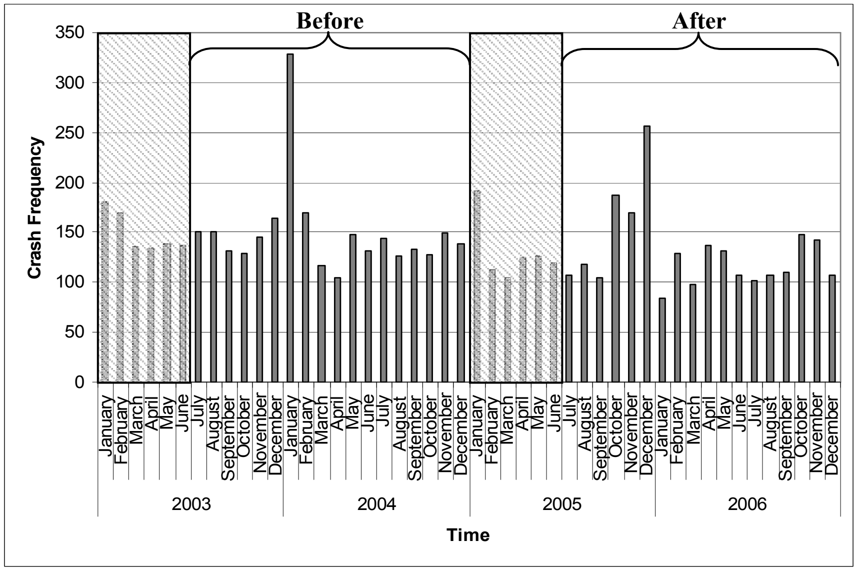

Figure 38. Urban Interstates All Crash Frequency

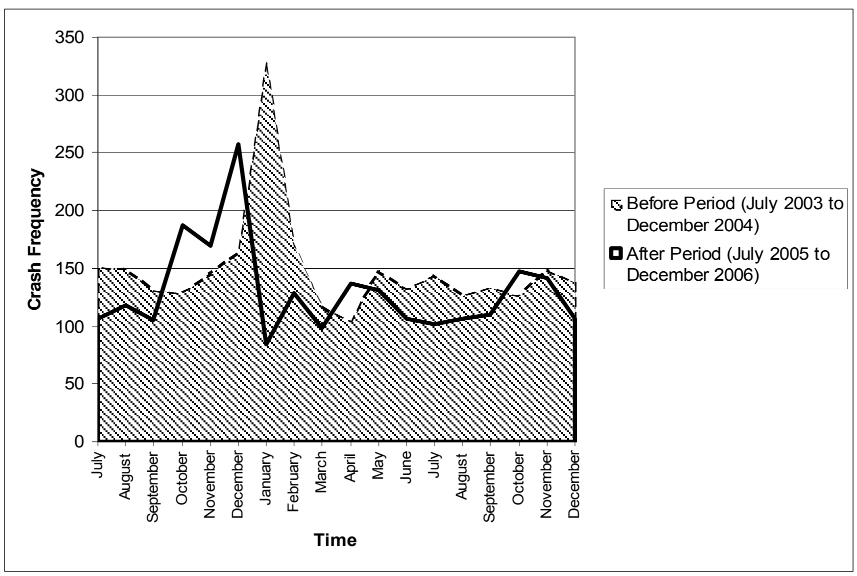

Figure 39. Urban Interstates All Crash Frequency for Similar Periods

Figure 40 displays the average and 85th percentile speeds of 55-mph *urban interstate* segments for the period of August, 2004 to December, 2006. Figure 41 displays the average and 85th percentile speeds of 60-mph *urban interstate* segments for the same period.

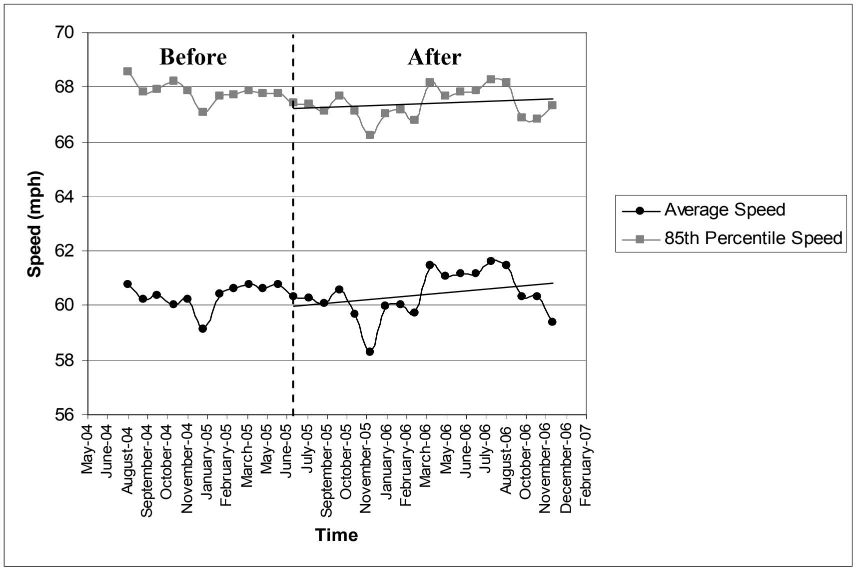

Figure 40. 55-mph Urban Interstate Segments Average and 85th Percentile Speeds

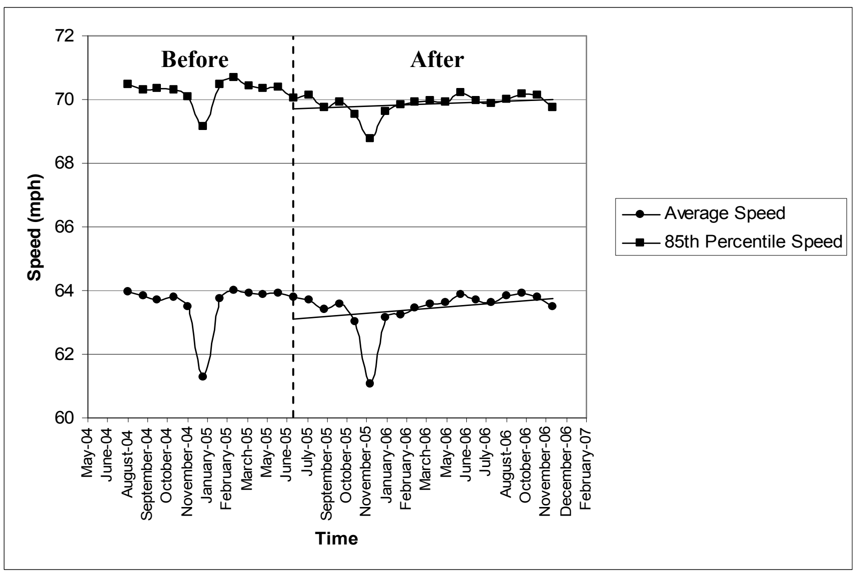

Figure 41. 60-mph Urban Interstate Segments Average and 85th Percentile Speeds

5.3 Rural Expressways

Figures 42 through 47 display the *rural expressway* crash frequencies for fatal, fatal and major, and all crashes before and after the *rural interstate* speed limit change. Figure 42 displays the *rural expressways* fatal crash frequency. Figure 43 displays the *rural expressways* fatal crash frequency for similar before and after periods.

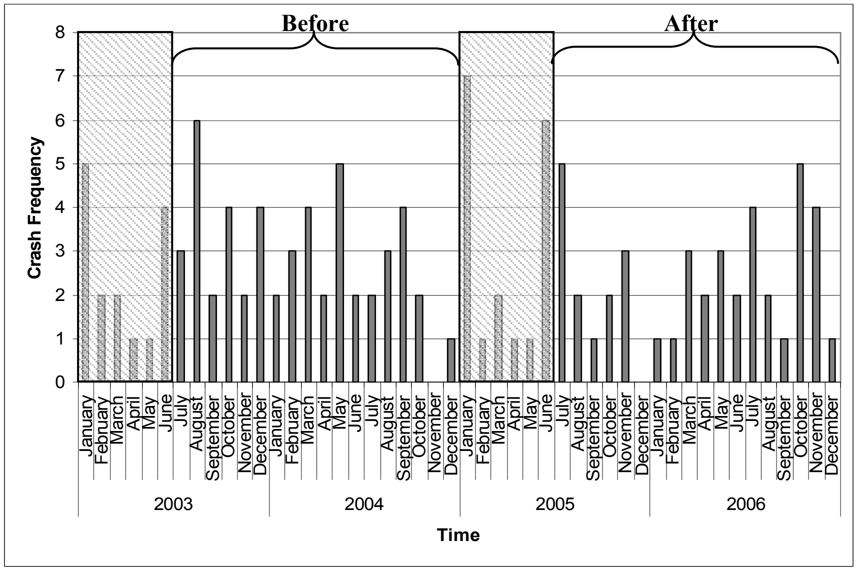

Figure 42. Rural Expressway Fatal Crash Frequency

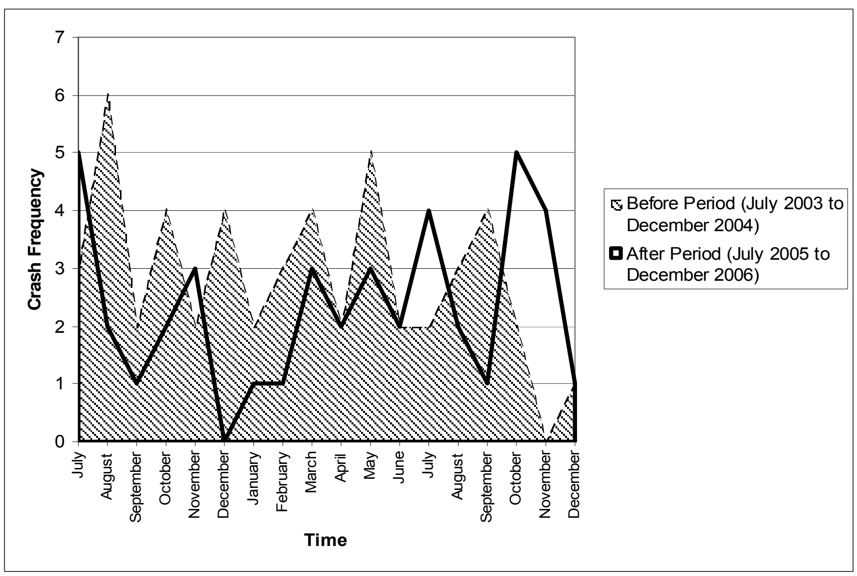

Figure 43. Rural Expressway Fatal Crash Frequency for Similar Periods

Figure 44 displays the *rural expressways* fatal and major injury crash frequency. Figure 45 displays the *rural expressways* fatal and major injury crash frequency for similar before and after periods.

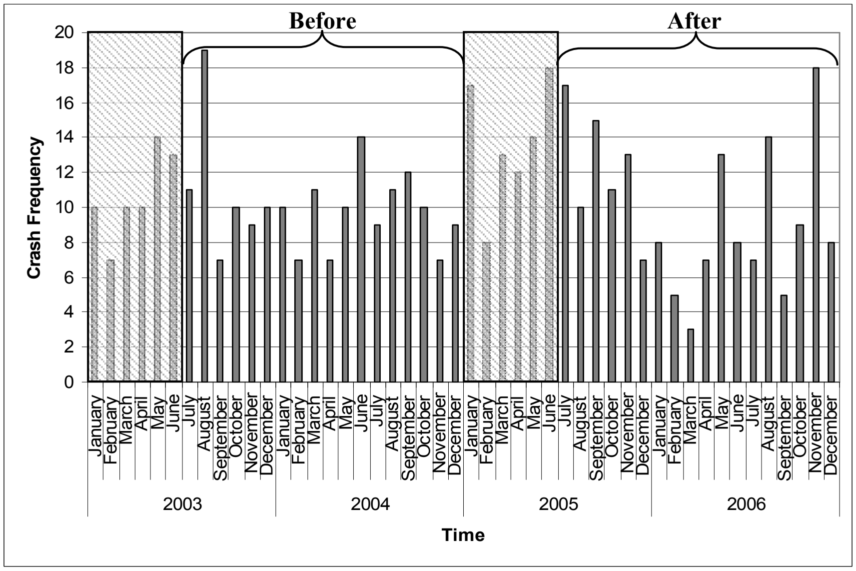

Figure 44. Rural Expressway Fatal and Major Injury Crash Frequency

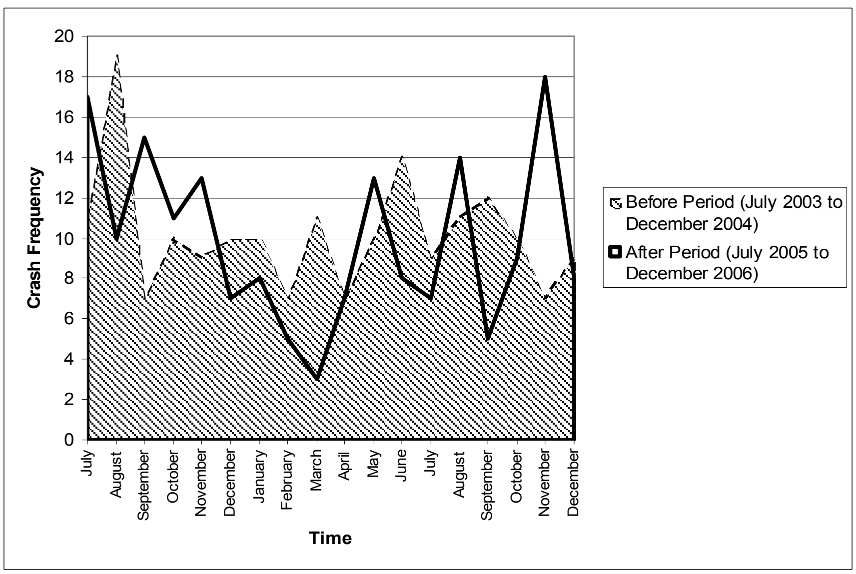

Figure 45. Rural Expressway Fatal and Major Injury Crash Frequency for Similar Periods

Figure 46 displays the crash frequency for all crashes on the *rural expressways*. Figure 47 displays the crash frequency of all crashes on the *rural expressways* for similar before and after periods.

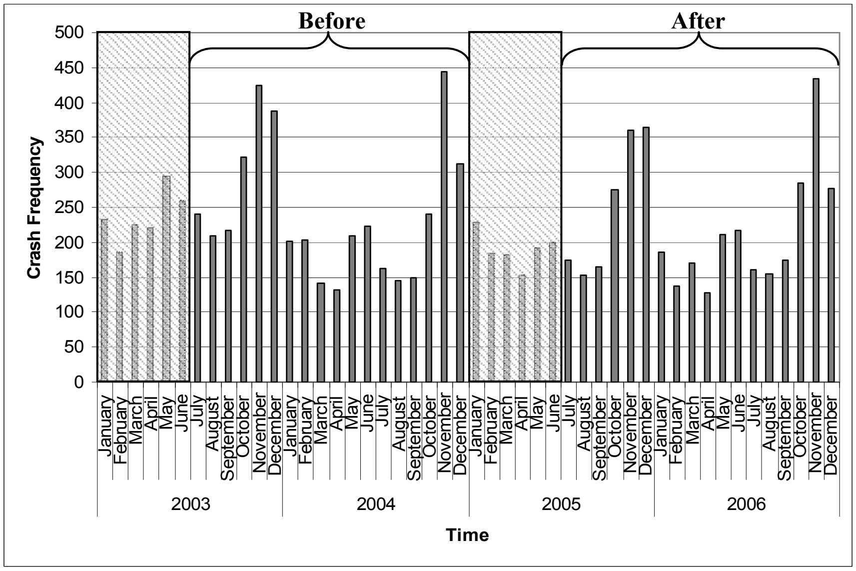

Figure 46. Rural Expressway All Crash Frequency

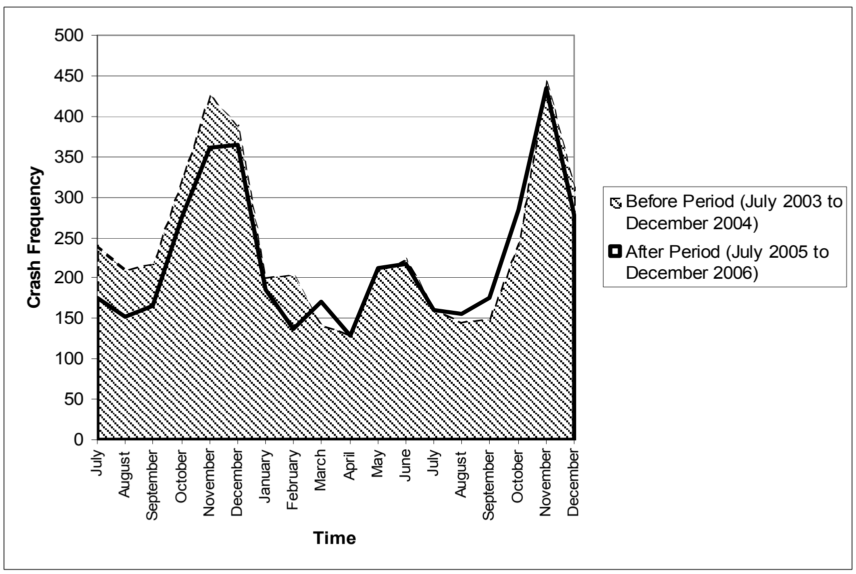

Figure 47. Rural Expressway All Crash Frequency for Similar Periods

Figure 48 displays the *rural expressway's* average and 85th percentile speeds for the period August, 2004 to December, 2006. Both the average and 85th percentile speeds are observed to be slowly increasing over time after the *rural interstate* speed limit change.

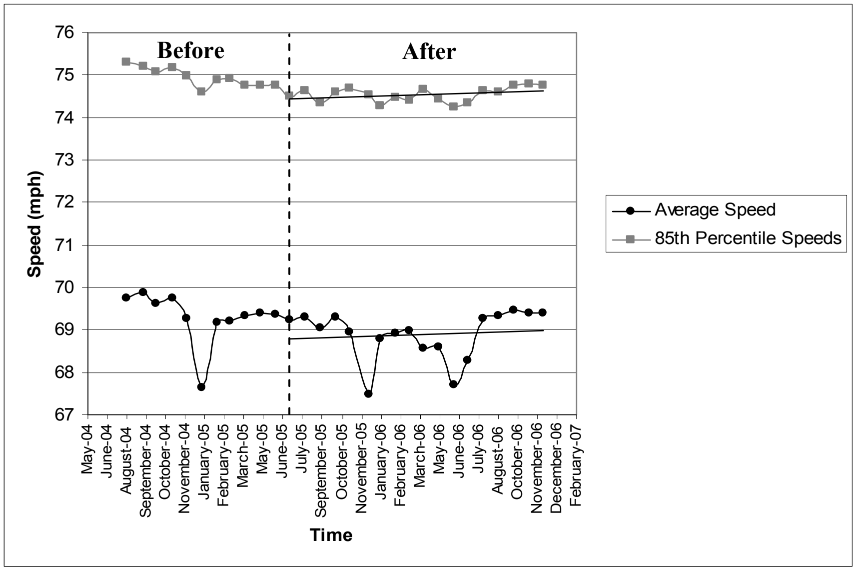

Figure 48. Rural Expressways Average and 85th Percentile Speeds

5.4 Rural Other Primary Highways

Figures 49 through 54 display the fatal, fatal and major, and all crash frequencies for the *rural other primary* highways before and after the *rural interstate* speed limit change. Figure 49 displays the *rural other primary* highways fatal crash frequency. Figure 50 displays the *rural other primary* highways fatal crash frequency for similar before and after periods.

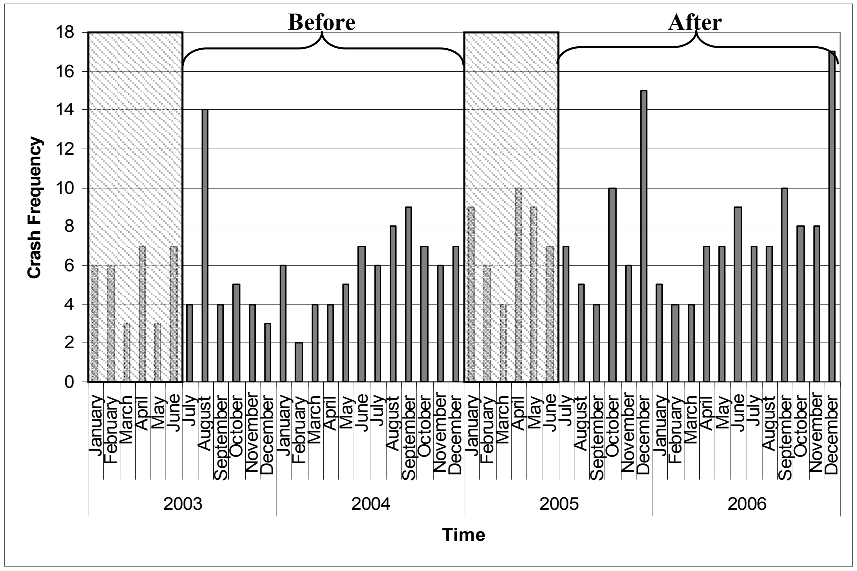

Figure 49. Rural Other Primary Highway Fatal Crash Frequency

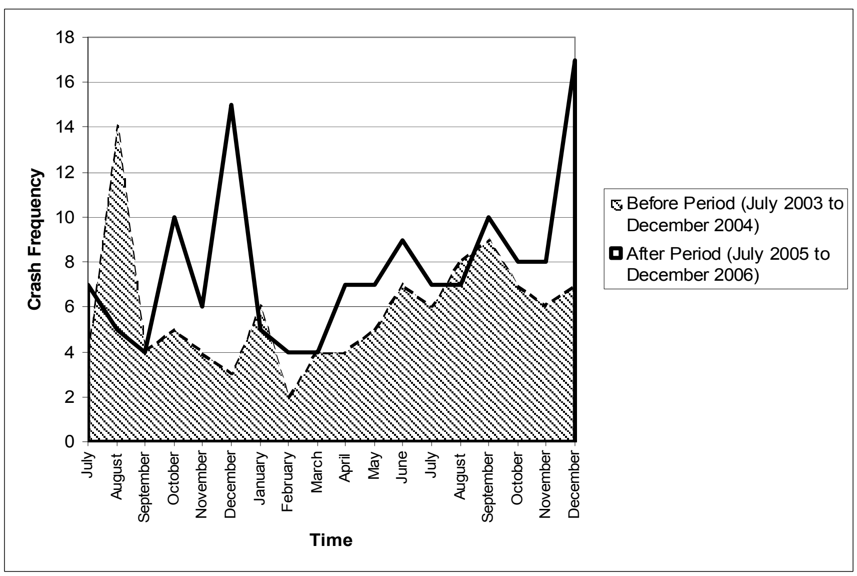

Figure 50. Rural Other Primary Highway Fatal Crash Frequency for Similar Periods

Figure 51 displays the other rural primary highways fatal and major injury crash frequency. Figure 52 displays the other rural primary highways fatal and major injury crash frequency for similar before and after periods.

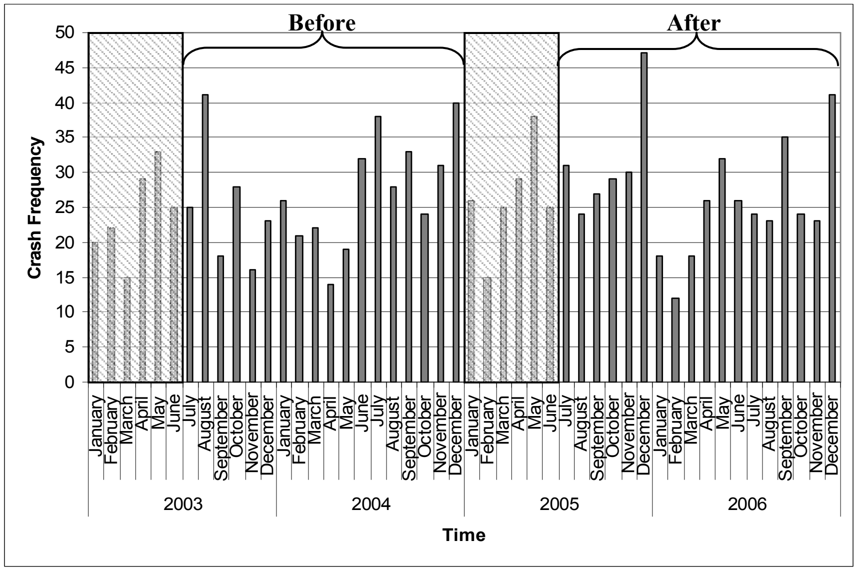

Figure 51. Rural Other Primary Highway Fatal and Major Injury Crash Frequency

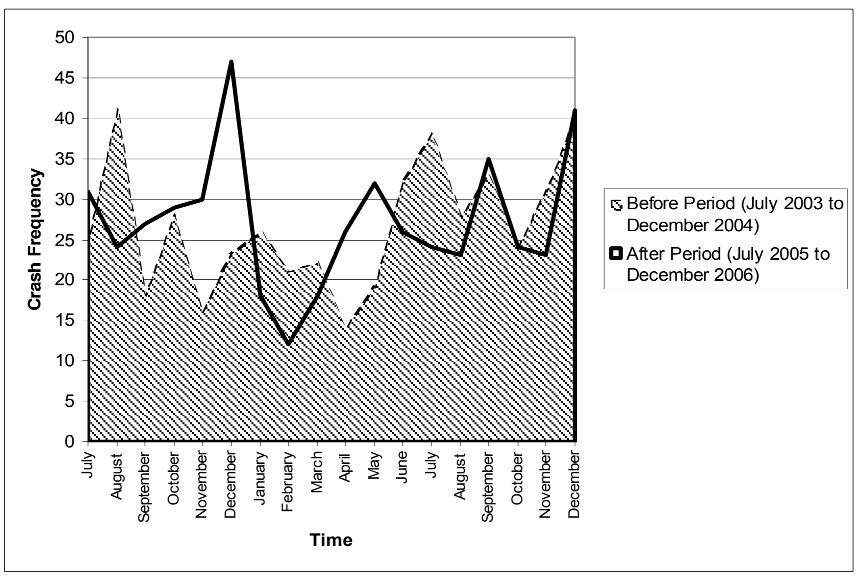

Figure 52. Rural Other Primary Highway Fatal and Major Injury Crash Frequency for Similar Periods

Figure 53 displays the crash frequency of all crashes on other rural primary highways. Figure 54 displays the crash frequency of all crashes on the rural primary highways for similar before and after periods. The two frequency curves are very similar.

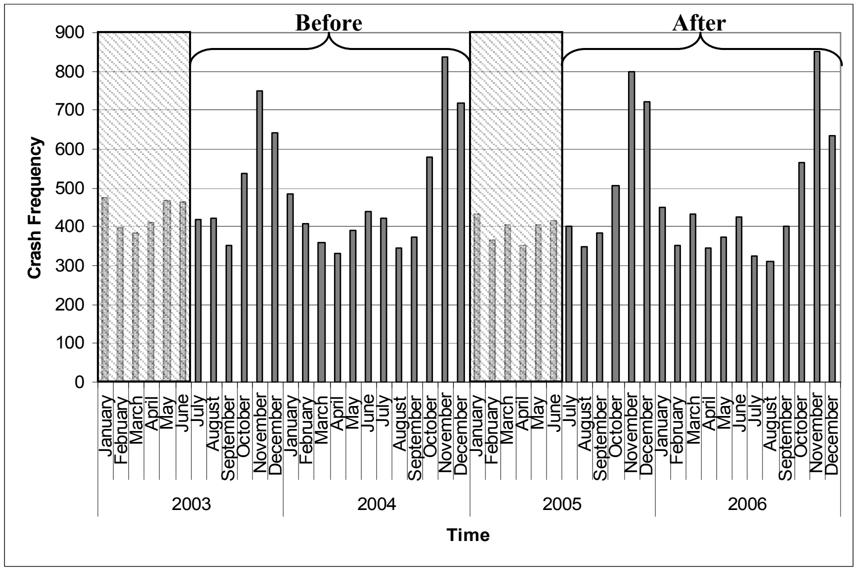

Figure 53. Rural Other Primary Highway All Crash Frequency

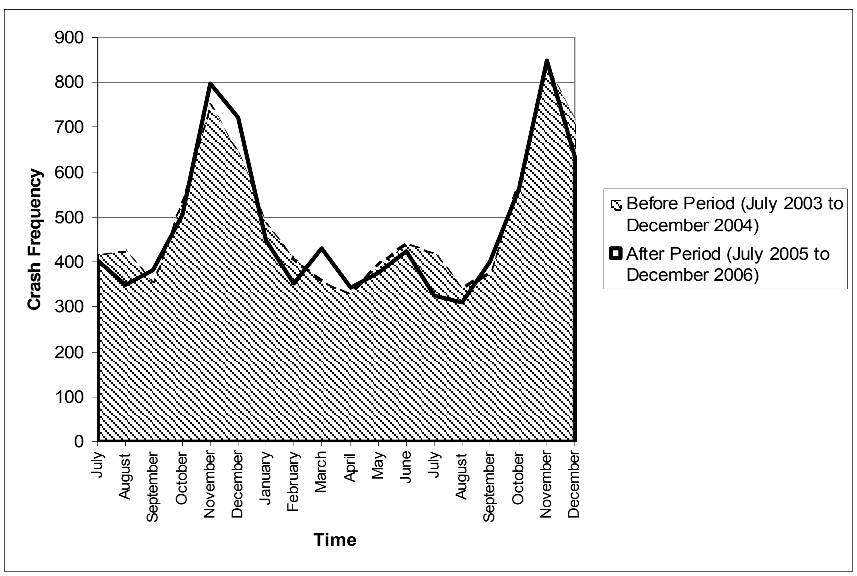

Figure 54. Rural Other Primary Highway All Crash Frequency for Similar Periods

Figure 55 displays the *rural other primary* highway's average and 85th percentile speeds for the period of August, 2004 to December, 2006. Both the average and 85th percentile speeds of *rural other primary* highways are observed to be decreasing over time after the *rural interstate* speed limit change.

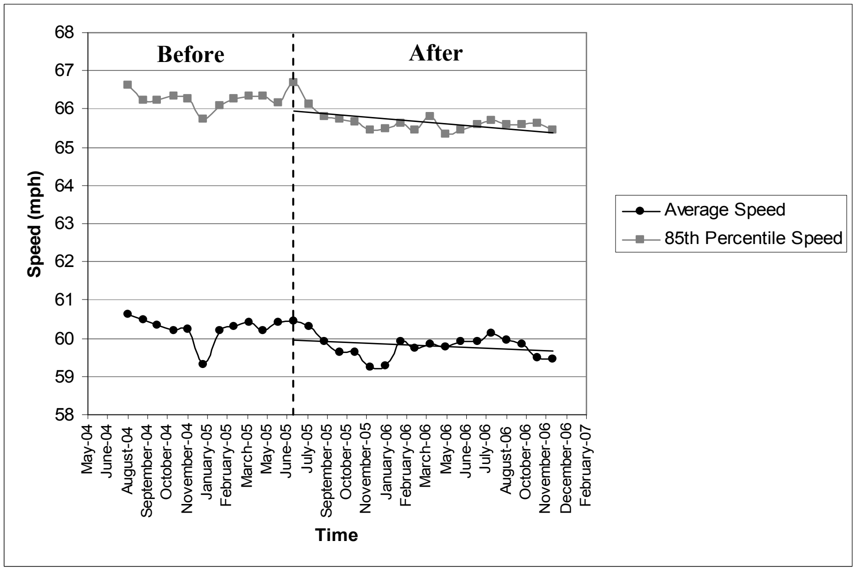

Figure 55. Rural Other Primary Highway Average and 85th Percentile Speeds

5.5 Rural Non-Primary Roads

Figures 56 through 61 display the fatal, fatal and major, and all crash frequencies for *rural non-primary* roads before and after the *rural interstate* speed limit change. Figure 56 displays the *rural non-primary* fatal crash frequency. Figure 57 displays the *rural non-primary* fatal crash frequency for similar before and after periods.

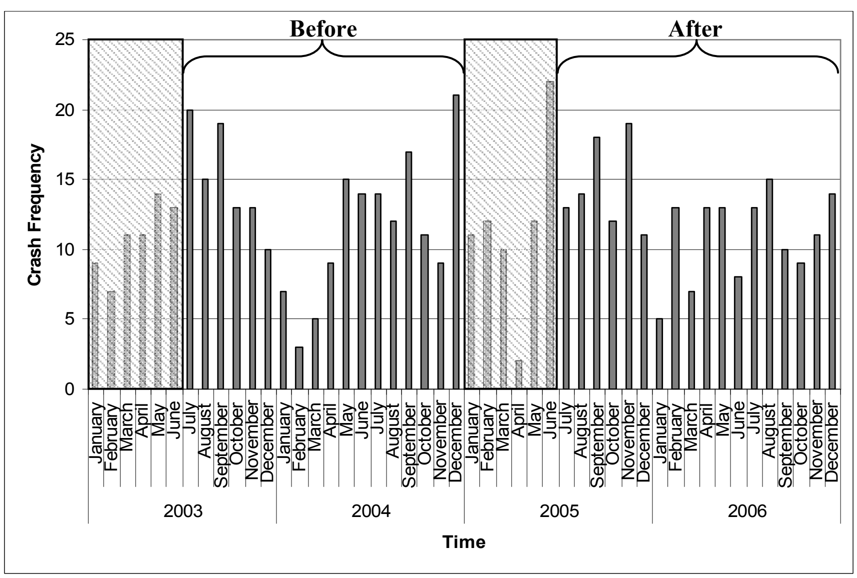

Figure 56. Rural Non-Primary Roads Fatal Crash Frequency

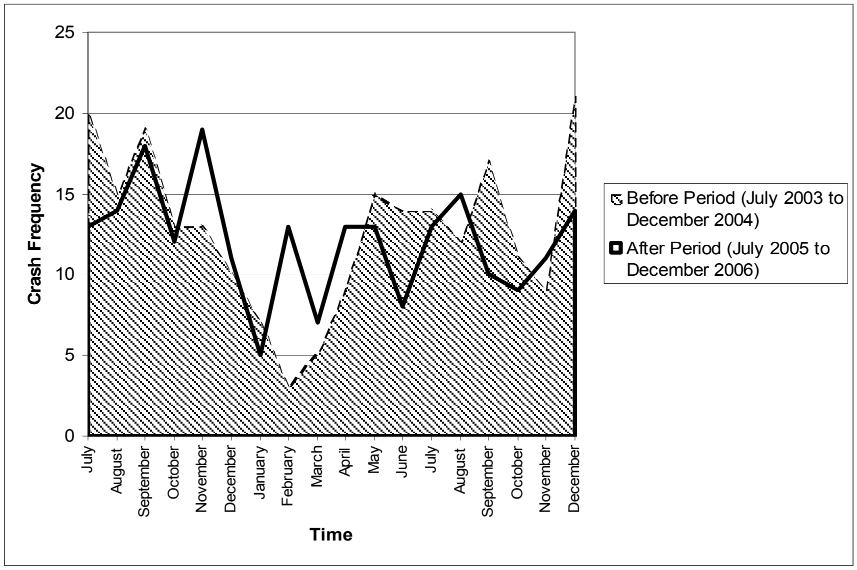

Figure 57. Rural Non-Primary Roads Fatal Crash Frequency For Similar Periods

Figure 58 displays the *rural non-primary* fatal and major injury crash frequency. Figure 59 displays the *rural non-primary* fatal and major injury crash frequency for similar before and after periods.

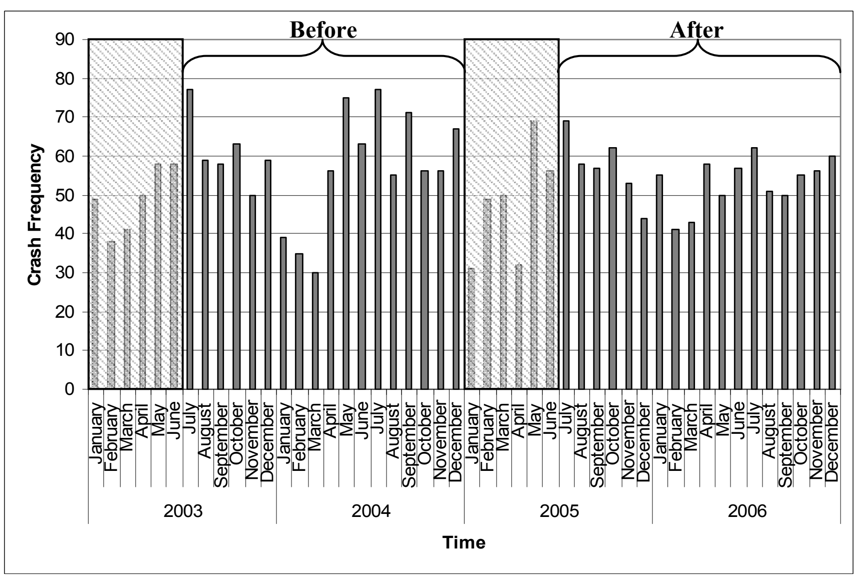

Figure 58. Rural Non-Primary Fatal and Major Injury Crash Frequency

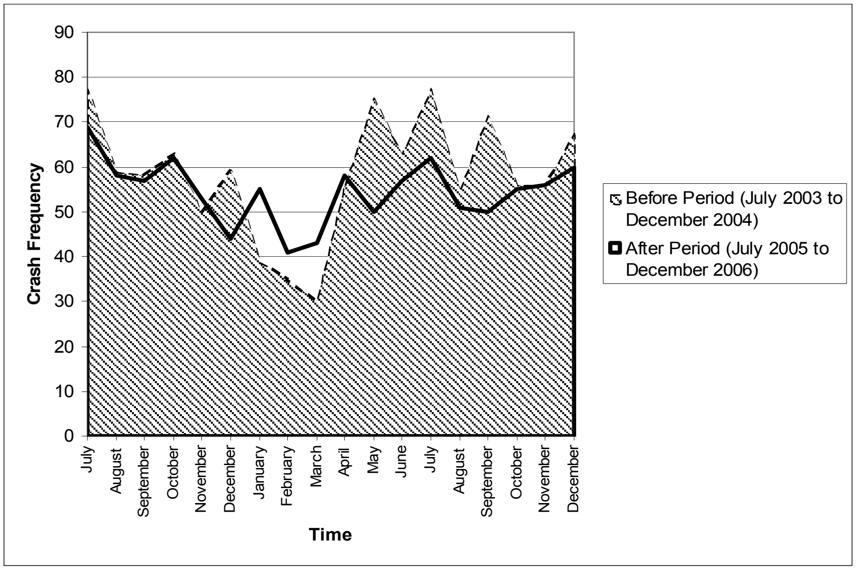

Figure 59. Rural Non-Primary Fatal and Major Injury Crash Frequency

Figure 60 displays the crash frequency of all crashes on *rural non-primary* roads. Figure 61 displays the crash frequency of all crashes on the *rural non-primary* roads for similar before and after periods.

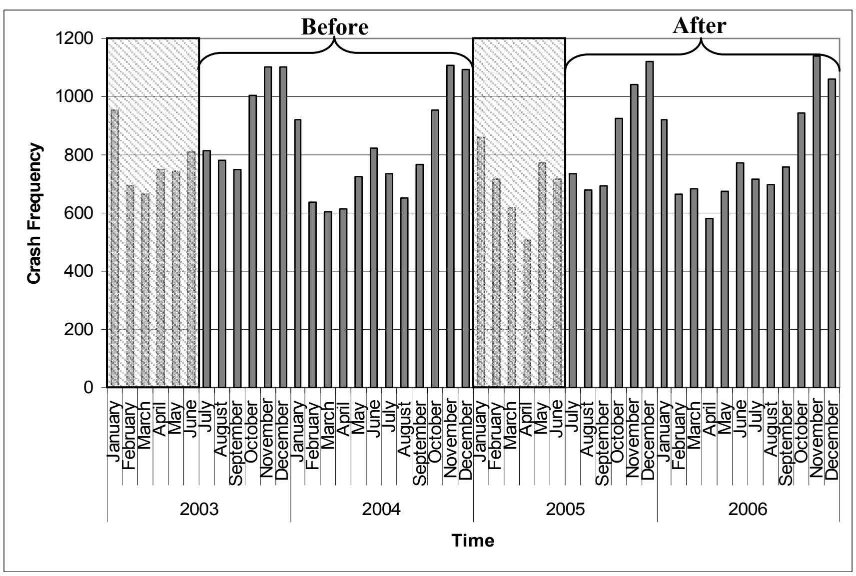

Figure 60. Rural Non-Primary All Crash Frequency

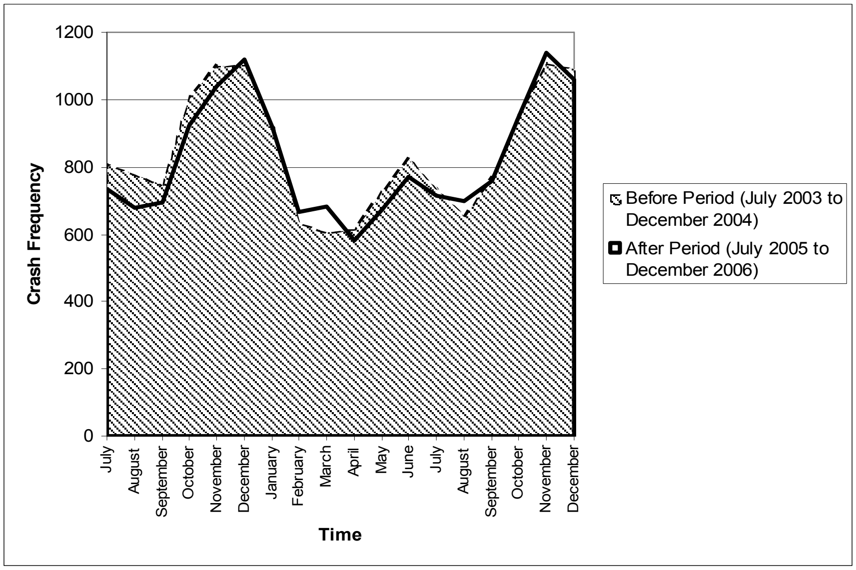

Figure 61. Rural Non-Primary All Crash Frequency for Similar Periods

Figure 62 displays the *rural non-primary* road's average and 85th percentile speeds for the period of August, 2004 to December, 2006. The 85th percentile speeds are observed to have little change after the rural interstate speed limit change.

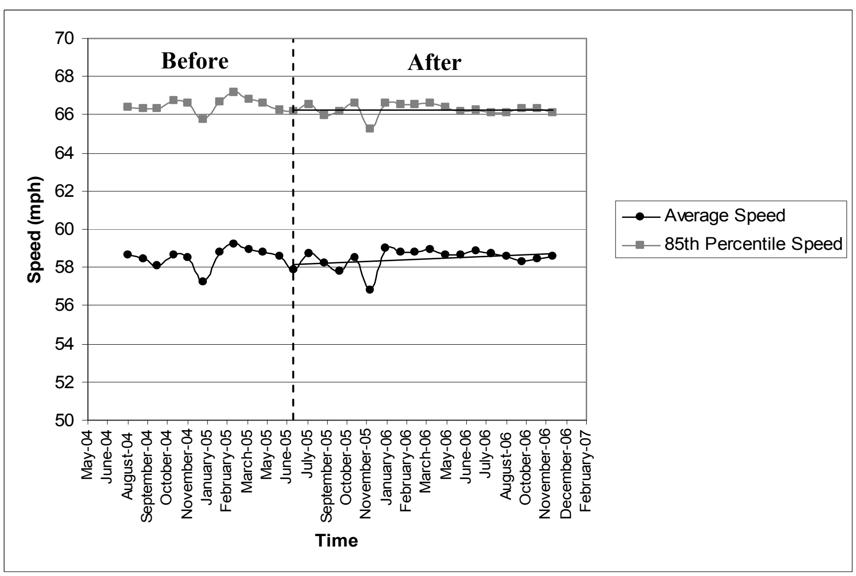

Figure 62. Rural Non-Primary Average and 85th Percentile Speeds

5.6 All Rural Roads

Figures 63 through 68 display the fatal, fatal and major, and all crash frequencies for all rural roads before and after the *rural interstate* speed limit change. Figure 63 displays the all rural roads fatal crash frequency. Figure 64 displays the all rural roads fatal crash frequency for similar before and after periods.

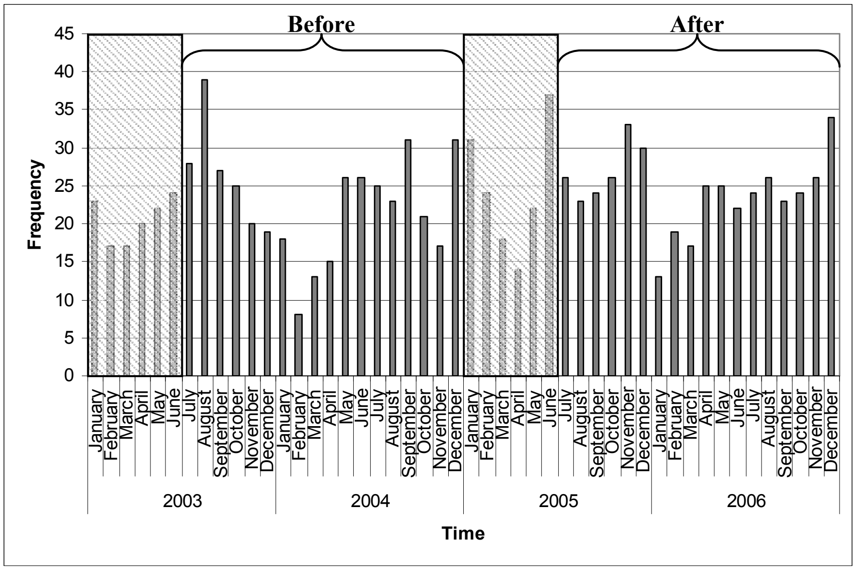

Figure 63. All Rural Roads Fatal Crash Frequency

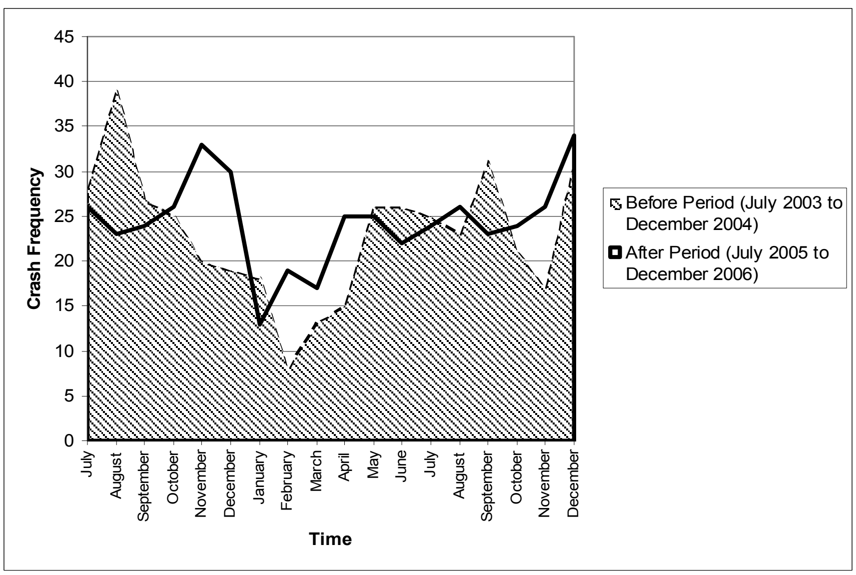

Figure 64. All Rural Roads Fatal Crash Frequency for Similar Periods

Figure 65 displays the all rural roads fatal and major injury crash frequency. Figure 66 displays the all rural roads fatal and major injury crash frequency for similar before and after periods.

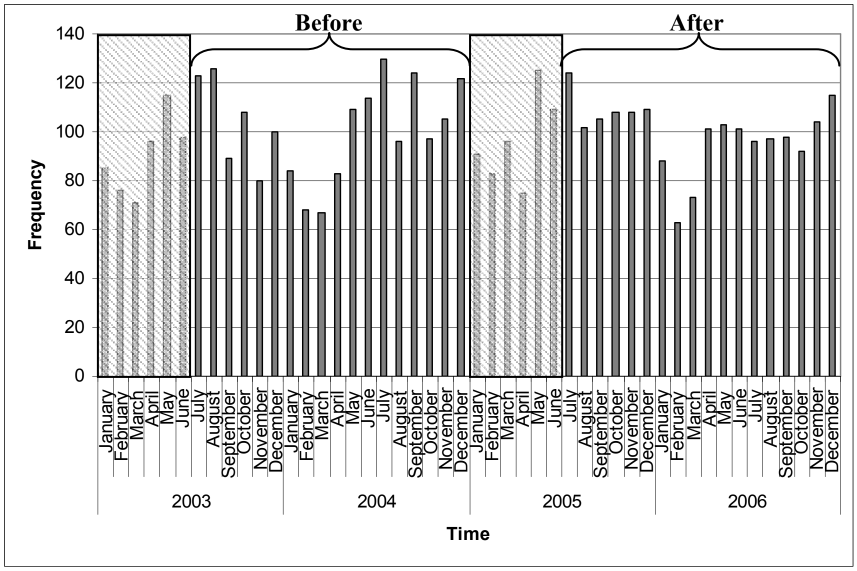

Figure 65. All Rural Roads Fatal and Major Injury Crash Frequency

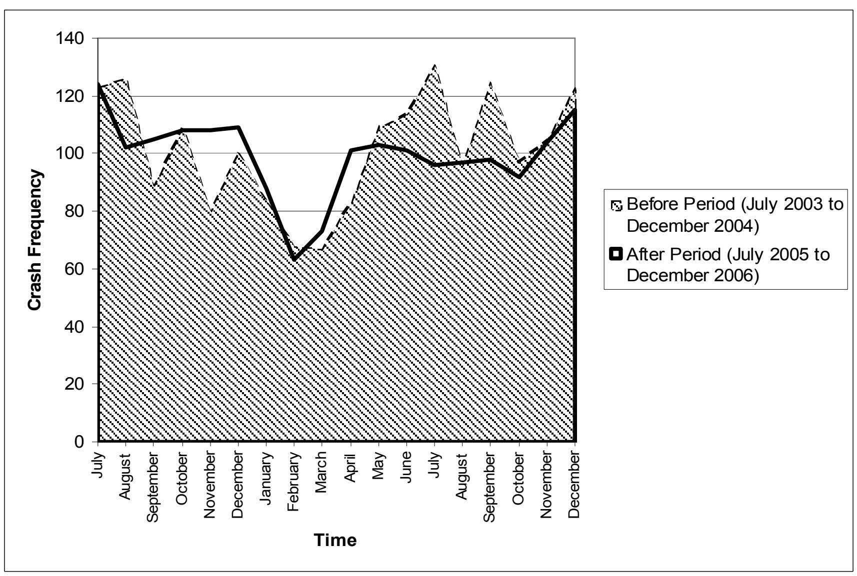

Figure 66. All Rural Roads Fatal and Major Injury Crash Frequency for Similar Periods

Figure 67 displays the crash frequency for all crashes on all rural roads. Figure 68 displays the crash frequency for all crashes on all rural roads for similar before and after periods.

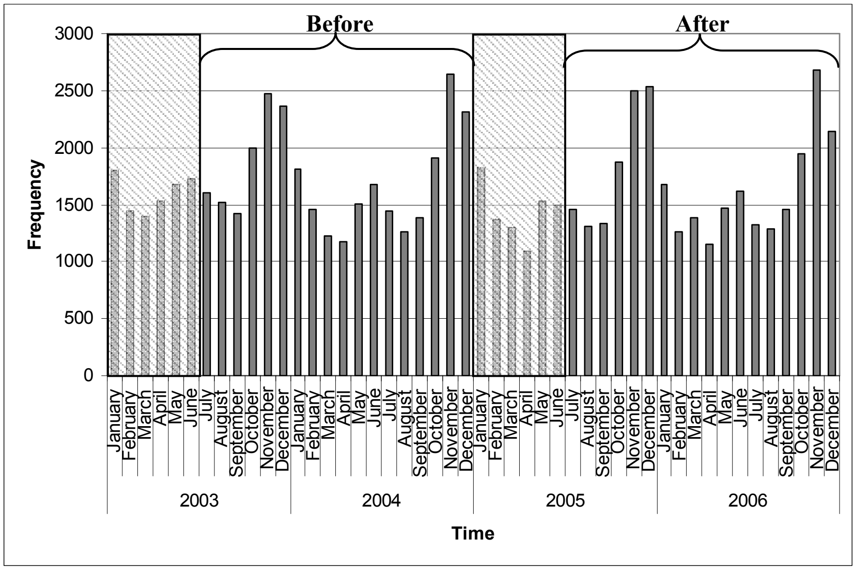

Figure 67. All Rural Roads All Crash Frequency

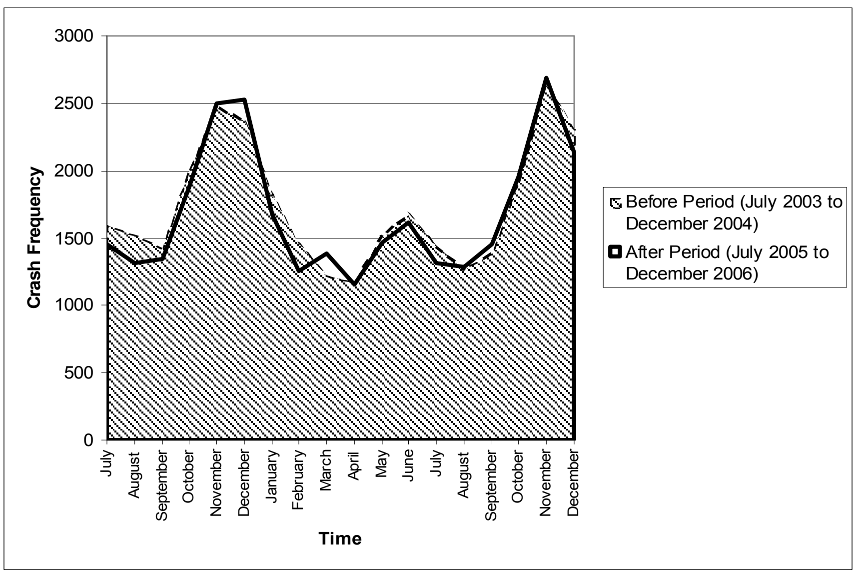

Figure 68. All Rural Roads All Crash Frequency for Similar Periods

5.7 Results Summary

Table 3 displays a comparison of the before and after period monthly crash frequency means with a before period of July, 2003 to December, 2004 and an after period of July, 2005 to December, 2006. The recorded monthly crash frequency means in Table 3 are not "adjusted" for any change in traffic volume. The *rural interstate* is observed to have experienced an increase for each crash severity. With respect to road type, *rural interstate* fatal crashes increased the most at 38 percent. *Rural interstate* nighttime fatal crashes however increased by 89 percent. Overall, *rural interstates* have experienced an increase in the higher severity crashes such as fatal and fatal and major injury crashes. Because of the higher speeds, crashes may have become more severe in the after period. *Rural other primary* highways have also experienced a larger increase in the after period fatal crash frequency mean relative to all other road types at 33 percent. Both *rural other primary* highways and *urban interstates* are observed to have experienced a similar change to the *rural interstates* in terms of an increase in the higher severity crashes. *Rural expressways* and *rural non-primary* roads experienced a decrease for all crash severities.

5.8 Results Hypothesis Tests

For each road type, a two-sample t-test assuming unequal variances was conducted to determine if the change in the mean crash frequency was statistically significant at the 95 percent confidence level. The null hypothesis was that there was no change in the mean while the alternative hypothesis was that the after period mean was greater than the before period mean. The results of a similar t-test are also displayed in Table 3 for average and 85th percentile speeds for each road type. A plus (+) sign indicates a statistically significant increase while a negative (-) sign indicates a statistically significant decrease. The only road type to experience a statistically significant increase in the mean crash frequency was *rural other primary* highway fatal crashes. Although the change in the *rural interstate* monthly mean crash frequency for the after period was not statistically significant, the reported p-values were low. Interestingly, the increase in the monthly mean crash frequency for *rural other primary* highway fatal crashes was statistically significant, while at the same time, a decrease in the after period average and 85th percentile mean speed were reported as statistically significant. Although the percent change in the monthly mean crash frequency for *rural other primary* highways is highlighted in Table 3, it is not an indication that it is related to the speed limit change on the *rural interstates*.

Table 4 displays a comparison of the before and after period crash frequencies with an "adjustment" for change in traffic volumes. The before and after periods are the same as those used in Table 3. The mean ADT for each category was calculated by summing the ADT for each month of the before and after period at each ATR site, dividing by the number of reporting sites, and then calculating the mean of the before and after period ADT monthly values. The value reported as the change in the crash percentage adjusted by traffic volume represents the actual change in the crash frequency assuming there was no change in traffic volumes and was calculated by multiplying the raw percent change in crashes by the volume ratio. Little change was observed in the before and after periods for each road type. Therefore, little change was required to "adjust" the crash frequencies.

Table 3. Summary of the Before and After Period Monthly Crash Frequency Means

Road Type	Crash Severity	Before Period Crash Frequency	Before Period Monthly Mean	After Period Crash Frequency	After Period Monthly Mean	Percent Change	Crash P-Value (one-tail)	Crash Significance (α = 0.05)	Average Speed Significance (α = 0.05)	85th Percentile Speed Significance (α = 0.05)
Rural Interstate	Fatal	29	1.61	40	2.22	37.9%	0.069	close	+	+
	Fatal and Major Injury	117	6.50	138	7.67	18.0%	0.070	close		
	All	2811	156.17	2940	163.33	4.6%	0.363			
Rural Interstate Daytime	Fatal	19	1.06	21	1.17	10.4%	0.376			
	Fatal and Major Injury	70	3.89	75	4.17	7.2%	0.374			
	All	1299	72.17	1325	73.61	2.0%	0.431			
Rural Interstate Nighttime	Fatal	10	0.56	19	1.06	89.3%	0.087			
	Fatal and Major Injury	47	2.61	63	3.50	34.1%	0.143			
	All	1512	84.00	1615	89.72	6.8%	0.373			
Urban Interstate	Fatal	15	0.83	16	0.89	6.8%	0.428			-
	Fatal and Major Injury	93	5.17	89	4.94	-4.4%	0.383			
	All	2685	149.17	2346	130.33	-12.6%	0.106	close		
Rural Expressway	Fatal	51	2.83	42	2.33	-17.7%	0.156		-	-
	Fatal and Major Injury	183	10.17	178	9.89	-2.8%	0.411			
	All	4365	242.50	4032	224.00	-7.6%	0.277			
Rural Other Primary	Fatal	105	5.83	140	7.78	33.4%	0.037	+	-	-
	Fatal and Major Injury	479	26.61	490	27.22	2.3%	0.412			
	All	8814	489.67	8620	478.89	-2.2%	0.421			
Rural Non-Primary	Fatal	227	12.61	218	12.11	-4.0%	0.365			
	Fatal and Major Injury	1046	58.11	981	54.50	-6.2%	0.162			
	All	15189	843.83	14801	822.28	-2.6%	0.359			
All Rural	Fatal	412	22.89	440	24.44	6.8%	0.233			
	Fatal and Major Injury	1825	101.39	1787	99.28	-2.1%	0.358			
	All	31179	1732.17	30393	1688.50	-2.5%	0.391			

Table 4. Summary of the Change in Crash Frequencies Adjusted by Traffic Volume

Road Type	Crash Frequency Before	Crash Frequency After	Δ Crashes (%)	Mean ADT Before	Mean ADT After	Volume Ratio (After/Before)	Δ Crashes Adjusted by Volume
Rural Interstate	Fatal						
	29	40	37.9%	23780	24885	1.05	39.7%
	Fatal and Major Injury						
	117	138	17.9%	23780	24885	1.05	18.8%
	All						
	2811	2940	4.6%	23780	24885	1.05	4.8%
Urban Interstate	Fatal						
	15	16	6.7%	67539	68670	1.02	6.8%
	Fatal and Major Injury						
	93	89	-4.3%	67539	68670	1.02	-4.4%
	All						
	2685	2346	-12.6%	67539	68670	1.02	-12.8%
Rural Expressway	Fatal						
	51	42	-17.6%	12363	13008	1.05	-18.6%
	Fatal and Major Injury						
	183	178	-2.7%	12363	13008	1.05	-2.9%
	All						
	4365	4032	-7.6%	12363	13008	1.05	-8.0%
Rural Other Primary	Fatal						
	105	140	33.3%	1741	1690	0.97	32.4%
	Fatal and Major Injury						
	479	490	2.3%	1741	1690	0.97	2.2%
	All						
	8814	8620	-2.2%	1741	1690	0.97	-2.1%
Rural Non-Primary	Fatal						
	227	218	-4.0%	756	806	1.07	-4.2%
	Fatal and Major Injury						
	1046	981	-6.2%	756	806	1.07	-6.6%
	All						
	15189	14801	-2.6%	756	806	1.07	-2.7%

Table 5 displays a summary of the before and after period average and 85th percentile speed means for each road type with a before period of August, 2004 to June, 2005, and an after period of August, 2005 to December, 2006. No summary was included for all rural roads because it was not possible to weight the sample speeds appropriately due to an insufficient sample size. A two sample t-test assuming unequal variances was conducted at the 95 percent confidence interval on the before and after period observations for each metric. As expected, the after period means of the *rural interstate* average and 85th percentile speeds were significantly higher. However, the *urban interstates* 55-mph and 60-mph segments', *rural expressways* and *rural other primary* highways 85th percentile speeds were significantly lower in the after period. The *rural expressways* and *rural other primary* highways average speeds also were found to be significantly lower in the after period.

Table 5. Summary of All Road Type Speeds

Road Type	Speed	Before Mean	After Mean	Absolute Change (mph)	P-Value (one-tail)	Significant (α = 0.05)
Rural Interstate	Average Speed	70.4	71.7	1.3	0.000	+
	85th Percentile Speed	76.3	77.7	1.4	0.000	+
Rural Interstate Daytime	Average Speed	70.9	72.1	1.3	0.000	+
	85th Percentile Speed	76.6	78.0	1.4	0.000	+
Rural Interstate Nighttime	Average Speed	69.4	70.7	1.3	0.000	+
	85th Percentile Speed	75.3	76.8	1.5	0.000	+
55 MPH Urban Interstate	Average Speed	60.4	60.2	0.1	0.318	
	85th Percentile Speed	67.8	67.3	0.5	0.006	-
60 MPH Urban Interstate	Average Speed	63.6	63.2	0.3	0.154	
	85th Percentile Speed	70.3	69.8	0.5	0.004	-
Rural Expressway	Average Speed	69.3	68.7	0.6	0.014	-
	85th Percentile Speed	74.9	74.5	0.5	0.000	-
Rural Other Primary	Average Speed	60.2	59.7	0.5	0.001	-
	85th Percentile Speed	66.2	65.6	0.6	0.000	-
Rural Non-Primary	Average Speed	58.7	58.4	0.2	0.208	
	85th Percentile Speed	66.8	66.3	0.5	0.084	

Table 6 displays the comparison of the before and after period ADT values for all road types. A similar t-test was conducted as described for Table 5. The *rural expressways* ADT increased significantly while the *rural non-primary* roads decreased significantly decreased in the after period. No other road type experienced any significant change in its ADT. Although there was an increase in the *rural interstate* ADT for the after period, the statistical analysis suggests that the change was not significant.

Table 6. Summary of All Road Type Traffic Volumes

Road Type	Before ADT Mean	After ADT Mean	Percent Change	P-Value (one-tail)	Significant (α = 0.05)
Rural Interstate	23780	24885	4.65%	0.110	
Urban Interstate	67539	68670	1.67%	0.113	
Rural Expressway	12363	13008	5.21%	0.011	+
Rural Other Primary	1741	1690	-2.92%	0.116	
Rural Non-Primary	756	806	6.68%	0.022	-

In addition to considering the change in volume between the before and after periods as defined by this study, the percent change in vehicle-miles-traveled (VMT) by system was calculated for the period of 1997 to 2006 (with a base year of 1997) displayed in Figure 69.

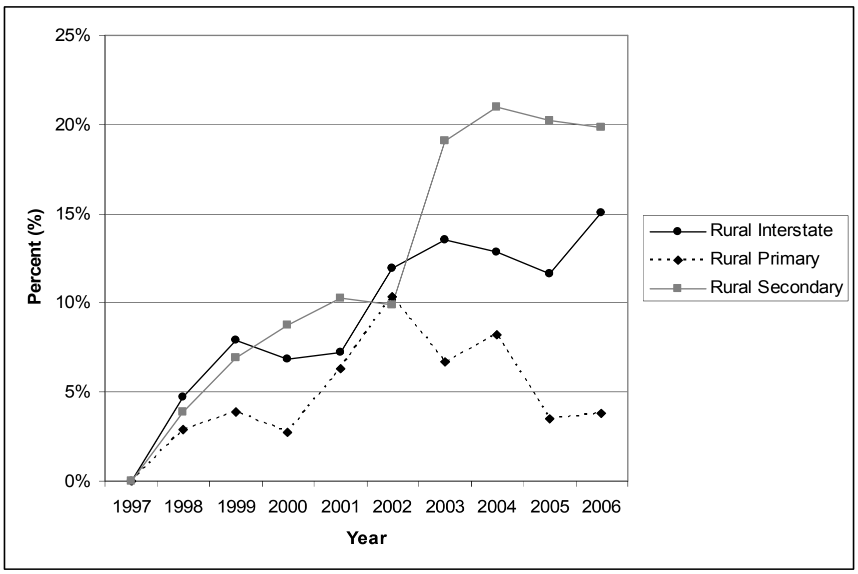

Figure 69. Percent Change in VMT by System

Since 2002, the rural primary system has had a negative trend in VMT. As shown in Table 6, the mean ADT of *rural other primary* highways have decreased in the after period. However, the mean ADT of *rural expressways* has increased in the after period. With a total mileage extent of 7,040 miles for all rural primary roads in 2004 (as calculated by this research), only 1,155 miles were attributed to the *rural expressways* which indicates the majority of the rural primary system is composed of *rural other primary* highways. This therefore suggests that the decrease observed for the *rural other* *primary* mean ADT is actually part of a larger trend that began in 2002 and is not related to the *rural interstate* speed limit change.

5.8 Rural Interstate Crash Trend Analysis

A crash trend analysis was completed for the *rural interstates*. *Rural interstates* were selected for this analysis because the speed limit was changed on this system only. The crash frequency for fatal, fatal and major injury and all crashes were plotted such that each data point represents the one-year running average, moderating any significant change of the observed monthly crash frequency. The trend lines were fit to the before period data and extrapolated through the after period data. To offset the effect of volume change, each observation was normalized by the rural interstate ADT. For each data point, the *rural interstate* ADT observed for the middle month of each data point was divided by the ADT observed in June, 2005. The raw crash frequency for each data point was then multiplied by this "volume ratio". This calculation adjusted the crash frequencies to a value expected if the traffic volume observed for June, 2005 was constant throughout the analysis period.

Adjusting the crash frequency by the ADT assumes a linear relationship between crashes and traffic volume. However, other research suggests the relationship between crashes and volume is not linear but rather logarithmic as illustrated in Figure 70. Therefore it was necessary to make the assumption that by selecting a small range of traffic volumes, the relationship between traffic volume and crashes is nearly linear as shown in Figure 70. An insert was placed onto the figure to provide a visual of the assumption of a linear relationship. It was assumed that the range of ADT from June, 2003 to June, 2006 was small enough to assume a linear relationship.

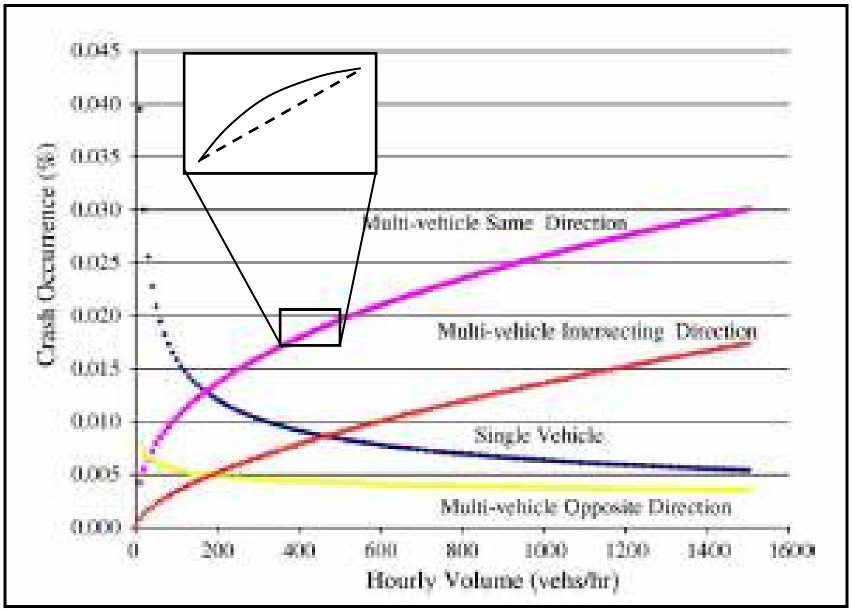

Figure 70. Relationship of Crashes to Traffic Volume (Qin et al., 2006)

Figures 71 through 73 display the results of *rural interstate* crash trend analysis. Figure 71 displays a trend analysis for fatal crashes on *rural interstates*. During the before period, eight observations are below the trend line whereas the after period has only two observations below the trend line.

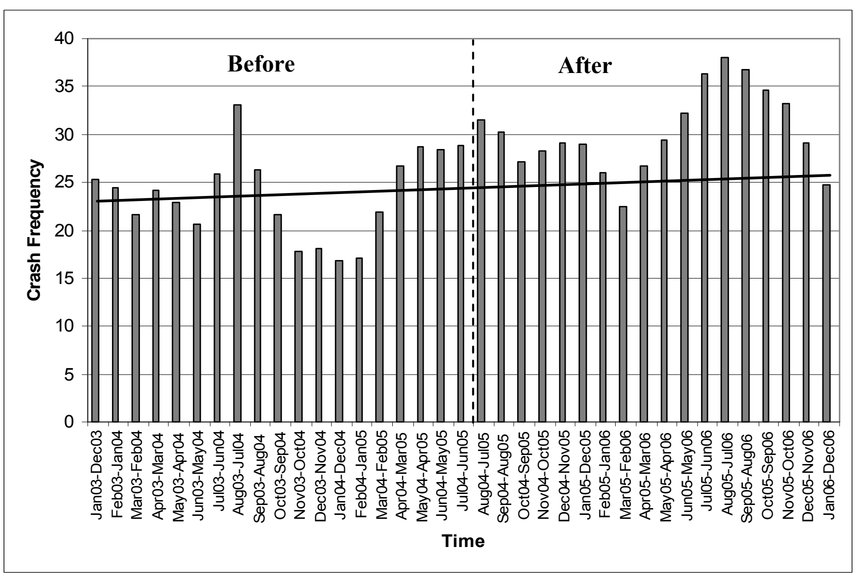

Figure 71. Rural Interstate Fatal Crash Frequency Trend Analysis

Figure 72 displays the *rural interstate* trend analysis for fatal and major injury crashes. During the before period there were seven observations below the trend line. In the after period, there were six observations below the trend line. By visual inspection, the trend line appears to be consistent with the after period observations.

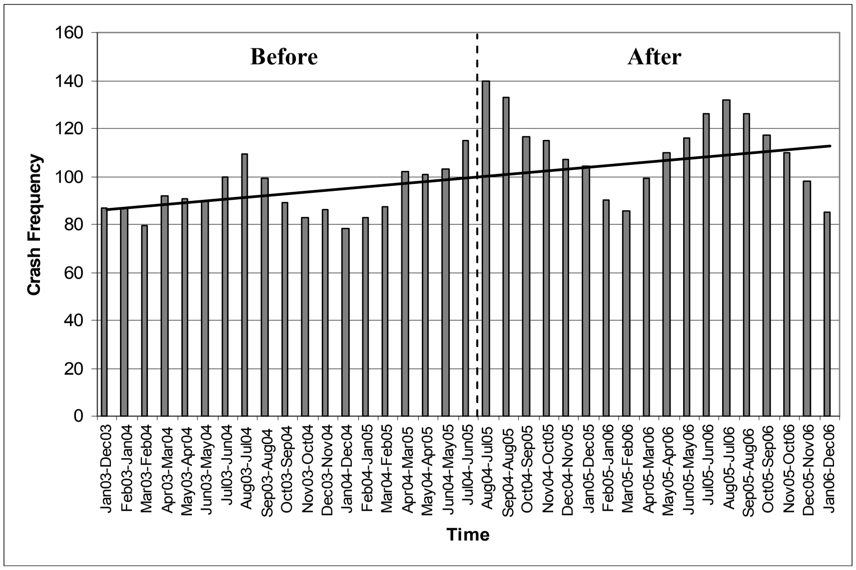

Figure 72. Rural Interstate Fatal and Major Injury Crash Frequency Trend Analysis

Figure 73 displays the *rural interstate* trend analysis for all crashes. During the before period there were nine observations below the trend line. In the after period, there were eight observations below the trend line. Just as shown in Figure 72, the trend line appears to be consistent with the after period observations.

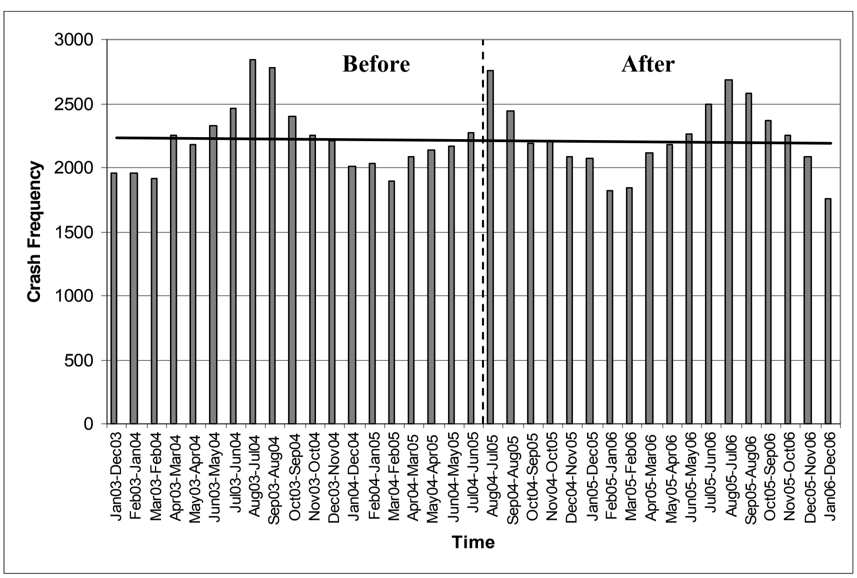

Figure 73. Rural Interstate All Crash Frequency Trend Analysis

The difference between the expected mean crash frequency and the observed crash frequency in the after period was then calculated and is summarized in Table 7. The observed average frequency was calculated by computing the average of the data points in the before period. The expected average frequency was estimated by the average value of the trend line which was obtained by estimating the value of the trend line at the middle of the before and after periods. For example, the middle of the before period would be located at the observation titled "Oct.03 – Sep.04." The difference between the observed and expected was then calculated. As expected, the difference between the observed and expected mean crash frequencies of the before period are equal to zero or near zero. Relative to the size of the observed and expected values, the most substantial difference between the observed and expected mean crash frequencies is fatal crashes.

Table 7. Rural Interstate Crash Trend Results

Crash Severity	Period	Observed Average Frequency	Expected Average Frequency	Difference
Fatal	before	24	24	0
	after	30	25	5
Fatal and Major Injury	before	93	93	0
	after	112	107	5
All	before	2217	2210	7
	after	2232	2175	57

5.9 Parallel Routes

The following figures and table report the results of the comparison of speeds and traffic volume between corresponding ATRs from *primary parallel* routes and *rural interstates*. Figure 74 displays the ATR sites that were used for this analysis. The *primary parallel* route to I-35 was established as US-65 while the *primary parallel* route to I-80 was established as IA-92. The analysis period for the speed measurements was August, 2004 to December, 2006. The analysis periods for the traffic volume included a before period of July, 2003 to December, 2004 and an after period of July, 2005 to December, 2006.

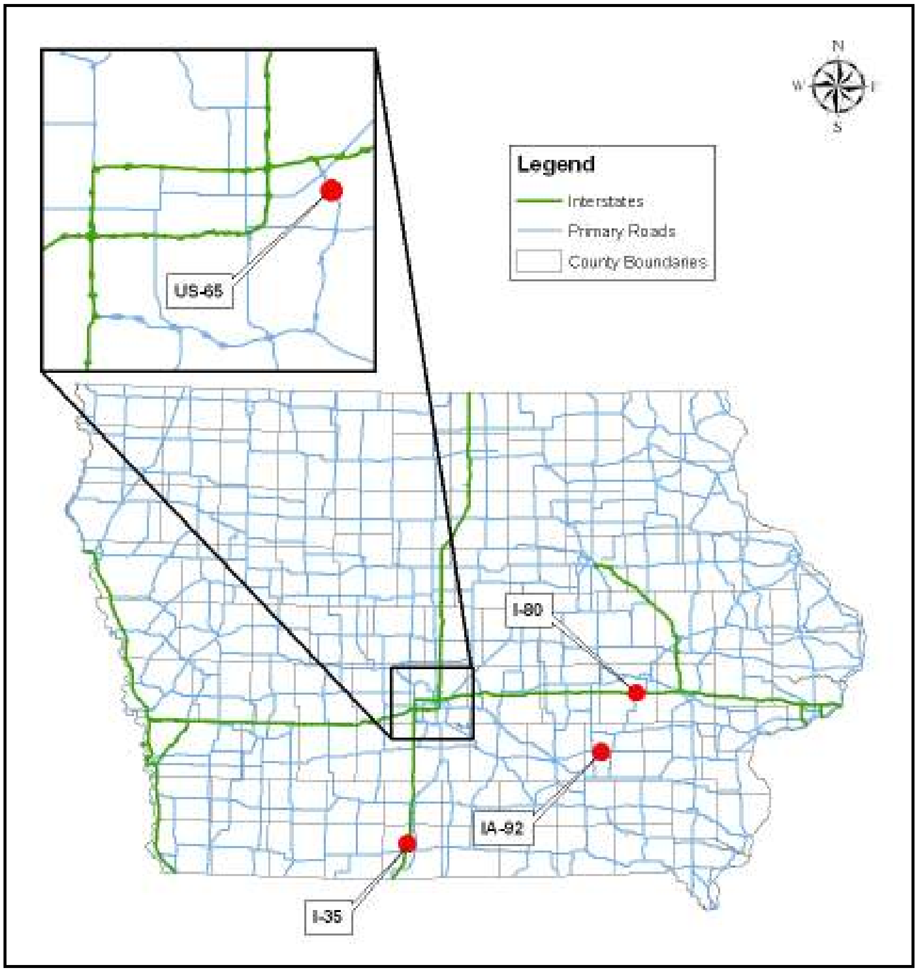

Figure 74. Parallel Routes ATR Sites

Figures 75 and 76 display the observed speeds for both route pairs. Figure 75 displays the observed speeds for the US-65 and I-35 sites. As expected, the average and 85th percentile speeds of I-35 increased after the speed limit change on the *rural interstates*. The average and 85th percentile speeds of US-65 are observed to have an increasing trend.

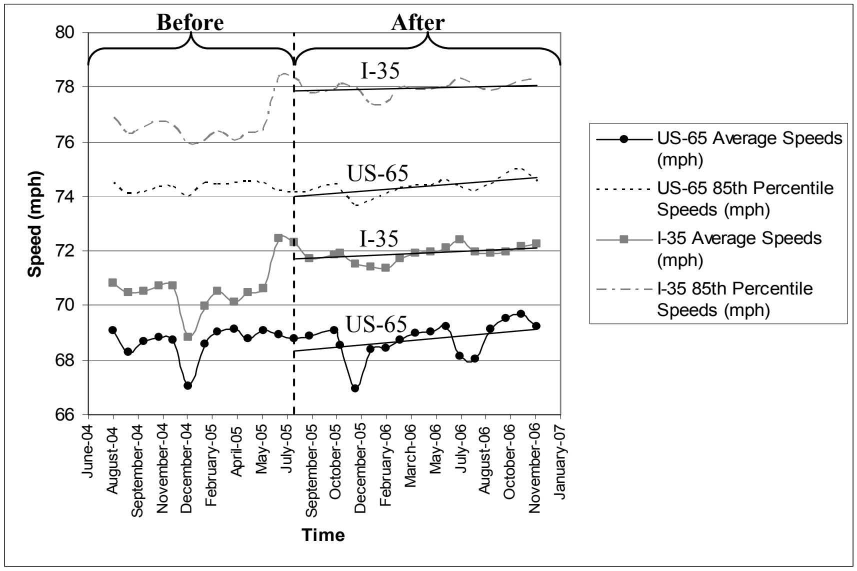

Figure 75. Comparison of US-65 and I-35 Speeds

Figure 76 displays the observed average and 85th percentile speeds for the IA-92 and I-80 sites. Similar to the observed speeds of I-35 in Figure 74, the average and 85th percentile speeds of I-80 increased after the *rural interstate* speed limit change. The average and 85th percentile speeds of IA-92 experienced nearly no changes after the *rural interstate* speed limit change.

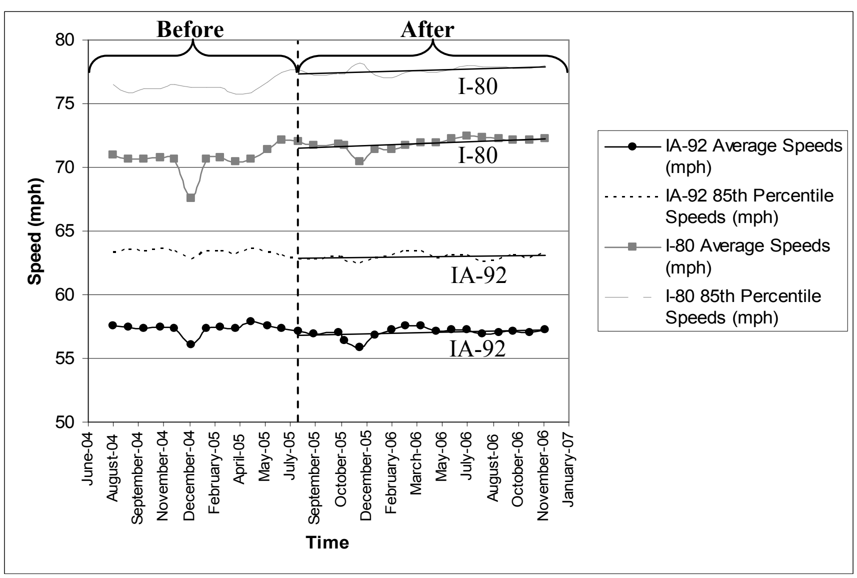

Figure 76. Comparison of IA-92 and I-80 Speeds

Table 8 displays a comparison of the average and 85th percentile speeds, and ADT observed at each site. A two-sample t-test assuming unequal variances was computed for the three metrics at a 95 percent confidence level. The null hypothesis was that there was no change in the before and after means while the alternative hypothesis was that the after period mean was greater than or less than the before period mean (one-tailed). The analysis period for the average and 85th percentile speeds comparison included a before period of August, 2004 to June, 2005 and an after period of August, 2005 to June, 2006. The analysis period of the ADT comparison included a before period of July, 2003 to December, 2004 and an after period of July, 2005 to December, 2006.

As expected, the means of the average and 85th percentile speeds of the I-80 and I-35 sites were significantly higher in the after period. For IA-92, the after period mean 85th percentile speed was significantly lower than the before period mean. A significant increase in the ADT on US-65 has occurred in the after period. In summary, there is no observable shift in traffic from the *primary parallel* routes to the interstates. Additionally, there is no observed speed spillover from the *rural interstate* to the *primary parallel* routes.

Table 8. Comparison of Parallel and Interstate Routes

Route	Metric	Before	After	Percent Change	P-Value (one-tail)	Significant (α = 0.05)
IA-92	*Average Speed*	57.3	57.0	-0.61%	0.348	
	85th Percentile Speed	63.4	62.9	-0.69%	0.000	-
	ADT	2825	2738	-3.05%	0.107	
I-80	*Average Speed*	70.5	71.7	1.70%	0.001	+
	85th Percentile Speed	76.2	77.5	1.66%	0.000	+
	ADT	31858	31740	-0.37%	0.463	
US-65	*Average Speed*	68.7	68.6	-0.04%	0.460	
	85th Percentile Speed	74.4	74.2	-0.20%	0.079	
	ADT	23734	25519	7.52%	0.014	+
I-35	*Average Speed*	70.3	71.8	2.07%	0.000	+
	85th Percentile Speed	76.4	77.9	1.98%	0.000	+
	ADT	13526	13355	-1.27%	0.349	

5.10 Rural Interstate Traffic Citations

The ratio of *rural interstate* electronic speeding citations to all *rural interstate* electronic citations was calculated per month for the period of January, 2004 to December, 2006. Figure 77 displays the calculated ratios for each month. Immediately following the change in the *rural interstate* speed limit, the months of July, October, and November of 2005 recorded a relatively higher ratio. Overall, there is observed to be no observable change in the ratio of electronic speeding citations to all electronic citations on the *rural interstate*.

The Iowa State Patrol reported that there was an increase in enforcement of the *rural interstates*. Because there was no observable change in the trend of the ratio of electronic speeding citations to all electronic citations, it suggests that there was no increase in the number of speeding citations issued in the after period. This may be a result of drivers reacting to a greater presence of law enforcement, thereby maintaining their speeds within the tolerance of the Iowa State Patrol.

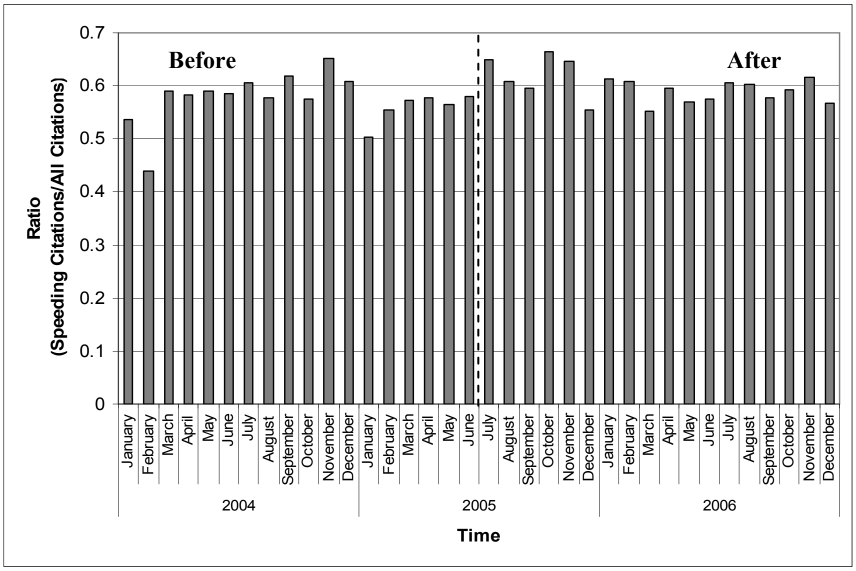

Figure 77. Ratio of Rural Interstate Electronic Speeding Citations to All Rural Interstate Electronic Citations Reported by the Iowa State Patrol

5.11 Effect of Retail Gasoline Price

Retail gasoline prices in Iowa were plotted with the *rural interstate* ADT, and average and 85th percentile speeds. Figures 78, 79, and 80 display a comparison of retail gasoline prices and *rural interstate* speeds and traffic volume over time. Figure 78 compares *rural interstate* average monthly traffic volume and the retail gasoline price over time. Initially it was thought that if the gasoline price increased, drivers might limit their discretionary travel. The growth of the traffic volume trend appears to have no interaction from the increase in the retail gasoline price in the recent time period. Although the retail gasoline price is presently much higher than in the recent past, it apparently has not affected drivers' choices of travel.

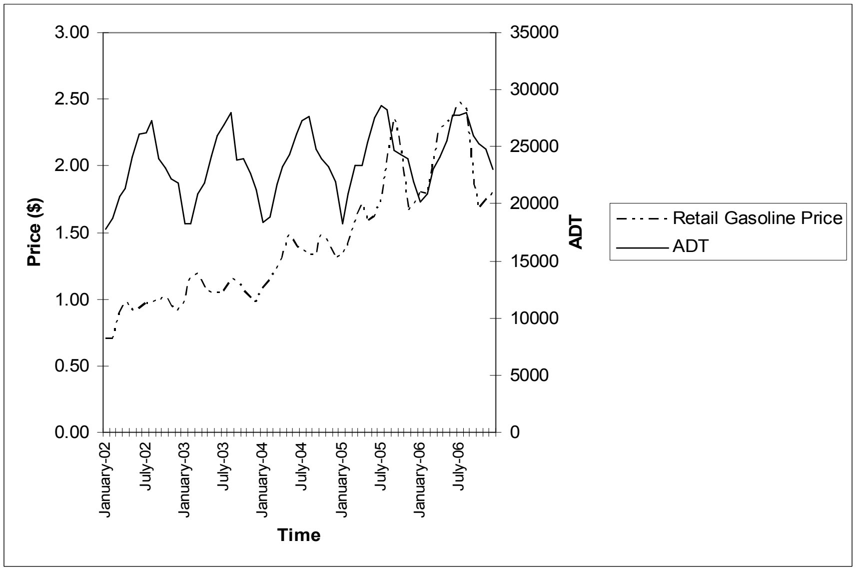

Figure 78. Rural Interstate ADT and Retail Gasoline Price by Time

To further investigate the relationship between *rural interstate* ADT and retail gasoline prices in Iowa, the ratio of *rural interstate* ADT and the retail gasoline price was calculated between corresponding months of 2006 and 2005 and is displayed in Figure 79. If the *rural interstate* ADT ratio decreased due to a dramatic increase in the retail gasoline price, the *rural interstate* ratio would decrease. The trend of the retail gasoline ratio is observed to be greater than one nearly throughout the entire analysis period, indicating the price was greater in 2006 than 2005. However, the ratio of the rural interstate hovered at approximately one without a negative trend. Because this ratio did not substantially deviate, it provides additional evidence that the higher retail gasoline price did not affect the amount of travel.

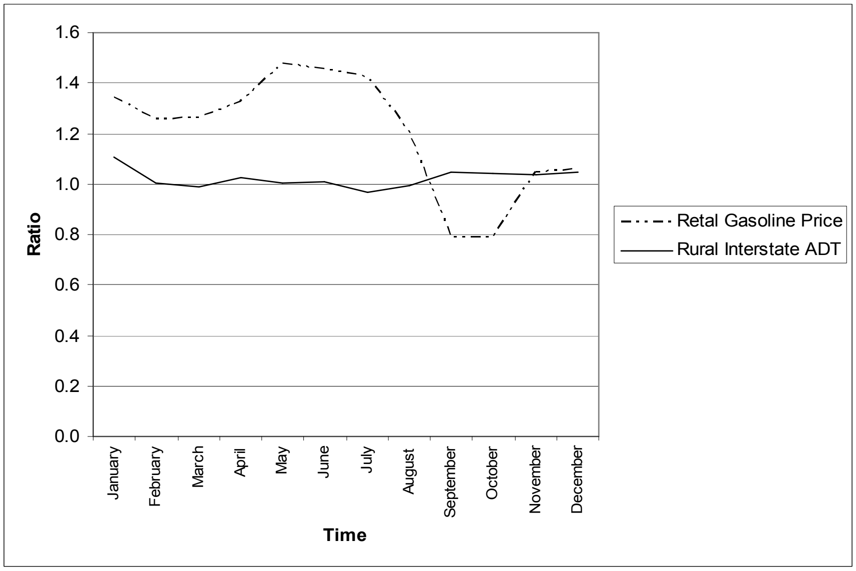

Figure 79. Ratio of Rural Interstate ADT and Retail Gasoline Price by Time

Figure 80 displays a plot of the *rural interstate* average speed to the retail gasoline price over the period of January, 2002 to December, 2006. For both the average speed and retail gasoline price, each data point is a three month running average. After the speed limit change, drivers' choice of speed did not appear to be affected by the increased retail gasoline price.

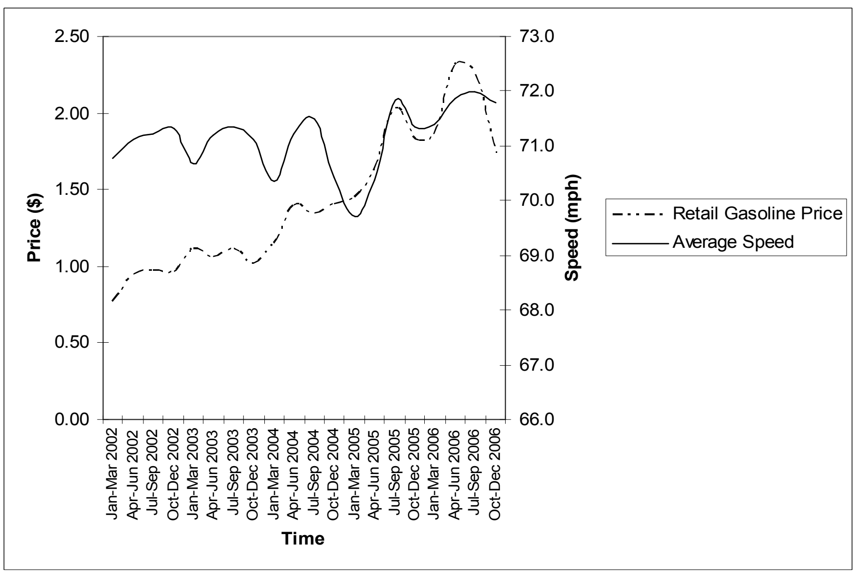

Figure 80. Rural Interstate Average Speeds and Retail Gasoline Price by Time

6.0 Summary and Conclusions

This chapter conducted crash, speed and traffic volume analysis for *rural interstates*, *urban interstates*, *rural expressways*, *rural other primary* highways, and *rural non-primary* roads. In addition, a study of electronic traffic citations issued on the *rural interstate* and the effect of retail gasoline prices on drivers was also completed.

The *rural interstates* experienced an increase in fatal crashes of 37.9 percent over the before period. Other severity categories also increased. However, the increases were not statistically significant at the 0.05 level but were significant at the 0.10 level. Additionally, it was found that the *rural interstates* did experience an increase in the severity of crashes. This increase in the crash severities is observed to be related to the increased speed limit resulting in more crashes that are more severe. The most striking results for the *rural interstates* were an 89.3 percent increase in fatal nighttime crashes. In contrast, *rural interstate* daytime fatal crashes increased by only 10.4 percent. These results indicate that an increase in the more severe crashes occurred during the night. These results make sense when one considers the results in the context of a decrease in drivers' nighttime perception and reaction times.

Fatal crashes were the only crash severity to increase on *urban interstates* (6.8 percent). All other crash severities decreased in frequency. *Urban interstates* are observed to have experienced a similar pattern to that of *rural interstates* with respect to an increase in the severity of the crashes. However, none of the changes were found to be statistically significant at the 0.05 level.

The *rural expressways* crash severities decreased with fatal crashes decreasing by 17.7 percent (the largest decrease for this road type). However, none of the changes were found to be statistically significant. The crash severity with the smallest decrease was fatal and major injury crashes at 2.8 percent.

Rural other primary highway crashes experienced a relatively large increase in fatal crashes at 33.4 percent. This increase was also found to be statistically significant. A 2.3 percent increase occurred when major injury crashes were included with those that were fatal. All crashes decreased 2.2 percent. This suggests an increase in crash severity not consistent with the decrease in speeds. It should be noted that it is not concluded that the significant change in fatal crashes was not related to the speed limit change but rather a result of some other phenomenon.

Rural non-primary roads experienced a decrease in all crash severities. Finally, when all road types were combined, the only crash severity to increase was fatal crashes at 6.8 percent. When the crashes for each road type were adjusted by traffic volume, there was little change due to a small change in traffic volume.

After the *rural interstate* speed limit change, the *rural interstate* average and 85^{th} percentile, and percent exceeding 80-mph are observed to be slowly increasing over time. Comparing the before and after periods, both the *rural interstate* average and 85^{th} percentile speeds significantly increased at the 0.05 level. All other road types' average and 85^{th} percentile speeds decreased during the after period. Both 55-mph and 60-mph *urban interstate* segments had a statistically significant decrease in the 85^{th} percentile speed only. Both the average and 85^{th} percentile speeds for *rural expressways* and *rural other primary* highways decreased significantly.

The *rural interstates* experienced an increase in traffic volume by 4.65 percent. The only road type to have a decrease in the traffic volume was *rural other primary* highways at 2.92 percent. However, the decrease in the after period was not statistically significant at a 0.05 level. Since *rural other primary* highways were the only road type to report a significant increase for any crash severity, it is possible the adverse effects in the after period could have been much worse if the change in traffic volume increased as it did for other road types.

Urban interstates experienced lower growth than *rural interstates* with an increase of 1.67 percent. Only the *rural expressways* and *rural non-primary* roads had a statistically significant increase in traffic volume.

The ratio of *rural interstate* electronic speeding citations to all *rural interstate* electronic citations appears to remain constant during the after period. The level of enforcement was reported to have increased after the *rural interstate* speed limit change. Although the percentage of drivers exceeding 80-mph is observed to be slowly increasing over time after the change in the speed limit, as shown in Figure 16, in conjunction with a reported increase in the level of enforcement, there still was no apparent relative increase in the number of speeding citations. This may result from the enforcement lasting only a short time after the speed limit change. Additionally, this may be an indication that driver behavior (eg. exceeding the speed limit) was not much different in the after period.

Finally, the comparison between the retail gasoline price in Iowa and the *rural interstate* vehicle speeds and traffic volume suggest the higher gasoline price did not have an effect on driving behavior. It was initially thought that because of the recent increase in the gasoline price, drivers might have changed their behavior by traveling less or slowing down to conserve gasoline. Therefore, if drivers did alter their behavior, the change may have "canceled" out some of the potential adverse effects due to the increased speed limit. Because there appeared to be no impact on the amount of travel and speeds that could be attributed to the higher gasoline prices, it is concluded there was no effect on safety.

In conclusion, the frequency of fatal crashes increased rather substantially on the *rural interstate*, especially at night. No type of spillover effect from the *rural interstates* in terms of speeds or crashes was observed.

7.0 Recommendations

This thesis only included in the analysis of *rural interstates* those crashes occurring on mainline segments. It was assumed that these crashes would provide the best representation of the effect of free flow speed conditions after the speed limit change. However, future studies could include crashes occurring on off-ramps. These crashes may also be related to the speed limit as in some instances drivers may overestimate the speed of their vehicle while exiting the interstate and then run off the ramp.

The change in *rural interstate* fatal, and fatal and major injury crashes are very close to being statistically significant. Because this study consists of a relatively short after period, it is possible that by extending the after period, the *rural interstate* may be calculated to have had statistically significant increase for the most severe crash severities. It is recommended that more data will need to be collected to make a more thorough judgment of the impact of the 70-mph speed limit.

Because the analysis period of the effect of the retail gasoline price included the time of the speed limit change, it may have been a confounding factor. For example, because the speed limit increased from 65-mph to 70-mph, it was shown drivers increased their speeds even though retail gasoline prices continued to increase. As illustrated by this behavior, it appears most drivers will drive at the maximum allowed speed limit plus some implicit or assumed tolerance value. To further investigate the effect of the retail gasoline price on driver behavior, it would be beneficial to included time periods that are separated by at least six months from any speed limit change and that had a substantial change in the price of gasoline.

Future research conducted on traffic citations could construct a safety performance model that includes traffic citations as an additional variable to typical variables such as segment length, speed, and traffic volume. With the addition of a traffic citation variable, this model may improve safety evaluations.

Kockelman (2006) reported many factors that could be accounted for in safety evaluations such as this. When additional data becomes available in Iowa, it may be very beneficial to construct a model to account for these various factors such as demographic changes, infrastructure improvements, change in vehicle type, change in police enforcement and weather. Because this research conducted a simple before and after study, other methodologies could be used in a future study. Kockelman (2006) suggests that before and after studies can be "naïve" in that they do not account for various factors such as weather, police enforcement, etc. Types of methodologies that have been performed by other safety evaluations which could be used in Iowa include time series, regression, Bayesian statistics, and autoregressive integrated moving average (ARIMA) models (Ledolter and Chan, 1996; McKnight and Klein, 1990; Ossiander and Cummings, 2002; Raju et al., 1998; Rock, 1995; Sidhu, 1990; Vernon et al., 2004).

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Chapter 3. Speed Adaptation Effects of Differential Speed Limits in Rural Iowa

1.0 Introduction

The difference in speed limits between two transportation facility types presents a special scenario for highway safety research. When entering a lower speed facility after some time at the higher speed, drivers may not appropriately adjust their vehicle speeds to reflect the posted speed limit. This situation may present a safety hazard for vehicles and pedestrians that are located in the lower speed environment and must negotiate safely among vehicles that might be traveling faster than the speed limit.

Additional interest in driver behavior in Iowa was created after the increase in the rural interstate speed limit from 65-mph to 70-mph on July 1, 2005. Of concern was whether the higher rural interstate speed limit might produce adverse safety effects on rural primary highways in close proximity to the rural interstates. With the rural interstates posted at 70-mph and most rural primary highways posted at 55-mph, a speed limit differential of 15-mph was created between the two facility types.

Because of the higher rural interstate speed limit, the speed limit differential between the interstates and those nearby primary facilities may have produced an immediate effect resulting in higher vehicle speeds onto rural primary highways. Drivers who operate vehicles on an interstate with a posted speed limit of 70-mph for an extended period of time and then exit the interstate onto a rural primary highway with a posted speed limit of 55-mph may tend to travel at higher speeds than they should. This effect has been identified as speed or velocity adaptation (Casey and Lund, 1987; Denton, 1976; Matthews, 1978; Schmidt and Tiffin, 1969). The effect of speed adaptation may occur when a driver encounters a speed limit differential after being conditioned to a higher speed facility; this conditioning may influence their immediate driving behavior on the lower speed facility.

Matthews (1978) terms the effect drivers experience exiting a higher speed facility onto a lower speed facility as “velocity adaptation”. He defines it as “a marked underestimation of the speed at which the driven car is traveling immediately upon encountering a slower traffic environment.” Casey and Lund (1992) refer to this effect as “speed adaptation” which is a “…sensory response of people when they experience a change in relative motion.” Today, a more widespread use of vehicle technology such as cruise control may have reduced or eliminated this effect. This report will attempt to determine if the speed adaptation effect exists in rural Iowa and if so, over what distance the effect lasts. By researching the speed adaptation effect, this report may help clarify the effect a 15-mph speed limit differential between two facilities in close proximity has on driver behavior.

2.0 Review of Literature

An earlier study that attempted to demonstrate the speed adaptation effect was conducted by Schmidt and Tiffin (1969). The study asked ten subjects to drive a vehicle while the experimenter observed the driver’s behavior from the passenger seat. The vehicle used in the experiment had the speedometer removed from the instrument panel and remounted in an unfixed box on top of the dashboard. When necessary for the driver to observe the vehicle’s speed as required by the experiment, the box with the speedometer was simply turned so the driver could see the current speed. The box could also be turned away from the driver when necessary. The experiment was conducted on a four-lane, limited access highway with a speed limit of 70-mph. During the experiment, the subject was asked to estimate the speed of the vehicle after driving for different lengths of time. After driving at these different time intervals, the driver was asked to allow the vehicle to naturally slow down without the assistance of brakes and notify the experimenter when he thought that the vehicle was traveling at 40-mph without the assistance of the speedometer. As the length of the time interval at which the driver was traveling 70-mph increased, the speed at which the vehicle was traveling when the subjects estimated the vehicle had slowed down to 40-mph also increased. One of the subjects noted after the experiment that, "You have to seem to be crawling to do 40-mph after driving 70-mph."

A similar study conducted by Denton (1976) used a driving simulator to detect the speed adaptation effect. The results of the study suggested that when a driver must make a large reduction in the vehicle's speed following a long period of time driving at high speeds, a distortion in perceived speed due to speed adaptation may be produced.

Matthews (1978) employed a method that identified the speed adaptation effect by measuring vehicle speeds at locations where vehicles were entering a lower speed facility from a higher speed facility and vice versa. For this study, the field site was a divided highway which ran north and south with the southern portion terminating at a T-intersection allowing access to a high-speed expressway. The expressway had a posted speed limit of 97 km/hr (60-mph), the southern end of the divided highway was posted at 80 km/hr (50-mph), and the northern end of the divided highway was posted at 64 km/hr (40-mph) where it entered a more urban area. Two observation points were located in the section of the divided highway that had a posted speed limit of 50-mph. Vehicles were observed for two two-hour periods which coincided with the morning and afternoon peak traffic periods. The study found that for all vehicle classifications, speeds of vehicles in the northbound direction (coming from the expressway) were significantly higher than those vehicles in the southbound direction (coming from the lower speed urbanized area). It was also reported that the difference in speed between north and southbound commercial vehicles was significantly lower than for non-commercial vehicles. The research concluded that drivers were apparently still adapting six minutes after exiting the expressway.

A similar study conducted by Casey and Lund (1987) referred to Matthews (1978) term of velocity adaptation as speed adaptation. Three field sites were selected for this study. At each site, vehicles were observed exiting various facility types to a connecting road. Vehicle speeds were then observed on the connecting road. Those vehicles exiting a facility such as a freeway and entering a lower speed environment were defined as "speed adapted" while vehicles traveling on the connecting road were defined as "non-speed adapted". For the first two test sites, "speed adapted" vehicles were traveling significantly faster than "non-speed adapted" vehicles. The third test site had an average speed of "speed adapted" vehicles that was faster than that of "non-speed adapted" vehicles; this difference was not statistically significant.

3.0 Hypothesis

This study attempted to determine if the speed adaptation effect exits in rural Iowa. If the effect does exist, this study also attempted to determine over what distance the effect lasts. As noted by Schmidt and Tiffin (1969), drivers that had been traveling at higher speeds for a sustained period of time reported the sensation that a lower speed felt as though the vehicle was barely moving. It is this conditioned state that this study attempted to capture.

It was hypothesized that vehicles exiting from the rural interstate onto a rural primary highway will travel at higher speeds than those vehicles that have been traveling on the rural primary highway. It was also hypothesized that the speed adaptation effect will wane as the driver travels along the rural primary highway. Those vehicles that have exited the interstate will be identified as experimental vehicles. Other vehicles located on the rural primary highway are identified as control vehicles. Any type of effect in terms of higher vehicle speeds should be identified as the existence of the speed adaptation effect of vehicles exiting the rural interstates onto the rural primary highways.

4.0 Methodology

The speed adaptation effect is thought to occur in locations where drivers exit a high-speed facility and enter a lower-speed facility. Therefore, when studying this effect, it was desirable to find two adjacent facilities (one being a rural interstate) with mutual access and a large speed limit differential. The locations that best support these criteria are rural interstate interchanges. Study sites were selected at locations in which a rural two-lane undivided primary connected to a rural interstate. At these rural interstate interchanges, ramps provide access to a county or state highway. In this thesis, rural primary highways that intersect an interstate are categorized as intersecting highways.

4.1 Selection of Sites

Several characteristics were required for an intersecting highway segment to be considered as a study site. First, the study segment was required to be located in a rural area, which, by definition, was to be located outside any corporate limits. Second, the intersecting highway was required to have a minimum length on at least one side of the interstate of six miles of uninterrupted flow. For an intersecting highway to have uninterrupted flow, the intersecting highway could not enter any corporate limits, require vehicles to stop at an intersection along the study segment's length, or have a small radius horizontal curve thereby requiring vehicles to slow. Any roadway characteristic which interrupted the traffic flow would interfere with the study of the speed adaptation effect. Third, the posted speed limit on the intersecting highway was required to be 55-mph. Fourth, stop control was required for vehicles exiting the interstate on the exit-ramp thus requiring vehicles to stop before entering the intersecting highway. And fifth, all sites were required to be located near Iowa State University in Ames, Iowa for economy of the study. These criteria limited the study sites to locations along I-35 in central Iowa.

After reviewing potential study sites, a total of four were selected. For each study site, the test section was located on the east side of I-35. All four sites were located on flat terrain with no horizontal curves. Aerial views of three of the sites are shown in Figures 82 through 84. The fourth site was eventually eliminated from the study because of data corruption that occurred during the data collection process. As shown in Figure 81, two county highways and one state highway, each with speed limits of 55-mph were selected for this study. During an initial visit to each of the study sites, the shoulder type was noted for each highway segment. The state and county highways had aggregate shoulders. The state highway was estimated to have a shoulder width of four feet while the county highways were estimated to have a shoulder width of two feet. It was assumed that the shoulder width of these facilities would not have an effect on a driver's choice in speed while driving on the intersecting highway.

4.2 Measurement of Vehicle Speeds

Vehicle speeds were measured by Jamar Technologies, Inc. automatic traffic recorders (ATRs). Two models of ATRs were used, the Trax Plus HS and Trax I. These models use mini road tubes, two for each ATR. A total of six ATRs were used at each study site. The data were collected during March and May of 2007. While collecting data, the study sites were visited frequently to confirm that the ATRs had not been disturbed.

The ATRs assign a time-stamp and classification to each vehicle. Since the ATR's times are synchronized, a vehicle that had exited from the interstate could be tracked through the study site from one ATR to the next.

Only two vehicle groups were observed for this study in order to prevent confounding variables such as which exit ramp vehicles used to enter the test section. The first vehicle group consisted of northbound vehicles that exited the interstate and then turned east to drive through the test section, and were classified as experimental vehicles. Drivers in this vehicle group were supposed to be conditioned to the higher speed rural interstate. The second vehicle group consisted of westbound vehicles on the intersecting highway traveling through the study site, and was identified as control vehicles. Drivers in this vehicle group were conditioned to the lower-speed intersecting highway.

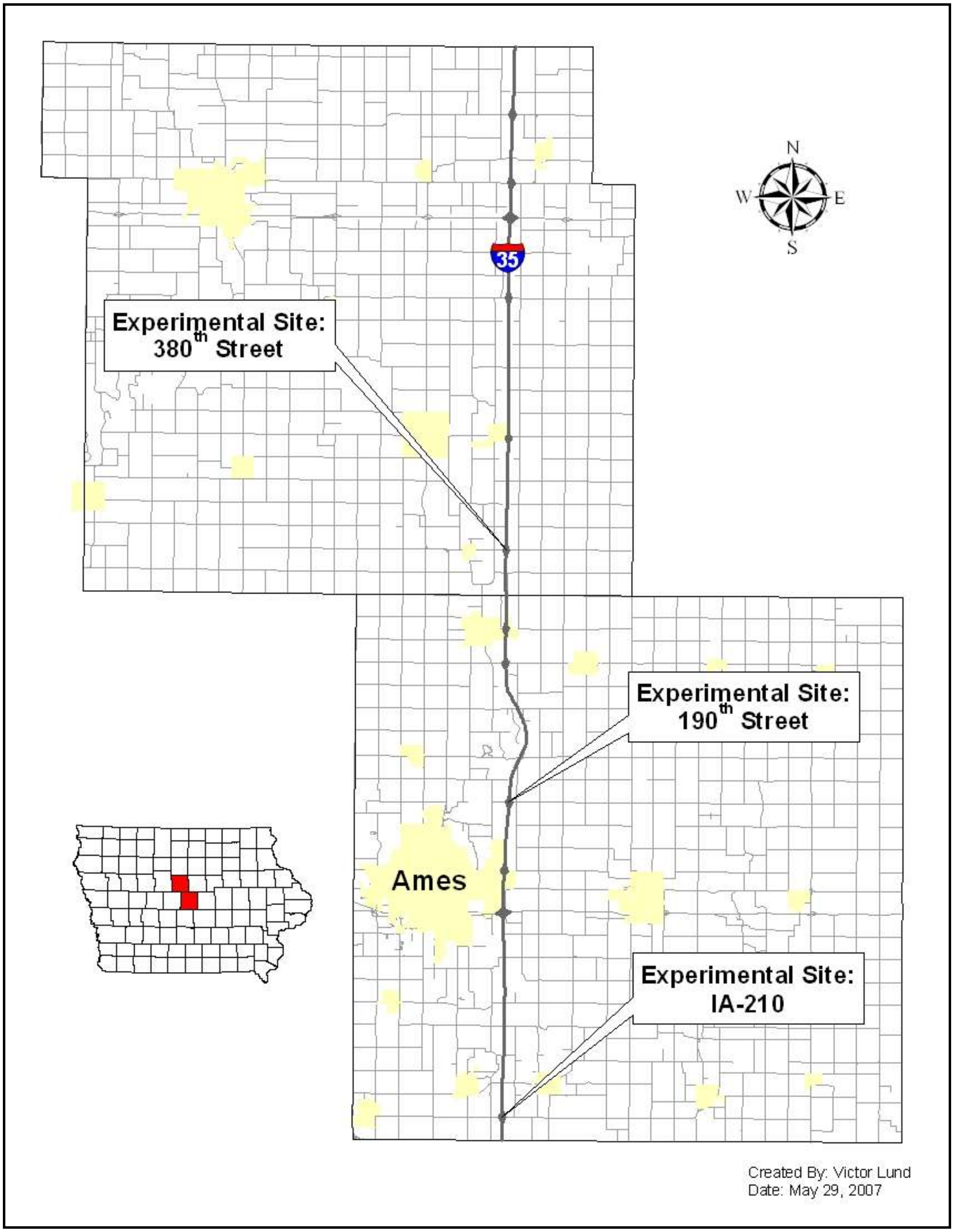

Figure 81. Location of Speed Adaptation Study Sites

Figure 82. Study Site 190th Street

Figure 83. Study Site 380th Street

Figure 84. Study Site IA-210

The first ATR was placed approximately 100 feet from the end of the exit ramp in order to differentiate between vehicles exiting from the interstate and those already traveling east on the intersecting highway. Because of the stop sign at the end of the exit ramp, it was assumed that these vehicles would stop or come to a near stop before turning onto the intersecting highway. Therefore, as the vehicle turned onto the intersecting highway from the exit ramp and crossed this first ATR, it would have a lower speed than other eastbound vehicles. In this way, these vehicles could be identified as exiting from the interstate.

A second ATR was placed at a location where it was assumed that a passenger vehicle which had come from the exit ramp would have time to attain a normal speed. This distance was determined during an initial site visit on February 1, 2007, using the researcher's vehicle. Using a conservative acceleration rate, the distance was found to be 0.3 miles. To assess the validity of this distance, the required acceleration distance was also calculated as the following (Roess, et al. 2004):

$$d_a = 1.075\left(\frac{S^2}{a}\right)$$

Where:

d_a = acceleration distance, ft.

S = speed at the end of acceleration (from a stop), mph

a = acceleration rate, ft/s^2

The value of a was given as 4.6 ft/s^2 for a typical passenger car accelerating to 50 to 60 mph. Assuming the speed at the end of acceleration distance was 55 mph, the distance required to accelerate to this speed was determined to be 706.9 feet which is approximately equal to 0.13 miles. Since this calculated distance is less than the estimated distance of the researcher's vehicle, any typical passenger vehicle which had accelerated from a stop on the exit ramp was assumed to be traveling at the driver's choice of speed by 0.3 miles. The remaining ATRs were placed 0.5, 1.0, 3.0 and 5.0 miles, respectively, from the exit ramp. If a speed adaptation effect was to be observed, these remaining ATRs would determine the length of the effect. Figure 85 displays the placement of the ATRs at the study sites.

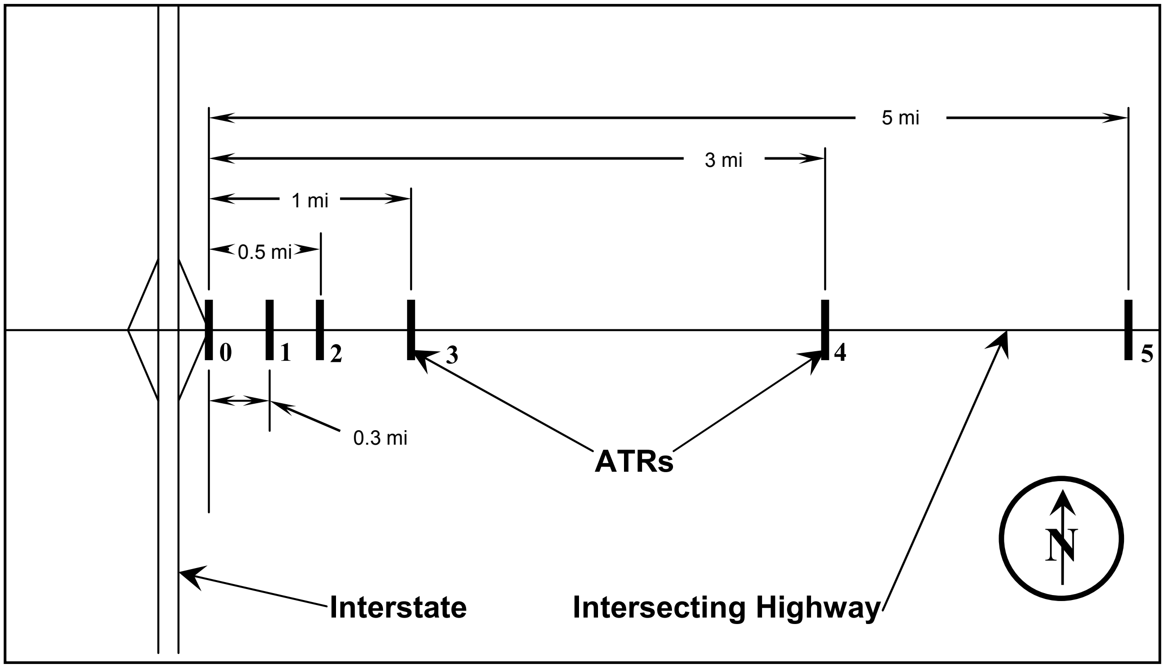

Figure 85. Layout of the ATRs

5.0 Data Analysis

Each ATR was placed in the field on a Monday and retrieved the following Friday. To eliminate irregularities that may exist in the data due to partial day recording for Mondays and Fridays, only Tuesdays, Wednesdays, and Thursdays were reserved for the analysis. While collecting the data, an ATR creates numerous data fields. However, most of these fields were not needed for this analysis. The fields retained were the date, time, lane of travel, vehicle class, and speed. The vehicle classification scheme follows Federal Highway Administration definitions (Jamar Technologies Inc. 2006). All vehicle speeds were recorded in miles-per-hour.

Data from each ATR were exported in Microsoft Excel format. During the export process, the data were refined to eliminate possible errors that occurred in the field. This refining process deleted speed observations under 5-mph and those vehicles that were unclassified. Once the refined data were exported, observations between 12:00am

Tuesday and 11:59pm Thursday were copied into a different spreadsheet as a modified set. The modified set of vehicles was then aggregated by direction of travel.

A common naming convention was created to simplify counter identification (see Table 9 displays this naming convention).

Table 9. Counter Naming Convention

Location	Name
Ramp	Counter 0
0.3 miles	Counter 1
0.5 miles	Counter 2
1.0 miles	Counter 3
3.0 miles	Counter 4
5.0 miles	Counter 5

5.1 Identifying Experimental Vehicles

The purpose of Counter 0 was to identify vehicles that had exited from the interstate (therefore it was only necessary to collect observations of eastbound vehicles). Vehicles exiting from the interstate were easily identified due to the short distance from the counter to the end of the exit-ramp. Because of this short distance, the speeds of vehicles exiting the interstate were lower relative to vehicles already on the intersecting highway. Because of the difference in the speeds of vehicles exiting the interstate and those already on the intersecting highway, two distinct speed distributions were created. To identify the experimental vehicles at Counter 0, a histogram showing the speed distribution of vehicles was created. Figures 86 through 88 display the speed distributions of eastbound vehicles at Counter 0 at each study site.

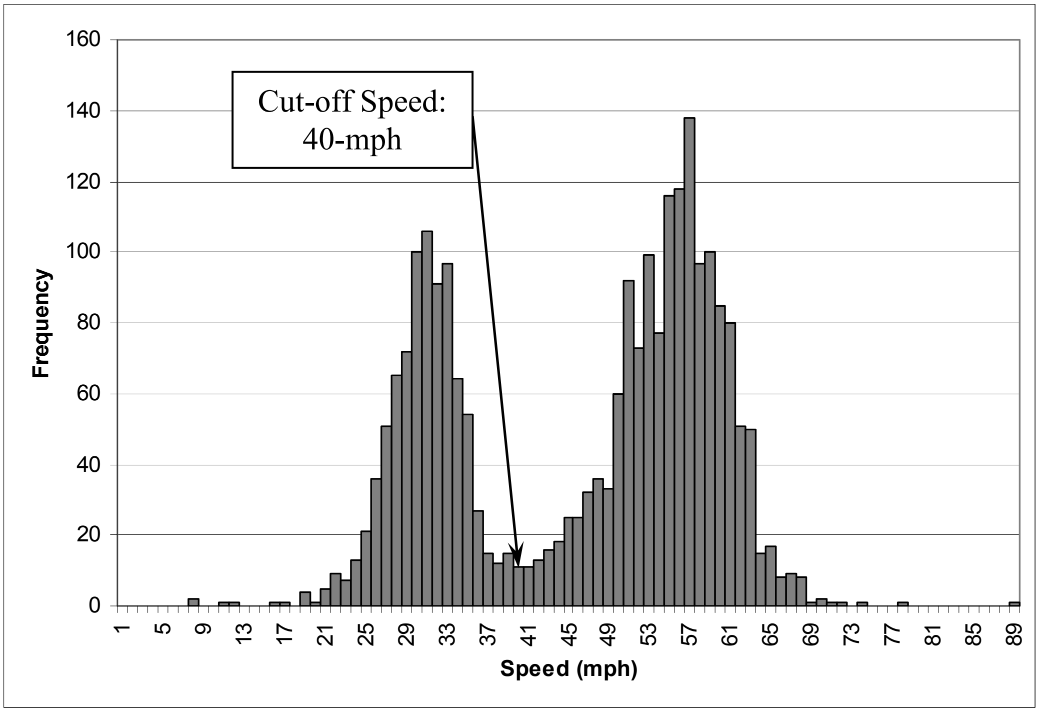

Figure 86. 190th Street Lane One Vehicle Speeds Distribution at Counter 0

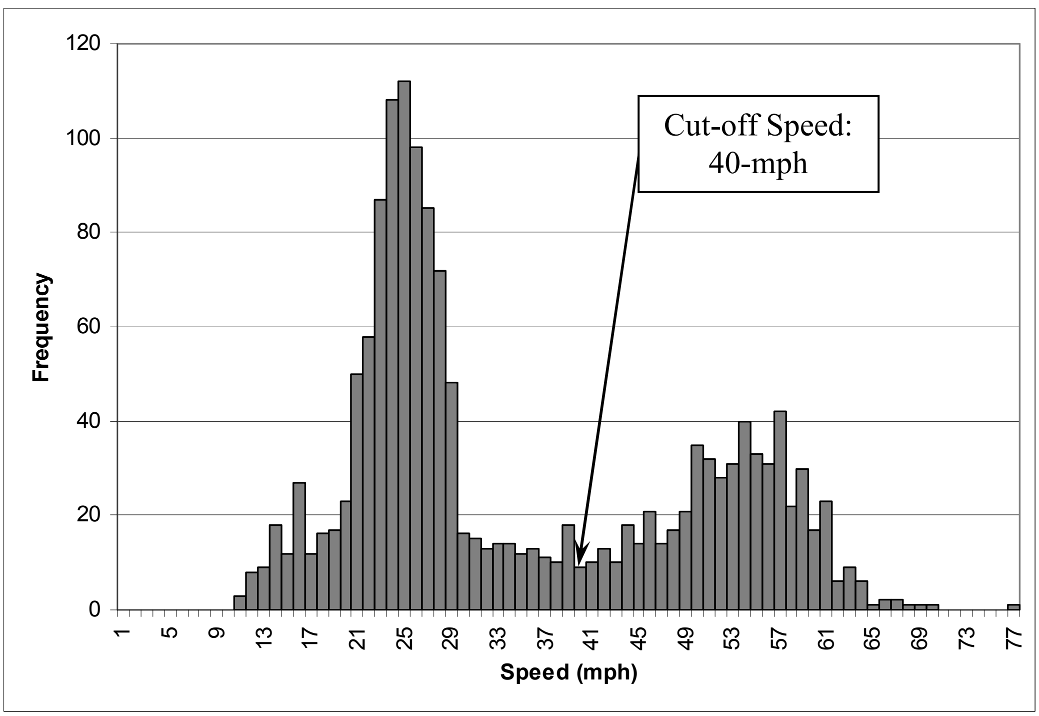

Figure 87. 380th Street Lane One Vehicle Speeds Distribution at Counter 0

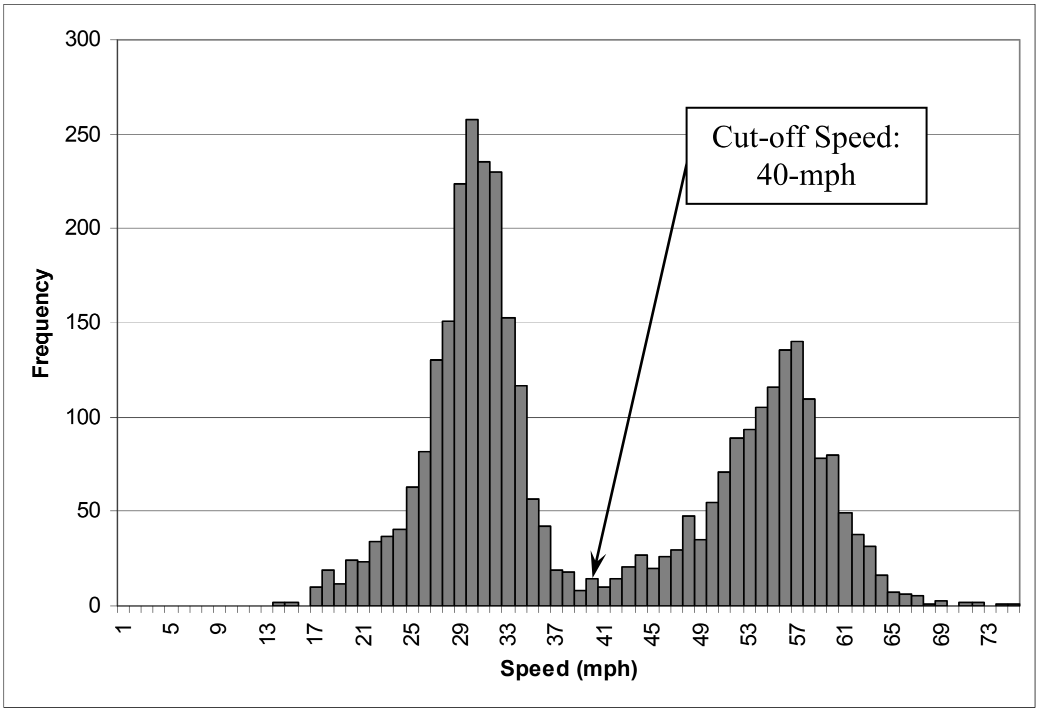

Figure 88. IA-210 Lane One Vehicle Speeds Distribution at Counter 0

The lower speed distribution identifies experimental vehicles while the higher speed distribution to the right identifies those vehicles which were already on the intersecting highway. Because the two distributions are overlapping, a criterion was established to determine what the cut-off speed should be to define the experimental vehicles.

Assuming that the speed distribution is bimodal normal, an appropriate cut-off speed could be a function of the standard deviations of the speed distributions. However, to calculate the standard deviation, the number of vehicles in each distribution must be known. To determine the number of vehicles in the lower speed distribution, a subjective point must be selected between the two distributions. Since the standard deviation of the distribution would therefore be subjective, the cut-off speed was identical to selecting a low-point between the two distributions. This was accomplished by visually estimating the foreslope and backslope of the two distributions as they appear in the chart and then estimating the point at which they intersect. The point where the two estimated slopes intersect was defined as the cut-off speed. For each site, the cut-off speed was 40-mph. Once the cut-off speed was established for each site, the experimental vehicles could be identified by sorting the vehicle speeds at Counter 0. Those vehicles with a speed less than or equal to the cut-off speed were extracted from the list of modified vehicles and identified as experimental vehicles. This process of identifying experimental vehicles was only conducted for Counter 0. Data from all vehicles identified as experimental at Counter 0 and those observed in the eastbound lane at the remaining counters were placed into a Microsoft Excel spreadsheet. Each observation in this spreadsheet was assigned the number of the counter where it was observed. This spreadsheet was then imported into a Microsoft Access database for further analysis.

5.2 Tracking Experimental Vehicles

The next step was to track the experimental vehicles through the study site. Since the ATRs could not communicate with each other so as to track a vehicle through the experimental system, a computer program was written to identify experimental vehicles at each ATR. The program used the date, time, and class fields to identify experimental vehicles at each ATR, and it used a progressive process to track the vehicles through the system. In simple terms, this progressive process operated by using all the experimental vehicles identified at Counter 0 as the basis for identifying those same vehicles at Counter 1. Once all the experimental vehicles had been tracked from Counter 0 to Counter 1, those experimental vehicles identified at Counter 1 were used as the basis for identifying vehicles at Counter 2. This progressive process repeated until all experimental vehicles that had traveled through the experimental system were identified. This type of process was necessary to maintain the accuracy of identifying experimental vehicles. If Counter 0 was the only basis for identifying vehicles at the remaining counters, the error in identifying experimental vehicles would increase as the tracking process moved to ATRs farther from Counter 0. For example, it is very possible that a non-experimental vehicle that crossed Counter 5 may have arrived at the same estimated time of arrival as an experimental vehicle of the same classification that had traveled from Counter 0.

When running the computer program, a range of arrival times of vehicles from previous counters and the vehicle class tolerance were required as an input. The arrival times were input as the minimum and maximum arrival time allowed for vehicles to arrive at the counter of interest. A class tolerance was included because the different ATRs were known to classify vehicles differently. This error in vehicle classification only affected trucks. Therefore a class tolerance was provided for trucks only. Estimates of the minimum and maximum arrival times of experimental vehicles were required for Counters 1 through 5. However, because the estimated arrival times were not known for every counter, an iterative process was employed.

The first step of this iterative process was to determine the estimated arrival time of experimental vehicles from Counter 0 to Counter 1. A sample of 30 vehicles was selected from Counter 0 and manually identified at Counter 1. The estimated arrival time for each vehicle was calculated based on the difference in time elapsing from a vehicle being observed at Counter 0 and Counter 1. Using the Central Limit Theorem, it was assumed that the sample of 30 vehicles' arrival times was approximately normally distributed. The mean and standard deviation of the arrival times were then calculated. Under the normal distribution assumption, approximately 99.7 percent of all values are within three standard deviations of the mean. Therefore, the minimum arrival time would be three standard deviations less than the mean (μ-3σ) while the maximum arrival time would be three standard deviations greater than the mean (μ+3σ). Once the first range of arrival times for Counter 1 was determined, they were input into the computer program and the program was executed.

After the first run of the computer program, a database of experimental vehicles was identified at Counter 1. In the second step, the range of arrival times was calculated for vehicles proceeding from Counter 1 to Counter 2. The computer program would sometimes identify more than one vehicle that matched the arrival time criteria of a vehicle at the previous counter. It was therefore necessary to filter this initial set to obtain only one matching vehicle. This filtering process was accomplished by using a filtering function within Microsoft Excel. If more than one identical record existed in the database, the filter function would keep the first identical record and hide the remaining identical records. Records not filtered by this function were copied into another worksheet to be used in the next step of analysis.

From this filtered set, the mean and standard deviations of the observed experimental vehicle speeds at Counter 1 were calculated. Since the distance between Counter 1 and Counter 2 was known, the estimated range of arrival times could be calculated. Again, because of the assumption of a normal distribution, the minimum arrival time was calculated as three standard deviations below while the maximum arrival time was three standard deviations above the mean. This range of arrival times for Counter 2 was then input into the computer program and the program was executed. The third through the fifth step followed this same procedure.

Figure 89 displays a visual of the methodology the computer program used for identifying experimental vehicles. Because each vehicle was assigned a date and time stamp, the computer program added to a vehicle's time at the basis counter the estimated range of arrival times. For example, an experimental vehicle at the basis counter may have a time of 12:00:00. If the estimated minimum and maximum arrival times were 40 seconds to 50 seconds respectively, any vehicle at the following counter with a time stamp of 12:00:40 to 12:00:50, with the same date and classification, was assumed to be the same experimental vehicle.

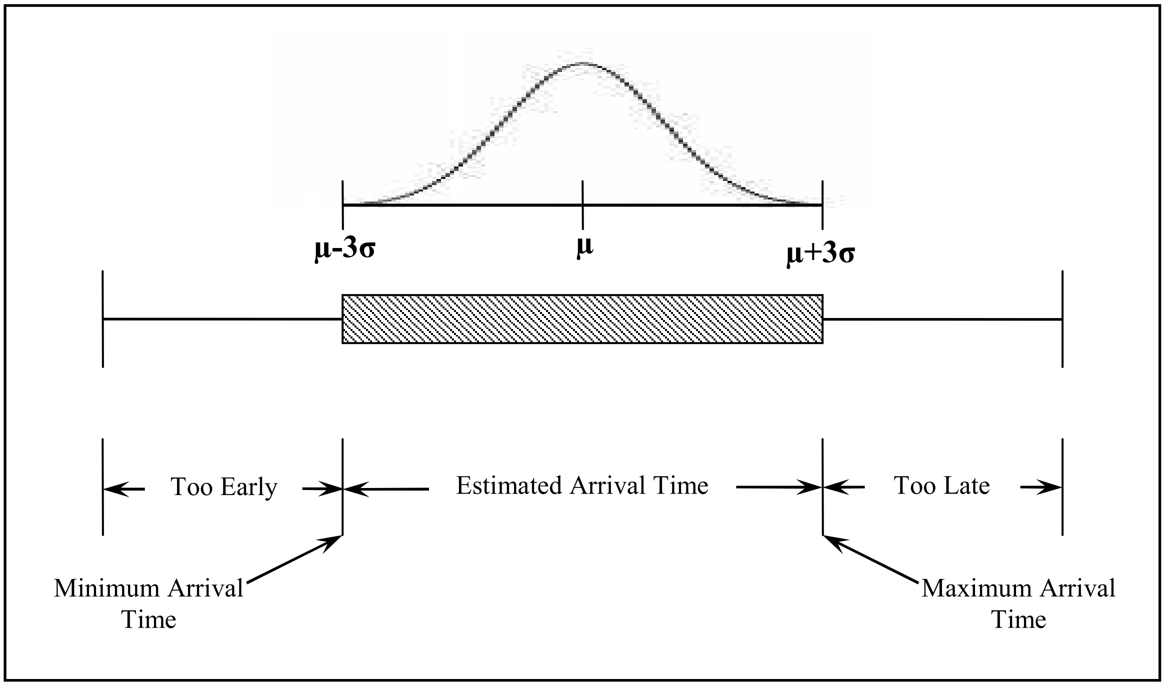

Figure 89. Criteria for Experimental Vehicle Range of Arrival Times Criteria

The computer program considered date, time, and classification of the first vehicle at the basis counter and assigned it an identification number. It would then consider the vehicles listed in the following counter. If a vehicle fit the date and time, and vehicle classification criteria, it would be assigned the same number as the vehicle under consideration at the basis counter. If no vehicle matched the criteria, the computer program would then consider the second vehicle at the basis counter.

Table 10 displays the estimated range of experimental vehicles' arrival times for each experimental site. These values were used in the computer program as the acceptable arrival times that were calculated for each counter.

Table 10. Range of Arrival Times for Experimental Vehicles

Experimental Site	Counters	Distance (mi)	Min. Arrival Time (s)	Max. Arrival Time (s)
190th Street	0 to 1	0.3	37	61
	1 to 2	0.2	10	17
	2 to 3	0.5	24	40
	3 to 4	2.0	94	161
	4 to 5	N/A	N/A	N/A
380th Street	0 to 1	0.3	62	80
	1 to 2	0.2	9	20
	2 to 3	0.5	23	45
	3 to 4	2.0	98	141
	4 to 5	2.0	94	147
IA-210	0 to 1	0.3	22	40
	1 to 2	0.2	10	17
	2 to 3	0.5	25	38
	3 to 4	2.0	103	143
	4 to 5	2.0	99	152

5.3 Identifying Control Vehicles

Identifying the control vehicles was a much simpler process. As stated earlier, control vehicles were traveling in the westbound lane. Only control vehicles observed at the last counter, or Counter 5 would be used for a comparison of vehicle speeds. In the case of the 190th Street site, the last counter was Counter 4 because of an intersection located near the intended location of Counter 5. The control vehicles' mean and standard deviation were calculated and used as the criteria for comparing the experimental vehicles.

5.4 Description of Statistical Analysis

The speeds of both experimental and control vehicles were analyzed for all vehicles, and for passenger vehicles only. Passenger vehicles were defined as motorcycles, passenger cars, pickups, vans, and other two-axle, four-tire vehicles (Jamar, 2007). An analysis of trucks as a separate class was not conducted due to the limited number of truck observations. The statistical summary for experimental vehicles included the mean, and 85th percentile speeds at each ATR location. The statistical summary for experimental vehicles was then plotted against the control vehicles' mean speed and the mean speed plus or minus one standard deviation. If the mean speed of the experimental vehicles exceeded plus one standard deviation of the control vehicles' mean speed, this would indicate that the experimental vehicles are traveling significantly faster than the control vehicles thereby suggesting that the speed adaptation effect exists on rural primary highways in Iowa.

Because of each sites' relative location to large employment centers located in Ames and Des Moines, Iowa, a separate analysis was conducted for those experimental vehicles driving through the test sites during the afternoon peak period of 4:00 to 6:00pm. It is assumed that during this peak period, many of the observed vehicles included those returning from work.

6.0 Results

6.1 190th Street Results

Figure 90 displays the results for the experimental and control vehicles' speeds comparison for all vehicles at the 190th Street site. The chart displays the control vehicles' mean speed and the speeds one standard deviation below and above the mean speed. Plotted against the control vehicles' speeds are the experimental vehicles' mean and 85th percentile speeds. The results show that the experimental vehicles' mean and 85th percentile speeds are similar to each other. The experimental vehicles' mean speeds are within one standard deviation of the control vehicles mean speed. This indicates that there was no statistically significant difference between the experimental and control vehicles' speeds.

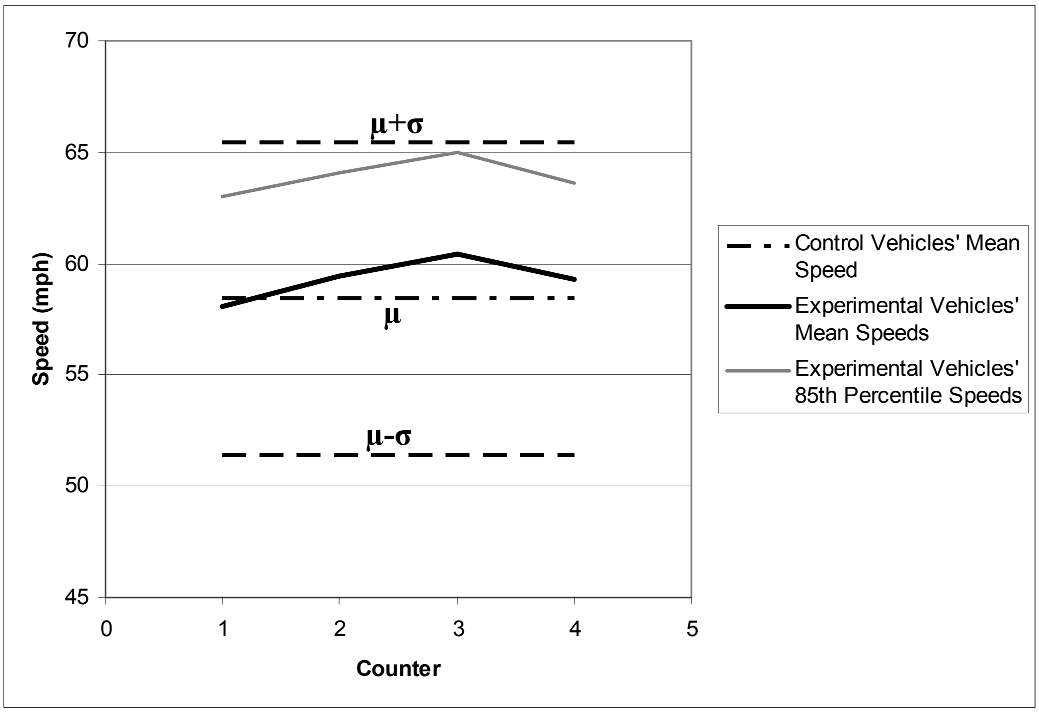

Figure 90. 190th Street All Vehicle Speeds Comparison

Figure 91 displays the results for the experimental and control vehicles' speeds comparison for passenger vehicles only at the 190th Street site. The results of the passenger vehicles are nearly identical to that of all vehicles shown in Figure 90. The experimental vehicles' mean speeds are within one standard deviation of the control vehicles' mean speed. As with the results from all vehicles, there is no indication of a significant difference between the experimental and control vehicles' speeds. Figure 92 displays the results for all experimental and control vehicles' speeds during the PM peak period.

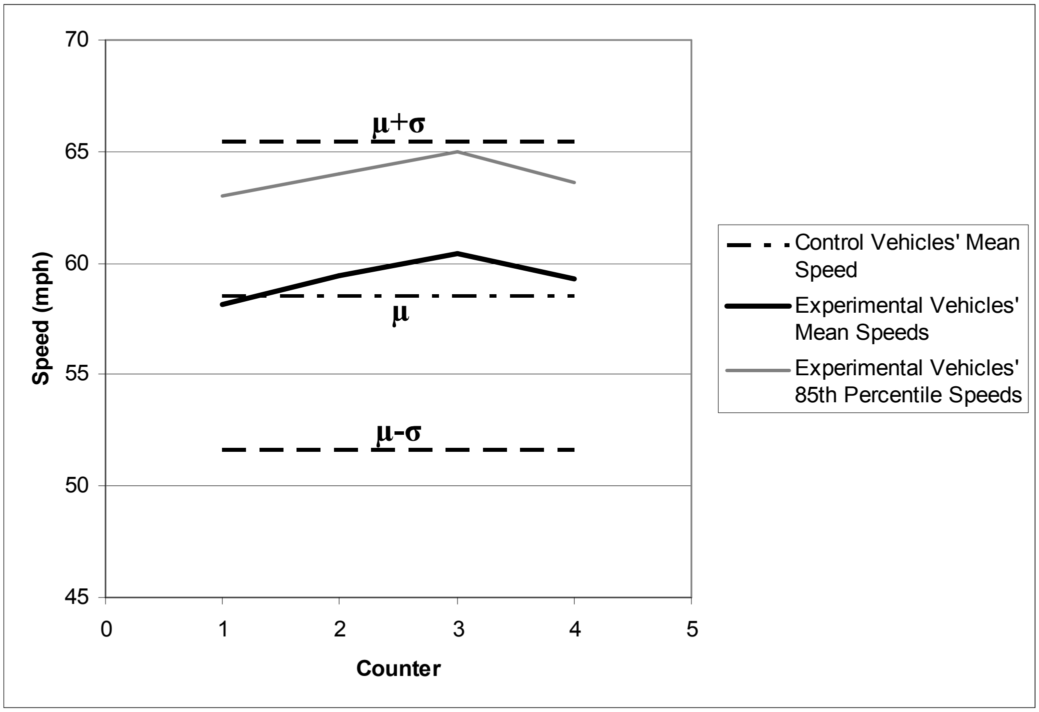

Figure 91. 190th Street Passenger Vehicle Speeds Comparison

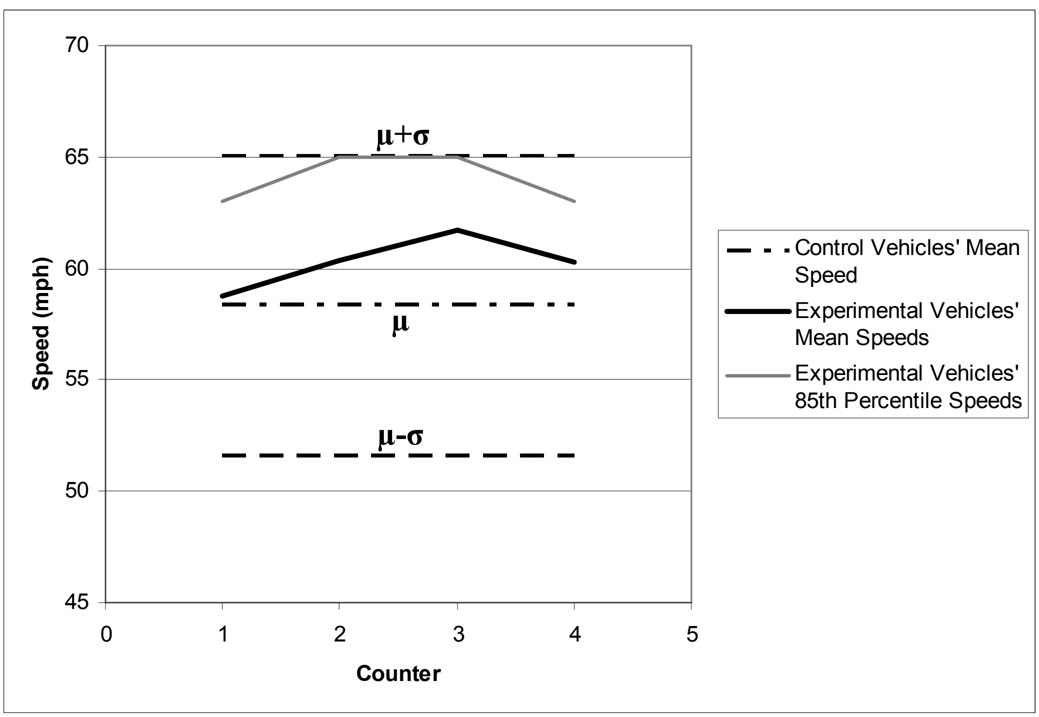

Figure 92. 190th Street All PM Peak Period Vehicle Speeds Comparison

6.2 380th Street Results

Figure 93 displays the results for the experimental and control vehicles' speeds comparison for all vehicles at the 380th Street site. The experimental vehicles' mean speeds are nearly all less than the control vehicles' mean speed. The experimental vehicles' mean speeds are within one standard deviation of the control vehicles' mean speed. This indicates there was no significant difference between the experimental and control vehicles' speeds. However, the same trend of speed increase followed by decrease in experimental vehicle speed may be observed. This could be drivers realizing they are traveling too fast, and reducing their speeds. Note that both experimental and control mean speeds are up to 8-mph over the speed limit.

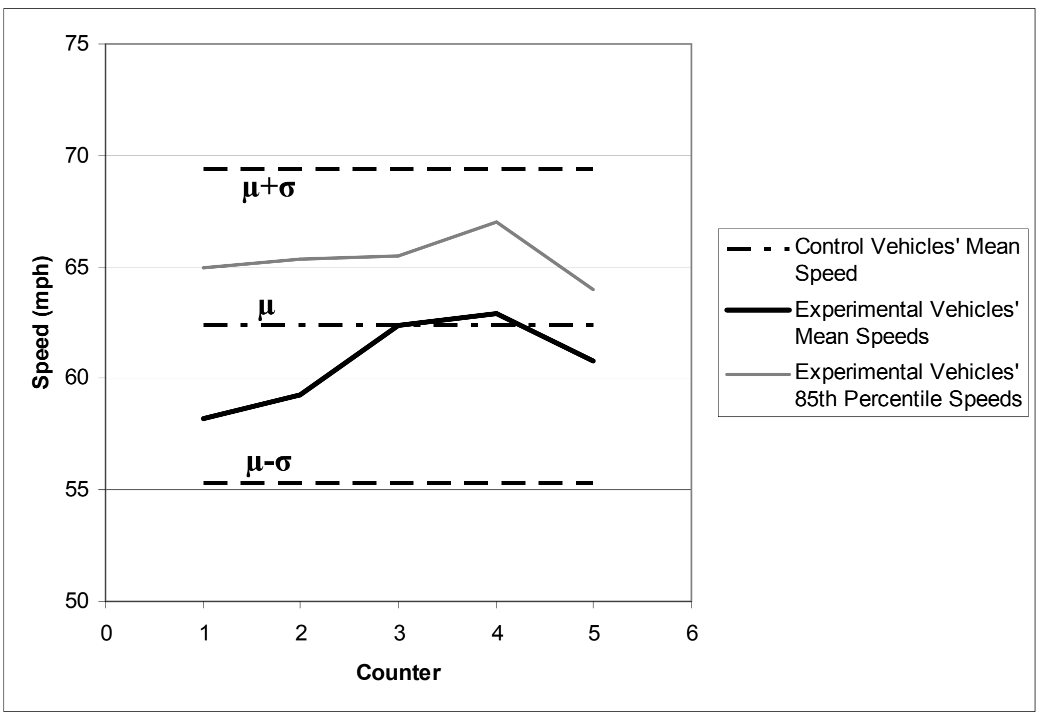

Figure 93. 380th Street All Vehicle Speeds Comparison

Figure 94 displays the results of experimental and control vehicles' speeds comparison for passenger vehicles only at the 380th Street site. As with Figure 93, the experimental vehicles' mean speeds may be seen to be nearly all less than the control vehicles' mean speeds. The experimental vehicles' mean speeds are within one standard deviation of the control vehicles' mean speed. This indicates there was no significant difference between the experimental and control vehicles' speeds. Figure 95 displays the results of all experimental and control vehicles' speeds for the PM peak period.

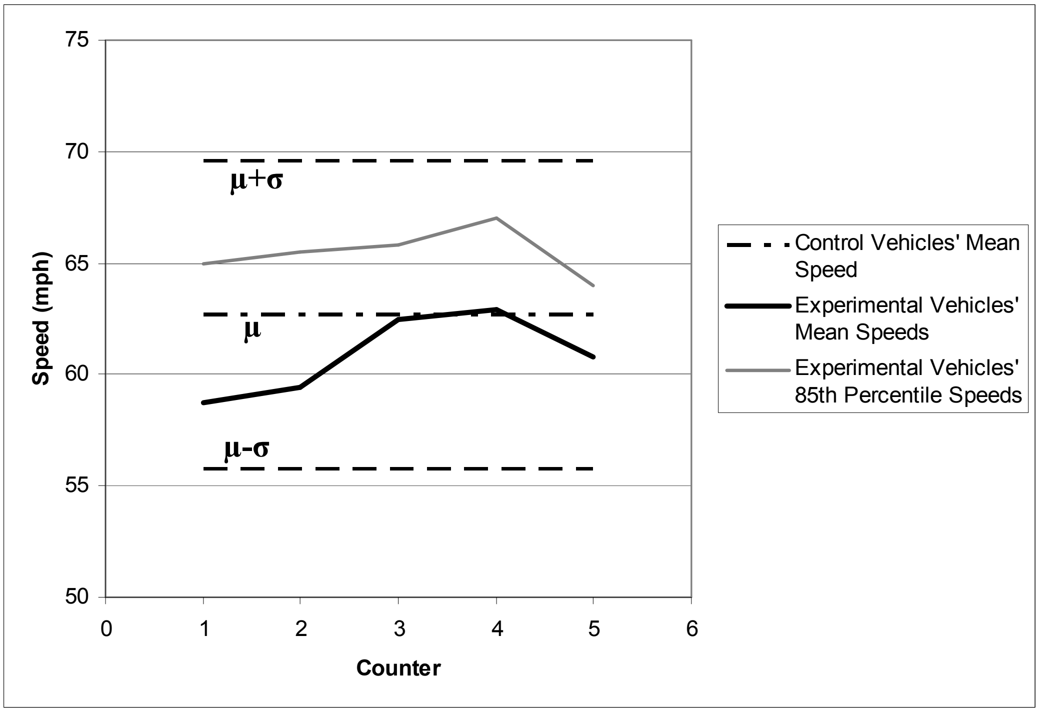

Figure 94. 380th Street Passenger Vehicle Speeds Comparison

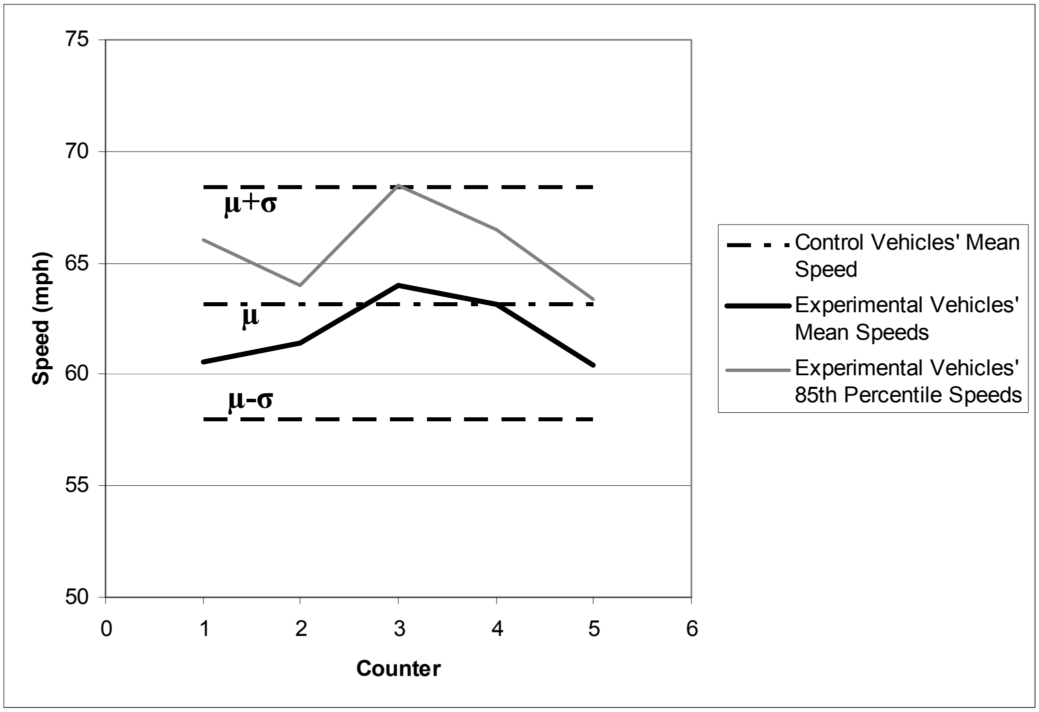

Figure 95. 380th Street All PM Peak Period Vehicle Speeds Comparison

6.3 IA-210 Results

Figure 96 displays the results for the experimental and control vehicles' speeds comparison for all vehicles at the IA-210 site. Again, all observed experimental vehicles' mean speeds are less than control vehicles' mean speeds. Experimental vehicles' mean speeds are again within one standard deviation of the control vehicles' mean speed. This indicates there was no significant difference between the experimental and control vehicles' speeds.

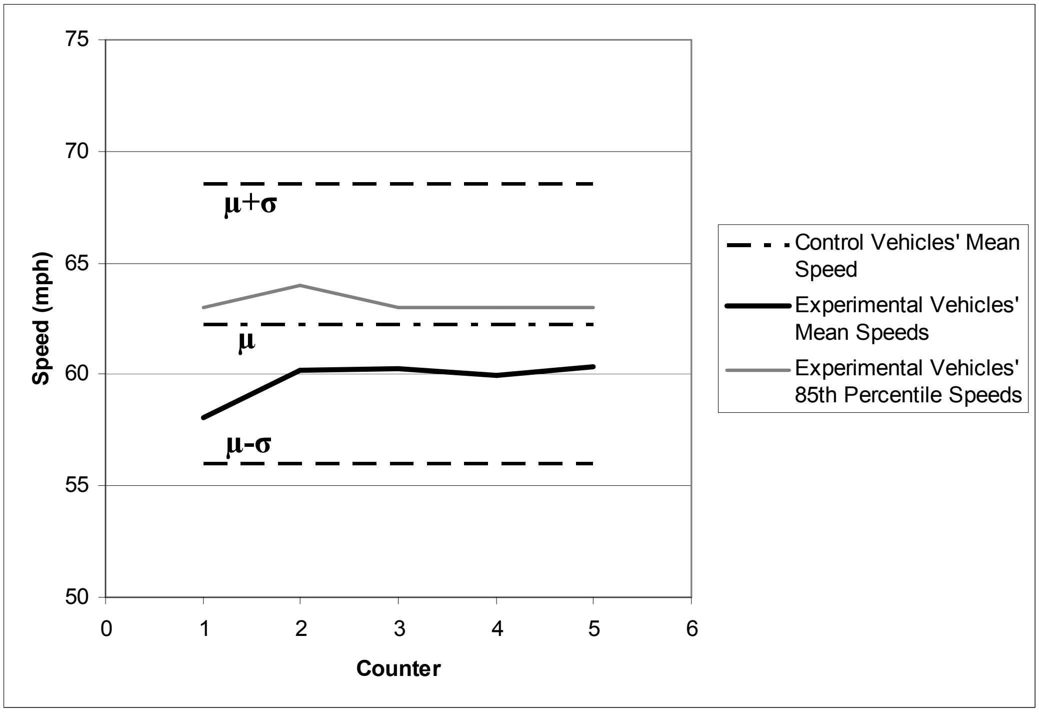

Figure 96. IA-210 All Vehicle Speeds Comparison

Figure 97 displays the results for the experimental and control vehicles' speeds comparison for passenger vehicles only at the IA-210 site. The observed experimental passenger vehicles' mean speeds are again less than the control vehicles' mean speeds. The mean speeds of the experimental vehicles are again within one standard deviation of the control vehicles' mean speed. This again indicates there was no significant difference between the experimental and control vehicles' speeds. Figure 98 displays the results of all experimental and control vehicles' speeds for the PM peak period.

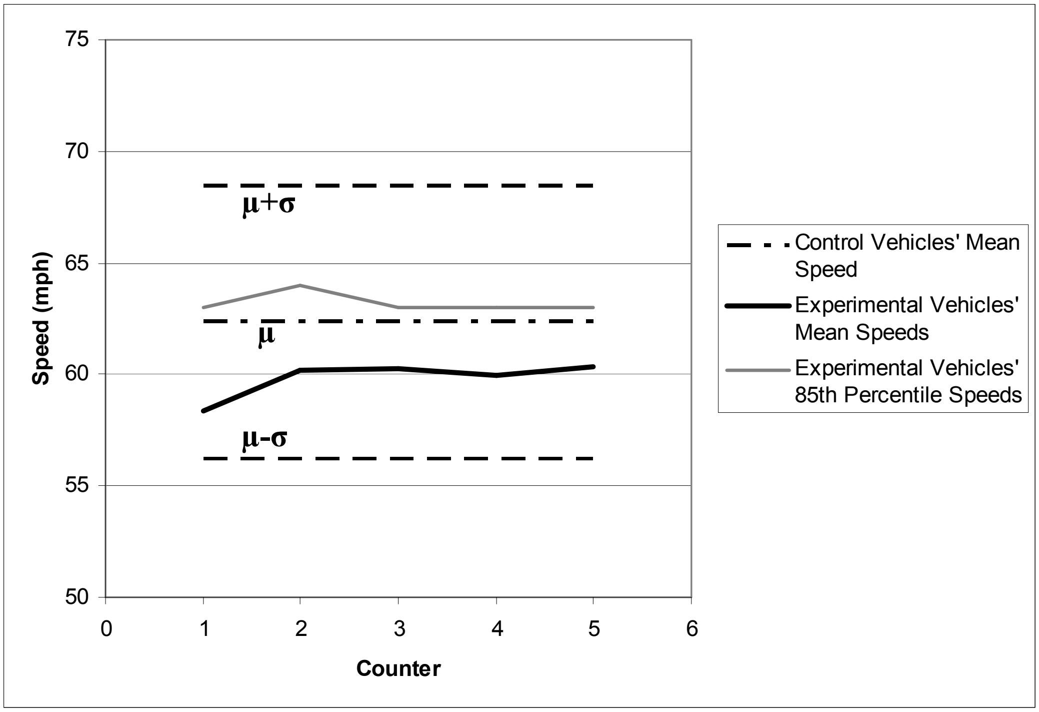

Figure 97. IA-210 Passenger Vehicle Speeds Comparison

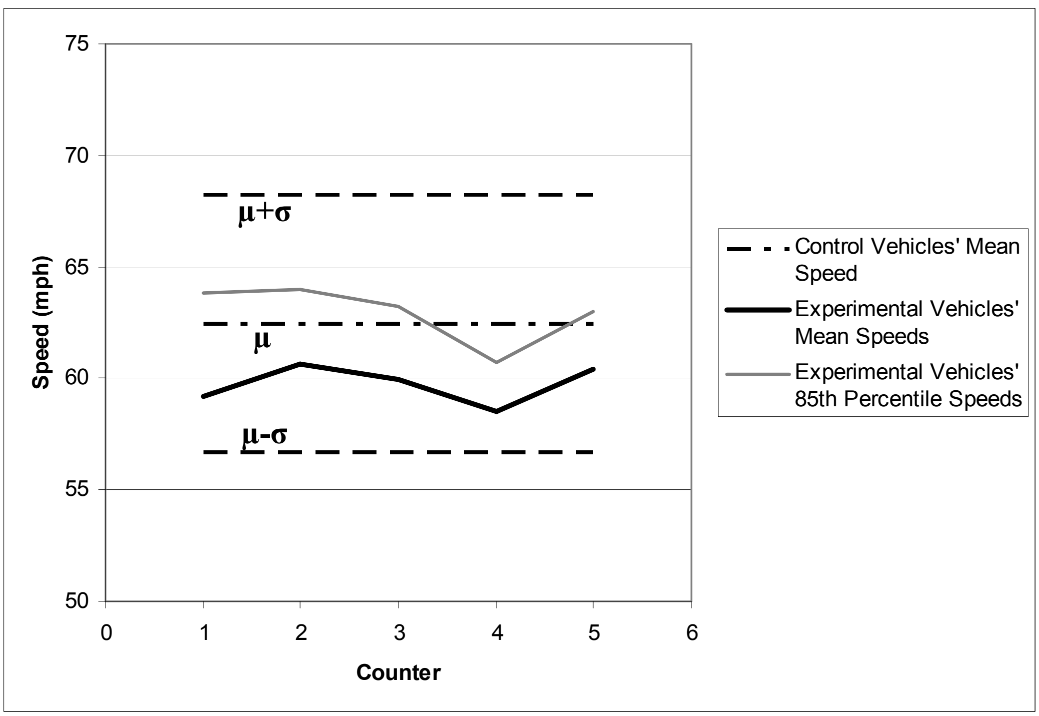

Figure 98. IA-210 All PM Peak Period Vehicle Speeds Comparison

7.0 Summary and Conclusions

The results for all three study sites indicate that there was no significant difference between the experimental and control vehicles' speeds for all vehicles, passenger vehicles, and all PM period vehicles. In fact, most of the observed experimental vehicles' mean speeds were less than the control vehicles' mean speeds. These results indicate there is little or no speed adaptation effect on those drivers that had exited the interstate onto a 55-mph rural primary highway. One of the concerns related to increasing the rural interstate speed limit was whether higher vehicle speeds would be observed on non-interstate roads. As noted in the hypothesis, an immediate effect of higher vehicle speeds should first be identified as the existence of the speed adaptation effect of vehicles exiting the rural interstates onto the non-interstate primary highways. However, if the speed adaptation effect does not exist in drivers who exit the rural interstate onto non-interstate rural primary highways as the results suggest, it is possible that there is no system-wide spillover effect of higher vehicle speeds.

It is possible that because vehicles exiting the interstate are required to stop before entering a county or state highway, the speed adaptation effect may be significantly dissipated. Because drivers must stop and look for traffic before turning onto the intersecting highway, it may provide a "reset" in their thought processes.

Another possible explanation for the results could be in part due to the significant change in the geometry of the two facilities. In the case of this study, those drivers that were considered speed adapted were exiting from an interstate onto a two-lane primary highway. Some of the differences between the two facilities include the speed limit, traffic volume, lane width, shoulder width, and the width and slope of the ditches. During the field data collection, it was observed that for the two-lane county or state highways, the shoulder widths were two to four feet in conjunction with some locations in which the slope of the ditch was non-recoverable. Drivers who have exited the interstate may become more cautious due to these changes in geometry and operations on the two-lane primary highways reduce their vehicle speed for those reasons.

Another possible explanation as to why there was no observation of the speed adaptation effect may be due in part to vehicle technology. The latest report cited, which studied this topic, was completed in 1992. It is possible that most vehicles observed during those earlier studies did not have automotive features such as cruise control. Since the speed adaptation effect is entirely related to a driver's perception of their vehicle's speed, drivers that do not have access to cruise control may continue to drive on lower speed facilities at a higher speed than they otherwise would have if they were able to set the vehicle's cruise control. Since the data used in this report was collected during 2007, it is possible that a higher percentage of vehicles have cruise control. Therefore, most drivers may eliminate the speed adaptation effect through the use of a vehicle's cruise control function.

Because there was little difference in the experimental and control vehicles' speeds, it is concluded that the speed adaptation effect is not significant on rural primary highways in close proximity to the rural interstates in Iowa. Although not observed in the present study, the speed adaptation effect may occur in more urbanized environments, or in different types of rural facilities or locations. The study of the spillover effect in Chapter 2 of this thesis indicated no speed spillover to the *primary parallel* routes or other systems. The effect of the 5-mph increase in speed limits in Iowa on other facilities may therefore be assumed to be an insignificant issue.

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Chapter 4. General Conclusions

1.0 General Discussion

Speed limit policy is a controversial issue which centers on finding a balance between a facility's efficiency and safety. Although the *rural interstate* system in Iowa has become more efficient in the transportation of goods and people, the increase in the speed limit is observed to have adversely affected its safety performance. As shown in Table 3, the percent change in fatal, and fatal and major injury crashes on the *rural interstate* was substantially greater than all crashes. The greater percent increase in more severe crashes also suggest that crashes may have become more severe as a result of a higher speed limit. This adverse effect in safety is observed to be the greatest on the *rural interstates* during the nighttime. While not quite statistically significant at the 0.05 level, these impacts appear large.

Considering the off-system safety performance, there is observed to be no adverse safety effect in terms of an increase in vehicle speeds or crashes. Reinforcing the conclusion that no spillover effect has been observed are the results reported from the speed adaptation study in Chapter 3. Lave and Elias (1994) purported the hypothesis that by increasing the *rural interstate* speed limit, it would create a more attractive facility to drivers therefore producing a shift in traffic from *rural other primary* highways to the *rural interstates*. As shown in Figure 69, the negative trend in *rural other primary* highways is observed to have started in 2002 and not be related to the speed limit change. This suggests no traffic diversion has been observed due to the speed limit change. Additionally, there was no observed shift in traffic from the *primary parallel* routes. Therefore, no type of spillover effect could be identified.

The speed adaptation study reported in Chapter 3 found no evidence of any significant differences in speeds of those vehicles exiting the interstate and those on the intersecting highways. This conclusion suggests that there was no immediate effect of higher speeds on rural roads with access to the *rural interstate*.

A hypothesis suggested by Kockelman (2006) suggests that negative effects on safety are minimized if a speed limit change has occurred over a higher range than a lower range of speeds. It is possible that because the increase in the speed limit in Iowa consisted of a relatively small (65-mph to 70-mph), no statistically significant changes in the *rural interstate* average monthly crash frequency were observed. However, additional after data will be needed to provide a more confident conclusion.

During this research, it was suggested that the recent increase in the retail gasoline price may have affected the safety performance on the *rural interstates*. If the relatively higher gasoline prices had resulted in a decrease in discretionary travel or a decrease in speeds as an energy saving measure, it may have partially "canceled" out the impact the speed limit change had on the *rural interstate* safety performance. However, as illustrated by Figures 78, 79 and 80, there were no observable effects on driver's choice of travel or speed. Therefore, the retail gasoline price was determined to have not been a confounding factor in this study.

In conclusion, most studies summarized in Table 1 reported adverse safety effects on-system after the speed limit was increased. The results from this study also indicate that Iowa has experienced similar results. This preliminary research suggests that the increase in the speed limit to 70-mph on the *rural interstate* may have negatively affected its safety performance in terms of more severe crashes.

2.0 Recommendations

The largest increase in fatal, and fatal and major injury crashes on the *rural interstate* was observed during the night. Because it is assumed drivers' perception and reaction times are diminished at night, it is recommended that future studies consider the possibility of establishing a *rural intestate* nighttime speed limit of 65-mph. This nighttime speed limit may reduce the adverse effects observed in this research.

Because this research conducted a before and after study on the safety effects of the speed limit change, it cannot answer the question of what is the correct balance between efficiency and safety. That is, what is an "optimum" speed limit to achieve this balance? To best quantify the location of this balance point, it is recommended that a thorough benefit-cost analysis be conducted for Iowa in relation to the *rural interstate* speed limit change. Although there has been an increase in the number of severe crashes on the *rural interstate* in the after period, no analysis was conducted as to whether there have been economic benefits that were achieved due to a more efficient system. If there were economic benefits, additional research could determine the magnitude of these benefits.

This study, although preliminary, has provided an initial review of the safety effects of the policy decision to increase the *rural interstate* speed limit. It is hoped this thesis will be beneficial to making informed decisions about future speed limit policy.

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