Evaluation of Speed Limit Policy Impacts on Iowa Highways

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7. Author(s)
Peter T. Savolainen (orcid.org/0000-0001-5767-9104), Christopher M. Day (orcid.org/0000-0002-3536-7211), Anuj Sharma (orcid.org/0000-0001-5929-5120), Jacob R. Warner (orcid.org/0000-0002-3896-0977), and Chao Zhou (orcid.org/0000-0002-7945-4413)

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Iowa State University
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16. Abstract

Iowa's maximum speed limit for rural interstates has been 70 mph since 2005, and the Iowa legislature has recently discussed the possibility of further increasing the maximum speed limit. This research aims to inform this discussion by examining how traffic fatality rates have changed over time as maximum speed limits have been increased in Iowa and other states, with emphasis on the changes resulting from the more recent increases to 75 mph and above in other states.

The study included state-level and road-level analyses using nationwide data sets and an Iowa-specific analysis using data from within the state. The nationwide analyses confirm prior research showing that states with higher rural interstate speed limits experience a higher number of traffic fatalities. The state-level analysis shows that this effect is even larger when accounting for the proportion of rural interstate mileage in each state posted at the maximum speed limit. However, this increase in traffic fatalities may begin to taper off at the highest speed limits. The road-level analysis indicates that speed limit more strongly affects fatal crashes involving driver distraction than total fatalities or fatal crashes. Additionally, fatal crashes involving speeding are more strongly affected by speed limit on roads posted at 70 or 75 mph than on roads posted at 80 mph.

A simple before-and-after comparison of fatal and serious crash rates on Iowa interstates from 1991 to 2017 shows that crashes increased in the few years after the 2005 speed limit increase but have generally declined since then. Further analyses showed that average and 85th percentile speeds were influenced by roadway geometric characteristics and that speed variance was the primary factor affecting crash rate. The impacts of speed variance are most pronounced for the most severe crashes.

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Principal Investigator
Christopher M. Day, Affiliate Researcher
Center for Transportation Research and Education, Iowa State University

Co-Principal Investigators
Anuj Sharma, Research Scientist
Center for Transportation Research and Education, Iowa State University

Peter T. Savolainen, Professor
Civil and Environmental Engineering, Michigan State University

Research Assistants
Jacob Warner and Chao Zhou

Authors
Peter T. Savolainen, Christopher Day, Anuj Sharma, Jacob Warner, and Chao Zhou

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A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

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1. INTRODUCTION

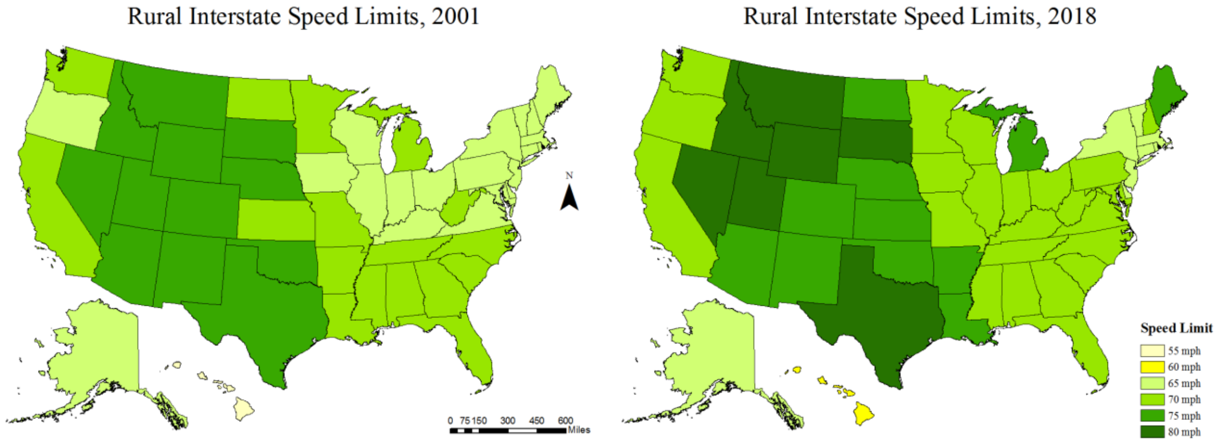
1.1 Background/Overview

Maximum statutory speed limits have been an issue of longstanding debate. Following the introduction of the National Maximum Speed Law (NMSL) in 1974, a series of longitudinal studies showed significant decreases in traffic fatalities (Borg et al. 1975, Enustun et al. 1974).

In 1987, states were given the authority to increase speed limits on rural interstates to 65 mph, spurring a series of additional research studies that showed marked increases in fatalities subsequent to these speed limit increases (Baum et al. 1989, Baum et al. 1991). Fatality rates were also observed to be higher in states with greater maximum speed limits following the complete repeal of the NMSL in 1995, which gave states full autonomy to establish maximum speed limits on all roads under their jurisdiction.

Rural interstates are generally subject to the highest maximum speed limits given the higher design standards for these facilities, which are often designed for speeds significantly greater than the posted limits. Consequently, speed limit compliance has generally been poor on rural interstates in particular (Lam and Wasielewski 1976, McKnight and Klein 1990). Poor speed limit compliance, particularly on rural interstates, is one of several potential reasons cited when state legislatures consider potential speed limit increases.

Since 2001, 25 states, including Iowa, have raised their maximum statutory speed limits on rural interstates. As of 2018, 18 states had a maximum speed limit of 75 or 80 mph, including Midwest states such as Kansas, Nebraska, and South Dakota. Maps illustrating the changes in speed limits between 2001 and 2018 are shown in Figure 1.


Rural Interstate Speed Limits, 2001

Rural Interstate Speed Limits, 2018

Figure 1. Maximum rural interstate speed limits in 2001 (left) and 2018 (right)

In contrast to many of the prior speed limit policy changes, which were often implemented on a system-wide basis (i.e., on the rural interstate system), the more recent speed limit increases to

75 mph and above have been more selective in nature, typically based on historical data related to traffic crashes, mean speed, speed variance, and other factors likely to impact safety in concert with the speed limit increase.

Iowa’s maximum speed limit for rural interstates has been 70 mph since July 1, 2005, when the limit was increased from 65 mph. A 2010 study examined the effects of the increased speed limit in terms of speed changes, traffic volume changes, and traffic safety impacts (Souleyrette and Cook 2010). The results of the study indicated that 85th percentile speeds on rural interstates increased by approximately 2 mph. With this increase, the percentage of drivers speeding by more than 10 mph was found to have decreased from 20 percent to 8 percent.

While no significant change in crash frequency or severity was found at that time, it is important to note the relatively small time period over which post-increase data were available. There is now a substantially larger volume of crash data after the speed limit change with which to examine the long-term safety trends.

1.2 Objectives

As the Iowa legislature has recently discussed potential increases to speed limits on rural interstates, this research aims to provide insights into the potential impacts that may occur if such increases are introduced. This research looks to inform this policy debate by examining how traffic fatalities have changed over time as maximum speed limits have been increased, with particular emphasis on the changes resulting from the more recent increases to 75 mph and above in other states. The study also revisits trends that have occurred in Iowa since the 2005 rural interstate speed limit increase.

1.3 Report Outline

This report is organized into seven chapters. This first chapter outlines the study, providing a background/overview and the objectives of the study. The remaining chapters are summarized as follows:

- Chapter 2 presents the results of an extensive literature review of prior research on the safety impacts of speed limit changes, as well as associated literature detailing the impacts of speed limits on driver speed selection and various speed measures.

- Chapter 3 details the data collection processes and explains the methods used to gather and compile the data used as part of a nationwide analysis focused on rural interstates across states with varying speed limit policies.

- Chapter 4 summarizes the data collection and quality assurance processes associated with the development of an Iowa-specific data set that was developed for the state’s existing rural interstate facilities that currently operate with a 70 mph maximum speed limit.

- Chapter 5 presents the details of the statistical analyses conducted using the nationwide data set. This chapter includes a brief summary of the statistical methods, the results of the analyses, and a discussion of the policy implications of these results, which compares trends over time on rural interstate fatalities in consideration of maximum speed limits.

- Chapter 6 presents the details of the statistical analysis conducted using the Iowa-specific data set. This chapter summarizes the statistical methods used, the results of the analysis, and an accompanying discussion. In this chapter, the emphasis is on examining how driver speed selection varies across different rural interstate segments, as well as the degree to which traffic crashes at various severity levels are associated with these speed measures.

- Chapter 7 summarizes the key findings from the research, provides recommendations based on the findings, and identifies areas where additional research is warranted.

- The Appendix includes the MATLAB code combining adjacent roadway segments that was used for this study.

2. LITERATURE REVIEW

Many studies have been performed to determine the effects of changes in speed limit on the number of crashes on roadways.

2.1 Studies on the Impacts of Speed Limit Reductions after 1974

In response to speed limit reductions imposed by the NMSL in 1974, several research studies were conducted to evaluate its effects.

One 1975 study in Indiana saw fatalities on rural highways decrease by 67 percent, personal injury crashes decrease by 32 percent, and property damage-only (PDO) crashes decrease by 13 percent in the first half of 1974 when compared to the same period from the previous three years (Borg et al. 1975). Another study in Michigan over the same time period saw a 20 percent decrease in total crashes and injury crashes and a 17 percent decrease in fatal crashes on freeways (Enustun et al. 1974).

2.2 Studies on the Impacts of the 1987 Speed Limit Increase on Rural Interstates

As the national 55 mph speed limit was phased out in the 1980s and states were given the authority to increase the speed limits on rural interstates to 65 mph, additional research on the effects of speed limit on crash rates was undertaken to examine the effects of the increase.

2.2.1 Studies Showing Increases in Crash Rates and Fatalities

An analysis of data from the Fatality Analysis Reporting System (FARS) conducted shortly after states were authorized to increase rural interstate speed limits from 55 to 65 mph found that, in the 38 states that increased the speed limit, fatalities on rural interstates were estimated to increase by 15 percent compared to the expected rate if the speed limits had remained at 55 mph. Meanwhile, among the states that retained the 55 mph speed limit, the number of fatalities was 6 percent lower than expected (Baum et al. 1989).

A follow-up study using FARS data from 1982 to 1989 found that the likelihood of a fatality on rural interstates in 1989 was 29 percent higher than expected based on the five years of data from 1982 through 1986 (Baum et al. 1991).

Additional analyses of national fatality data showed that 19 of 40 states experienced a significant increase in fatal crashes after speed limits were increased on rural interstates in 1987, and 10 of 36 states saw fatal crashes increase after the speed limit increase on rural interstates in 1996 (Balkin and Ord 2001). This study also showed that 6 of 31 states saw an increase in fatal crashes when urban interstate speed limits were increased in 1996.

An analysis of crash and traffic data from the state of Washington between 1970 and 1994 was performed that showed that the 1987 speed limit change from 55 to 65 mph was associated with an increase in fatalities per year on rural freeways to 48.4 fatalities, which was more than double the expected rate of 22.0 fatalities if the speed limit had not been increased (Ossiander and Cummings 2002).

A 1990 study took a broader look at the effects of the speed limit increase in Michigan in 1987 and found a 19.2 percent increase in fatalities, a 39.8 percent increase in serious injuries, a 25.4 percent increase in moderate injuries, and a 16.1 percent increase in PDO crashes when comparing the data from the first year of the higher limit (1988) against the trends from the 10 years prior to the increase (i.e., 1978 through 1987) (Wagenaar et al. 1990).

A similar study was performed in Michigan in 1990, and the results of the monthly time-series intervention analyses estimated that the rates of fatalities, major injuries, and minor injuries increased by 28.4 percent, 38.8 percent, and 24.0 percent, respectively, over the 25-month study period (Streff and Schultz 1990).

In Iowa, a 10-year study analyzing data from 1981 through 1991 was performed to determine the safety impacts of the increased speed limit (i.e., to 65 mph) on rural interstates. The researchers concluded that the higher speed limits had led to a higher fatality rate, and the speed limit change resulted in approximately 20 percent more fatal crashes statewide. However, the number of major injury crashes during the study period was unaffected (Ledolter and Chan 1994).

In a subsequent study, this analysis was expanded to include a wider variety of sample locations, including 18 locations along interstates, primary roads, and secondary roads in rural areas, as well as urban interstates. While this study drew the same conclusion about fatal crashes as the previous study, it also found that the adverse effect of increasing speed limits to 65 mph was most prevalent on rural interstates, where a 57 percent increase in the number of fatal crashes was determined to have occurred due to the speed limit increase (Ledolter and Chan 1996).

An additional study on rural interstate highways in Iowa used 14 years of fatal crash data from 1980 through 1993 and a dynamic model that showed an average increase of four fatal crashes per quarter due to the increase in the speed limit to 65 mph (Raju et al. 1998).

2.2.2 Studies on the Relationships between Speed Limits, Operating Speeds, and Traffic Safety

The relationships between speed limits, operating speeds, and traffic safety have also been a significant topic of research that arises with changes in speed limit.

One study examined drivers’ responses to the NMSL along a freeway in the Detroit metropolitan area. The speed limit on the roadway sampled in the study decreased from 70 to 55 mph for passenger cars, and the proportion of passenger cars exceeding 60 mph dropped from 64 percent to 27 percent following the decrease in speed limit. However, only about 30 percent of the vehicles in the study traveled below 55 mph after the speed limit decrease (Lam and Wasielewski 1976).

A 2004 study in Florida focused on driver behavior in relation to speed limits. While the primary focus of the study was on minimum speed limits, the six-year study period included the point at which the maximum speed limit was increased from 65 to 70 mph. At sites where the increase was applied, it was found that the average speed increased by 5 mph to 72 mph (Muchuruza and Mussa 2006).

Another study analyzed fatal crash and speed data in the five years preceding and one year following the increase in the national maximum speed limit to 65 mph in 1987. The results showed that the speed limit increase resulted in 48 percent more drivers exceeding the speed limit and a 22 percent increase in fatal crashes on rural interstates. Even in states where the speed limit remained at 55 mph, the number of fatal crashes still increased by 10 percent on rural interstates and 13 percent on other non-interstate 55 mph highways (McKnight and Klein 1990).

A National Cooperative Highway Research Program (NCHRP) study examined the impacts of raising the speed limit to 65 mph on high-speed roads in the state of Washington. The results suggested that a 3 mph increase in average speed was expected for a 10 mph speed limit increase. Additionally, the raised speed limit led to a 3 percent increase in the crash rate and a 24 percent increase in the probability of a vehicle occupant being fatally injured in a crash (Kockelman 2006).

Another study collected rural interstate speed and crash data from 118 locations in California, Oregon, and Washington in the 1980s and 1990s and concluded that a 1 mph increase in the speed limit was associated with a 0.3 mph to 0.4 mph increase in travel speed (van Benthem 2015). Furthermore, the study indicated that increasing the speed limit by 10 mph resulted in a 9 to 15 percent increase in crashes and a 34 to 60 percent increase in fatal crashes.

A study in Virginia within that time frame (specifically, 1986 to 1989) used interstate speed data and fatal crash data to assess the effects of increasing the speed limit from 55 to 65 mph. This study found a significant positive relationship between average speed and number of fatalities on rural interstates, with a 1 mph increase in average speed corresponding to approximately 2 to 6 additional fatalities (Jernigan and Lynn 1991).

A study from Illinois examined the safety impact of the 65 mph speed limit on rural interstate highways using speed and crash data for 15 segments for 52 months before and 15 months after the speed limit increase in 1987. This study found that the 85th-percentile speed for cars increased by 4 mph, and the rate of fatal and injury crashes increased by 18.5 percent (Pfefer et al. 1991). The increase in crash rates was not found to be statistically significant.

2.2.3 Studies Showing Mixed Results for Crash Rates and Fatalities

Mixed results have been found in other studies regarding the speed limit increase from 55 to 65 mph on rural highways.

One study employed a state-by-state analysis using FARS data from 1976 through 1988, and the researchers found that the new 65 mph speed limit had disparate effects on rural highway fatalities. Most states experienced an increase in rural interstate fatalities, but some states experienced a decrease or no detectable difference in fatalities. The median effect on rural interstate fatalities was approximately a 15 percent increase nationwide. The study also suggested that the 65 mph speed limit contributed to traffic diversion as well as speed spillover effects on rural non-interstate highways, and the researchers found that the median effect of the new speed limit on rural non-interstate fatalities was an increase in fatalities of about 5 percent (Garber and Graham 1990).

When a study in Illinois evaluated the effects of the increased speed limit on rural interstates by comparing fatal and personal injury crashes as proportions of total crashes in the five years before and one year after the speed limit increase, no significant difference was found. Therefore, the researchers concluded that the severity of crashes on Illinois's rural interstates did not worsen, and no noticeable adverse effect was observed as a result of the speed limit increase in the first year after the speed limit increase (Sidhu 1990).

Another study from the same year yielded similar results examining data from Alabama. The study assessed the impact of the increased 65 mph speed limit on the entire Alabama roadway system using data from two years before and one year after the speed limit change. The authors pointed out that the proportions of PDO, injury, and fatal crashes did not change, but the total crash frequency increased by 18.88 percent on rural interstates in the first year of the new speed limit (Brown et al. 1990).

In addition, several studies found that the growth in the number of vehicle miles traveled (VMT) on rural interstate highways following increases in speed limits was significantly greater than the overall VMT growth. This implies that rural interstates with higher speed limits diverted traffic away from more highly traveled highways, such as the two-lane highways that maintained a speed limit of 55 mph.

When aggregating the fatality rates for three years, from 1986 through 1988, in all states that raised their speed limits versus all that did not, the states that increased their speed limits experienced a 3.62 percent higher decrease in fatality rates than states that did not increase their speed limits. Furthermore, a linear regression curve was fitted using fatality rate per VMT for 15 years, from 1976 through 1990, and this demonstrated that the traffic fatality rate dropped by 3.4 percent to 5.1 percent in states that increased their speed limit compared to states that did not (Lave and Elias 1994, Lave and Elias 1997).

An Ohio study used three years of crash data for interstates and non-interstate highways before and after the implementation of the raised speed limit and reported that the fatal crash rate did not significantly change on rural interstate highways. However, the injury and PDO crash rates increased on rural interstates by 16 percent and 10 percent, respectively, whereas injury and PDO crash rates decreased by 5 percent and 3 percent, respectively, on non-interstate highways that did not implement a speed limit increase (Pant et al. 1992).

Another study examined the nationwide effects of the increased speed limit to 65 mph by analyzing long-term fatality data from the 12 years before and nearly 3 years after the 1987 speed limit increase in 48 states (Alaska, Delaware, and the District of Columbia did not have any interstate highways that were eligible for a speed limit increase). The researchers found that while a significant increase in fatalities was experienced at first, the effects of the speed limit increase diminished after approximately one year. Fatality rates in larger/more heavily populated states, such as California, Florida, Illinois, and Texas, were found to be insensitive to the speed limit increase, while smaller/less populated states had more dramatic reactions to the speed limit increase (Chang et al. 1993).

2.3 Studies on the Impacts of More Recent Speed Limit Changes

In addition to studies on the speed limit changes brought about by the 1987 increase in the NMSL, numerous studies have been conducted in reaction to speed limit changes that have happened more recently.

A study by the National Highway Traffic Safety Administration (NHTSA) compiled speed data for five years, from 1991 to 1996, in 10 states that increased their speed limits immediately following the NMSL's repeal. The report that was submitted to Congress found that the interstate fatalities in these states increased by about nine percent more than expected, while the fatalities in states that did not increase their speed limit remained consistent. The increase in fatalities found in this study followed historical patterns that had been seen after the increase in the NMSL from 55 to 65 mph 10 years prior. It should be noted that this study had limited data available, given both the relatively short study period after the speed limit change for which data were used and the unavailability of supplementary data such as VMT (NHTSA 1998).

A study was conducted in Iowa after the rural interstate speed limit increased from 65 to 70 mph in 2005 to evaluate the effects of the new speed limit on crash frequency. The study found a 52 percent increase in nighttime fatal crashes and a 25 percent increase in severe cross-median crashes. The increases varied more than usual, but these differences were not statistically significant. Total crashes in the state increased by 25 percent after the speed limit increase, which was significant at a 90 percent confidence level (Souleyrette and Cook 2010).

When speed limits on rural interstates in Indiana increased from 65 to 70 mph in 2005, a study on the effects of the increase found that socioeconomic variables, such as age, gender, and income, correlated to a driver's speed choice. It was also found that drivers do not believe that driving above the speed limit significantly threatens their safety (Mannering 2007).

A further study in Indiana that was performed in response to the speed limit increase to 70 mph examined crash risk versus speed limit. The study did not find a statistically significant effect on the severity of crashes on interstate highways. However, on non-interstate highways, the study found that higher speed limits were associated with a greater likelihood of injury and higher injury severity (Malyshkina and Mannering 2008).

After the state of Michigan increased its speed limit on freeways in 1997 from 65 to 70 mph for passenger vehicles only, a study found a 16.4 percent increase in crashes for the sites studied over a period of three months after the speed limit was increased. A 2.4 percent decrease in crashes over the same study period was found for sites where the speed limit did not change (Taylor and Maleck 1996).

A continuation of this study was performed in 1998 that examined drivers' speeds in the three months after the speed limit increase in Michigan. The study did not find significant speed changes for sites where the speed limit did not change, nor did it find a spillover effect of increased speeds for locations near sites where the speed limit increase was applied. For sites where the change was applied, it was found that the median speed increased by 1 mph and the 85th-percentile speed increased by 0.8 mph (Binkowski et al. 1998).

A later Michigan study found that fatal crashes increased by 5 percent and total crashes increased by 10.5 percent after the speed limit change. It was observed that major injury crashes decreased by 9 percent after the speed limit increased and a higher proportion of statewide crashes occurred on freeways after 1997. The study also found a decrease in severe truck crashes but found an increase in the total number of truck crashes after the speed limit change (Taylor 2000).

2.4 Studies on the Impacts of Multiple Simultaneous Speed Limit Changes

Many studies have examined the effects of multiple speed limit changes simultaneously.

A California study defined three groups of highways: roadways with speed limits that increased from 55 to 65 mph, roadways with speed limits that increased from 65 to 70 mph, and roadways that had a speed limit of 55 mph throughout the study period. It was found that fatal collisions increased significantly for the two groups that experienced a speed limit increase, although the increase among the 65 to 70 mph group was only marginally significant (Haselton et al. 2002).

A Utah study analyzed crash data on rural and urban interstates, rural non-interstates, and high-speed non-interstates from 1992 to 1999. Within these roadway categories, various speed limit changes were experienced, such as 55 to 60 mph, 55 to 65 mph, 65 to 70 mph, and 65 to 75 mph. Segments for which the speed limit remained at 65 mph throughout the study period were also included in this study.

The study reported that total crash rates on urban interstates where the speed limit was raised from 60 to 65 mph and fatal crash rates on high-speed rural non-interstates where the speed limit increased from 60 to 65 mph increased sharply. Meanwhile, other statistics, including fatal crash rates and total crash rates on rural interstates, remained stable after a speed limit change (Vernon et al. 2004).

Another study examined roads for 20 years, from 1993 to 2013, in 41 states that each had at least 10 billion VMT in each year of the analysis. During the study period, some states increased the maximum speed limit from 55 to 65 mph or from 65 to 70 mph on different roadway types. The study results revealed that the fatality rate generally decreased over the study period; however, increased maximum speed limits were associated with higher fatality rates. For all roads collectively, a 1 mph increase in the maximum speed limit resulted in a 0.9 percent increase in the fatality rate, while this positive relationship was almost doubled to 1.6 percent for freeways and interstates. For roads other than freeways and interstates, fatality rates increased by 0.8 percent for each 1 mph increase in the maximum speed limit (Farmer 2017).

A recent study evaluated the safety impacts of increased speed limits on Kansas freeways after the speed limits on a number of Kansas freeway segments were increased from 70 to 75 mph in 2011. The study collected crash data and other pertinent factors for three years before (2008 through 2010) and three years after (2012 through 2014) the speed limit change. The results suggest that the speed limit change was associated with a 27 percent increase in total crashes and a 35 percent increase in fatal and injury crashes (Dissanayake and Shirazinejad 2018).

In 2019, a meta-analysis of 39 studies was performed to examine the effects of speed limit increases on traffic fatalities. The authors of the meta-analysis gathered data and results from these 39 studies to formulate two different scenarios for analysis: one for rural interstate roads where speed limits increased and one for statewide road networks. Through their meta-analysis, the authors found that, in general, higher speed limits were correlated with higher fatality counts at both the road level and the state level (Castillo-Manzano et al. 2019).

2.5 Summary of Studies on the Impacts of Speed Limit Changes

Table 1 provides a summary of results from the selected studies outlined previously in this chapter.

Table 1. Summary of literature review results

State	Study Period	Old Speed Limit (mph)	New Speed Limit (mph)	Year of Change	Change in Fatalities after Limit Change	Reference
Indiana	1971–1974	70	55	1974	-67%	Borg et al. 1975
Michigan	1971–1974	65	55	1974	-17%	Enustun et al. 1974
Nationwide	1982–1989	55	65	1987	29% increase in probability	Baum et al. 1991
Washington	1970–1994	55	65	1987	110% compared to expected values	Ossiander and Cummings 2002
Michigan	1978–1988	55	65	1987	+19.2%	Wagenaar et al. 1990
Iowa	1981–1991	55	65	1987	+20%	Ledolter and Chan 1994
Nationwide	1982–1988	55	65	1987	+22%	McKnight and Klein 1990
Nationwide	1976–1988	55	65	1987	+15% (median statewide change)	Garber and Graham 1990
Alabama	1985–1988	55	65	1987	No significant change	Brown et al. 1990
Ohio	1984-1990	55	65	1987	No significant change	Pant et al. 1992
10 states	1991–1996	65	Varies	1996	+9%	NHTSA 1998
Michigan	1994–1999	65	70	1997	+5%	Taylor 2000
Iowa	1991–2009	65	70	2005	+52% at night	Souleyrette and Cook 2010
Nationwide	1993–2013	Varies	Varies	Varies	+0.8% per 1 mph increase	Farmer 2017
Kansas	2008–2014	70	75	2011	+35% increase in fatal and injury crashes	Dissanayake and Shirazinejad 2018

Despite the extensive coverage of this topic in the literature, research has been somewhat limited with respect to the most recent speed limit increases, particularly to speeds of 75 mph and above. Consequently, this study aims to address this gap by providing insights into the potential impacts of these increases while controlling for other pertinent factors.

2.6 Studies on Average Speed and Speed Variance

Beyond the relationship between speed limits and traffic crashes and fatalities, understanding how average speeds and speed variation affect crash rates and crash severities can help further improve roadway safety.

Early research in this area reported that a driver has a higher risk of experiencing a crash as the difference between the vehicle speed and the average traffic speed increases (Solomon 1964).

Lave (1985) concluded that no evident relationship was observed between fatality rate and average speed, but speed variance was highly correlated with fatality rate. The author reported that the safest driving speed was the median speed and that deviations from this speed in either direction increased the crash risk, meaning both slower and faster vehicles were more likely to be involved in crashes.

Later, Garber and Gadiraju (1989) studied the factors that cause increased speed variances and the relationship between speed variance and crash rate. The authors reported that the minimum speed variance was observed when the posted speed limit was 5 to 10 mph lower than the design speed and that the speed variance increased as the differential between the design speed and the posted speed limit increased. The authors explained that drivers chose their driving speed based on the roadway's geometric characteristics, and higher driving speeds could be anticipated on roadways with improved geometry regardless of the posted speed limits. Also, similar to the previous findings, the authors reported that crash rates increased with higher speed variances and found no significant relationship between crash rates and average speeds.

Oh et al. (2005) also identified that the standard deviation of speed was the most significant variable when estimating the likelihood of crashes. Research conducted by Abdel-Aty et al. (2004) determined that the average lane occupancy at upstream locations and the variation in speeds downstream were the most significant variables in predicting the likelihood of crash occurrences.

However, other studies have reported contradictory results. For example, a study in Australia quantified the relationship between travel speed and fatal crash risk using a case-control study. The researchers concluded that vehicles traveling 10 km/h above the average speed had double the risk of being involved in a fatal crash and that this risk increased to six times greater when the vehicle speed was 20 km/h higher than the average speed. The results also indicated that slower vehicles did not have a significantly higher risk of being involved in a fatal crash. The researchers concluded that reducing traffic speed was more effective in reducing crash frequency than reducing speed differences (Kloeden et al. 2001).

A year later, a study conducted by the same researchers reported similar findings that correlated crash frequency with vehicle speed rather than speed variation and other factors. The researchers indicated that a small reduction in absolute traveling speed could lead to a decrease in fatal crash frequency (Kloeden et al. 2002).

Overall, there remains ambiguity as to the relationship between crashes, travel speed, and speed variance. Some studies have found that speed variance has a greater impact on crash risk than average speed, while others report that crash risk is affected more by mean speed than by speed variance.

Ultimately, traffic crashes occur due to a complex combination of factors, including traffic flow, roadway conditions and geometry, human behavior, etc. This study aims to provide further research that can inform continuing policy debates regarding maximum statutory speed limits.

3. DATA COLLECTION AND SUMMARY FOR NATIONWIDE ANALYSES

A series of nationwide data sets was developed to conduct a longitudinal comparison of fatality trends on rural interstates in consideration of maximum speed limits. These data sets were prepared at two levels of aggregation: the state-level, where total rural interstate fatalities were aggregated for each state over each year of the analysis period, and the segment-level, where rural interstate fatalities were aggregated on individual road segments within each state.

The state-level aggregation scheme allowed for a comparison of total rural interstate fatalities across states with different maximum posted speed limits, while the segment-level data set allowed for an evaluation of the safety performance of individual segments where speed limits have changed over time.

3.1 Nationwide State-Level Fatality Data Set

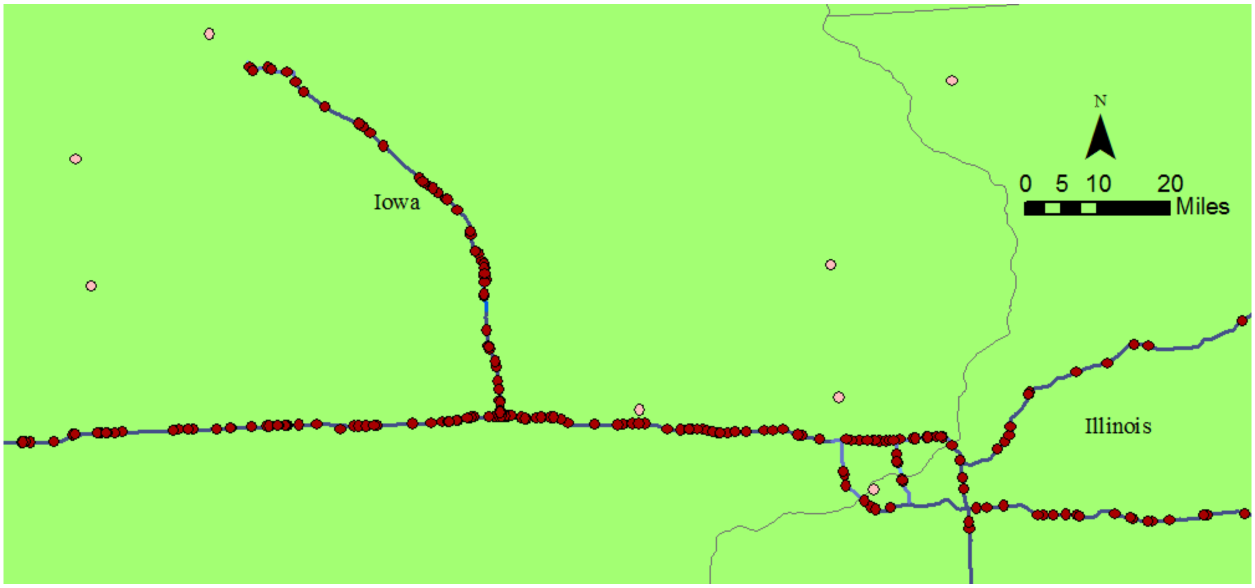
The state-level analysis for this study required assembly of a data set from a variety of sources. The data used include information on population demographics, roadway mileage, VMT, seat belt usage, fuel prices, fatality rates, and speed limit information. Due to the nature of some of these variables, all data were aggregated to the state-year level. This yielded a longitudinal data set where each state, as well as the District of Columbia, has one record per year for each of these variables. The data cover the 16-year period from 2001 through 2016.

The fatality data used for this study come from NHTSA's annual FARS database, which provides information about all traffic crashes nationwide that produce a fatality. Examples of information provided by FARS include the following:

- Crash-level information, such as location and time of crash, type of crash, first harmful event, functional class of roadway, weather and lighting conditions, and number of vehicles and persons involved in the crash
- Vehicle-level information, such as area of impact, sequence of events, and travel speed
- Person-level information, such as type of occupant (e.g., driver or passenger), position within the vehicle, age, race, gender, and evidence of alcohol or drug use

For this analysis, the pertinent fatal crashes are those that occurred on interstate highways between 2000 and 2016. To obtain these data, all crashes where the roadway functional classification was either Interstate, Rural Interstate, or Urban Interstate were queried. This query produced 73,540 fatal crashes along interstate highways. These crashes were mapped using the database fields indicating latitude and longitude, which were available for most crashes occurring in 2001 or later.

On examining the locations of the fatal crashes, errors in geocoding were discovered that resulted in some non-interstate crashes being included. There were some cases where the geocoding of a crash was nowhere near the physical interstate, such as those shown in Figure 2, where those crashes are denoted with a lighter color.



Lighter/yellow circles indicate crashes incorrectly geocoded to be along interstates.

Figure 2. Example of crashes not along interstate roadways

Other crashes included in the data set occurred on a ramp, a cross street, or a nearby frontage road. Figure 3 shows an example of a crash on a ramp on I-80 near Des Moines, Iowa.

Imagery Source: ESRI ArcGIS Online and data partners

Figure 3. Example of a crash on a ramp

Because many of these crashes could not easily be linked to the characteristics of the nearest roadway, the data set needed to be refined.

The goal of refining the crash data set was to include only fatal crashes that occurred on an interstate mainline. This meant that any crash that had missing latitude and longitude information had to be eliminated, because there was no clear way of knowing exactly where along the mainline the crash occurred or whether the crash was on the mainline at all. Additionally, all crashes that were not coded on an interstate mainline had to be eliminated. To achieve this goal, manual review of a subset of these fatal crashes was undertaken.

This subset consisted of all crashes located outside of a 200-foot radius of the mainline of the interstate as determined by the shapefile. A 200-foot radius was chosen because that is a general estimate of the width of an average interstate right-of-way. The subset was reviewed manually due to cases of wide medians, where a crash could be located outside the radius but still on the mainline interstate. An extreme example of this is shown in Figure 4, which shows part of I-24 northwest of Chattanooga, Tennessee, where the directions of travel are separated by nearly a mile to navigate through a mountain pass.

Imagery Source: ESRI ArcGIS Online and data partners

Figure 4. Example of a roadway with a wide median

In this case, the shapefile only shows the southbound direction of travel (shown in blue).

In addition to the crash points found outside the buffer that belong in the data set, many crashes were found inside the buffer that do not belong in the data set. Specifically, the crashes that occurred along a ramp within 200 feet of a mainline interstate needed to be eliminated. To determine those eligible for review, a filter was applied to the “relation to junction” field to only include crashes marked Intersection, Intersection-related, Driveway Access, Entrance/Exit Ramp Related, Driveway Access Related, or Other Location within Interchange Area. An example of one of these crashes is shown in Figure 5, located on I-290 in suburban Chicago, Illinois.

Imagery Source: ESRI ArcGIS Online and data partners

Figure 5. Example of a crash on a ramp within the 200-foot buffer

In this case, the crash fell within the 200-foot buffer (denoted with white lines) but was located along the eastbound off-ramp. Because there was no guarantee that any given crash in the subset needed to be eliminated, each crash in the subset had to be manually reviewed.

After manual review of the crash data set, the number of crashes useful for this study decreased to 57,493. This data set was then linked with the shapefiles from the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) that were compiled for the state-level fatality analysis. This was performed using the Spatial Join feature in ArcGIS.

Most of the roadway information for the analyses came from the FHWA Highway Statistics series (FHWA Office of Highway Policy Information 2017), which provides annual information about lane length and VMT for each state. This information is broken down by roadway functional class, as well as whether the road is in an urban or rural location, allowing for straightforward disaggregation of the data specific to rural interstates.

In addition, the FHWA Highway Statistics series provides information about motor vehicle registration and licensed drivers by state. This motor vehicle registration information is broken down by vehicle type (i.e., auto, bus, truck, or motorcycle) and ownership (i.e., privately or publicly owned). The licensed driver information breaks down all licensed drivers by age and gender, with the age ranges broken down into five-year increments. In addition, young drivers (i.e., less than 25 years of age) are broken down by age in increments of one year.

The demographic information is based on U.S. Census Bureau population estimates (U.S. Census Bureau 2018). Like the licensed driver fields, the population fields are broken down by gender and age range in five-year increments. These data were largely collected to confirm which states have higher populations and therefore higher crash risk. In addition to population data, information was collected on seat belt usage for each state and year. These data came from the NHTSA Traffic Safety Fact Sheets (NHTSA 2017).

Data were also collected for several other factors that may be expected to be associated with fatality rates. These include air temperature, total precipitation, and average fuel prices.

The temperature and precipitation information was collected from the National Oceanic and Atmospheric Administration’s National Centers for Environmental Information (NOAA National Centers for Environmental Information 2018), and averages were taken within each state. Because weather can vary greatly within states, the weather fields were only used as general estimates for weather, not necessarily the actual weather conditions of the entire state.

The fuel price information came from the Energy Information Administration (U.S. Energy Information Administration 2017) and included average fuel prices in cost per million BTU. This was converted into the cost per gallon of gasoline, following the assumption that one gallon of gasoline is the energy equivalent of 115,000 BTU.

The final set of data that was collected is the most important: the speed limit data. This data set included the maximum rural interstate speed limit in each state, as well as the total mileage, VMT, and lane mileage values for all roadways in the state and the percentages of these values for roadways at the maximum speed limit. The data were collected from a number of different sources. The current maximum speed limits can be found via several sources, including the Insurance Institute for Highway Safety (IIHS) (IIHS Highway Loss Data Institute 2018) and an FHWA Highway Information Quarterly Newsletter from April 2002 outlining the maximum speed limits in 2000 (FHWA Office of Highway Policy Information 2002). The dates of any speed limit changes since then were found by searching press bulletins and news articles.

The total mileage of urban and rural interstates and the percentage of mileage at each speed limit in each state were calculated using the FHWA HPMS shapefiles (FHWA Office of Highway Policy Information 2018). Through the segment milepost, speed limit, and urban zone fields within the HPMS, the research team was able to determine the milepost of each change in speed limit along each interstate highway.

The Google Street View mapping service was also used to supplement the shapefiles in determining the locations of speed limit changes. This process was completed for each state using the most recent shapefile available at the time the data were collected. For most states, this was the 2015 shapefile. However, the 2015 shapefiles for California, Missouri, and Utah were missing significant lengths of interstate highway; the 2014 shapefiles were therefore used instead for these three states. A map of the speed limits on interstates across the country is found in Figure 6.

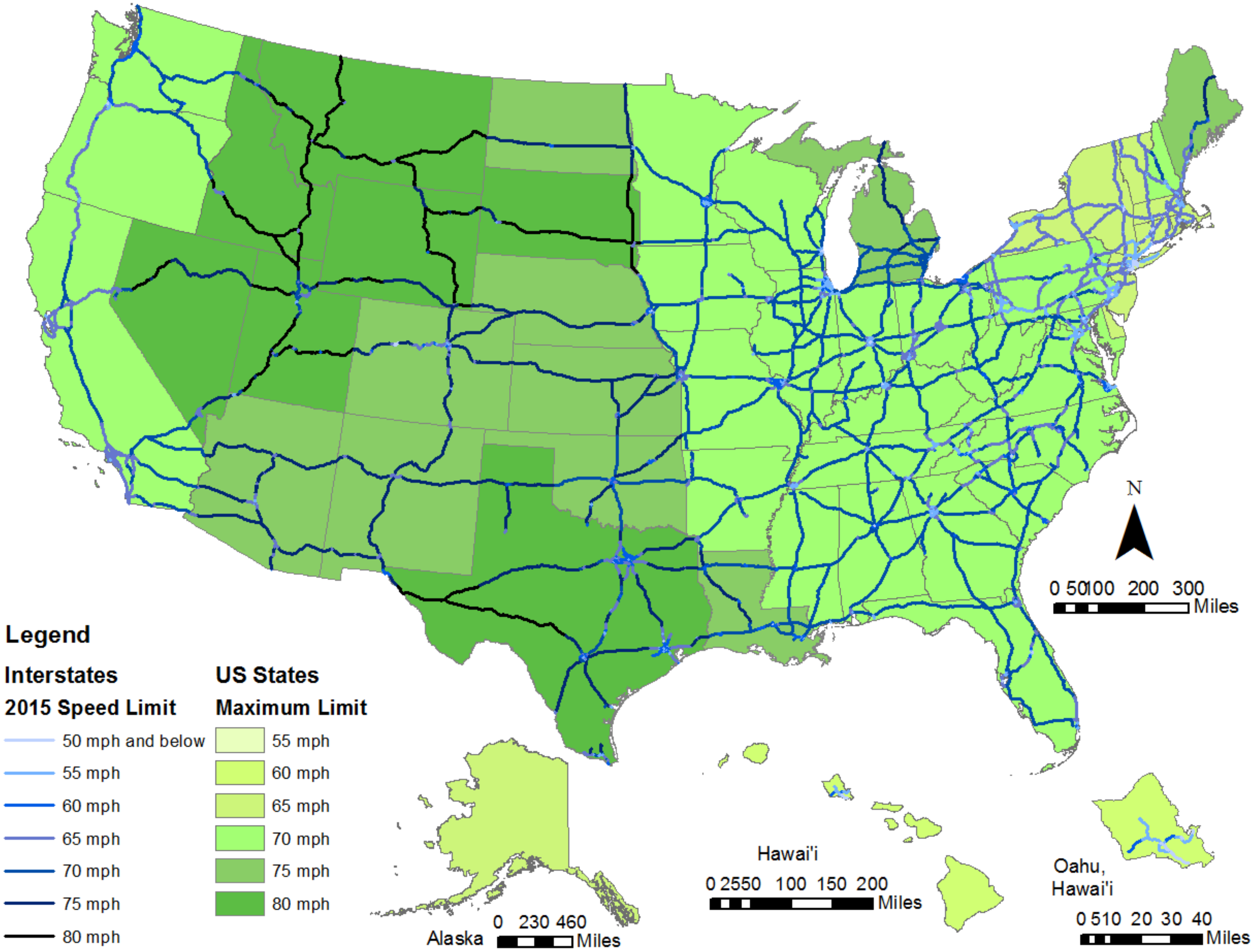


Figure 6. Speed limits across the interstate system

Once the speed limit was obtained for every segment of interstate highway in each state, the urban and rural interstate mileage fields and the percentage of urban and rural interstate mileage at each speed limit were calculated. To determine any mileage that had been added or subtracted to the interstate system since 2000, a 1999 Rand McNally Road Atlas was used to compare mileage (Rand McNally 1999).

To calculate the speed limits in years prior to 2015, the assumption was made that the speed limit of any given roadway had not changed unless the state's maximum limit had also changed and that a road segment with the maximum speed limit in 2015 also had the maximum speed limit prior to any statewide change. In addition, due to the unavailability of historical records, it was assumed that the urban area boundaries outlined in the HPMS did not change over the course of the study period.

Because the data in the FHWA Highway Statistics series are given in terms of lane mileage and VMT, the percentages of lane mileage and VMT for roadways at the maximum speed limit in each state were also calculated. These percentages provided a better estimate of the risk of speed limit-related crashes than percentage of mileage. However, due to time constraints and FHWA shapefile availability, only the percentages for the most recent year (i.e., 2015 or 2014) were recorded. The values for these fields for the remaining years are estimates based on the percentage of total miles for each record and the trends of lane mileage and VMT from year to year within each state.

Table 2 presents summary statistics (i.e., minimum, maximum, average, and standard deviation) for each of the data sources presented in this section.

Table 2. Summary statistics for state-level rural model

Variable	Average	Std. Dev.	Minimum	Maximum
Fatal crashes on rural interstates	30.23	30.45	0.00	206.00
Proportion of younger drivers (<25 years)	0.133	0.020	0.049	0.227
Proportion of older drivers (≥65 years)	0.164	0.024	0.096	0.249
Rural interstate VMT (hundred millions)	53.42	37.50	2.94	202.26
Proportion of vehicles that are autos	0.432	0.070	0.246	0.750
Proportion of vehicles that are motorcycles	0.037	0.017	0.012	0.162
Proportion of vehicles that are trucks	0.528	0.065	0.211	0.713
Population density (persons/mi^2)	190.67	262.14	5.09	1,216.24
Seat belt usage rate (proportion)	0.823	0.090	0.496	0.984
Average monthly average temperature (°F)	53.15	7.82	38.50	73.40
Average monthly maximum temperature (°F)	64.06	8.04	48.70	83.20
Average monthly minimum temperature (°F)	41.52	7.72	27.30	63.60
Average monthly precipitation (in.)	37.49	14.84	6.24	73.78
Gas price per gallon ($)	2.37	0.71	1.08	3.71
Maximum speed limit (mph)	70.22	4.22	65.00	80.00
Maximum speed limit 80 (1=yes, 0=no)	0.040	0.20	0.00	1.00
Maximum speed limit 75 (1=yes, 0=no)	0.261	0.44	0.00	1.00
Maximum speed limit 70 (1=yes, 0=no)	0.404	0.49	0.00	1.00
Maximum speed limit 65 (1=yes, 0=no)	0.295	0.46	0.00	1.00
Rural interstate mileage	583.58	349.05	17.84	1,998.44
Proportion of rural mileage at speed limit 80	0.024	0.130	0.000	0.945
Proportion of rural mileage at speed limit 75	0.235	0.394	0.000	1.000
Proportion of rural mileage at speed limit 70	0.402	0.455	0.000	1.000
Proportion of rural mileage at speed limit 65	0.326	0.433	0.000	1.000
Proportion of rural mileage at speed limit 60	0.004	0.011	0.000	0.058
Proportion of rural mileage at speed limit 55	0.007	0.023	0.000	0.137
Proportion of rural mileage at speed limit ≤50	0.002	0.007	0.000	0.040

n=752 state-years

Because all crash data from before 2001 were eliminated due to lack of geographic information, this study's state-level analysis began at 2001. Thus, the total number of observations comprises 16 years of data for 47 states for the rural model. (Data for Alaska were not recorded due to the state's relative lack of interstates and because its interstates that do exist are unsigned and not necessarily designed to the same standards as those of the remaining 49 states. Also, data for Delaware, Hawaii, and the District of Columbia were not recorded because their interstates are all classified as urban.)

3.2 Nationwide Roadway-Level Fatality Data Set

Once the state-level information had been collected, the goal was to create a data set for a regression model where each data point corresponded to a segment-year combination with information about traffic volume, number of lanes, speed limit, and number of fatal crashes.

Because the original data set from the HPMS included hundreds of thousands of segments, the research team decided that it would be easier to work with a data set that combined adjacent segments with identical characteristics. To achieve this, MATLAB code was formulated and run to automatically combine adjacent segments with the same route number, urban code, speed limit, traffic volume, and number of lanes. Before the code was run, the original data set was sorted by state, route number, and milepost to ensure that segments that are adjacent in the shapefile appeared in the correct order in the data set. The MATLAB code can be found in the Appendix.

The *Highway Safety Manual* discourages using segments shorter than 0.1 miles for highway safety analyses (AASHTO 2010), so all segments less than 0.1 miles long were combined with adjacent segments. While most of these shorter segments were combined with adjacent segments when the MATLAB code was run, for some short segments at least one of the four parameters differed from the corresponding parameter(s) for the adjacent segment. If the parameter that differed between the adjacent segments was traffic volume or number of lanes, the short segment and the adjacent segment were combined, and the value of the new parameter for traffic volume or number of lanes was the weighted average of the values of the original segments. If the parameter that differed was urban code, the urban code of the short segment was changed to that of the longer segment, and the two segments were combined. Since this was the case for only approximately 50 segments, the model results were not expected to be affected significantly by this change. After these changes were made to the data set, all segments shorter than 0.1 miles had been merged with longer segments. The final data set consisted of 23,065 segments ranging in length from 0.1 miles to over 37 miles.

The roadway data set thus far consisted of all interstate segments in the HPMS shapefiles but included data for only one year. Since the goal in building the data set for the regression model was to associate each data point with a segment-year combination, the data set was copied for each year from 2001 to 2016, increasing the size of the roadway data set sixteenfold to 369,040 segments. To ensure the accuracy of the roadway-level data set, the crashes were broken down by year, allowing data from the state-year data set to be incorporated into the segment-year data set.

If a state’s maximum speed limit had increased at some point during the study period, the speed limits of certain segments in the roadway data set would be higher than what was legally allowed in the state at the time. In such cases, the speed limit was updated to reflect the then-current laws, following the previously stated assumption that any road that currently has the state’s maximum speed limit also had the maximum speed limit before the speed limit was increased.

The final change made to the roadway data set was the elimination of segments that did not exist during a particular year of the study. Since 2001, nearly 1,500 miles of interstate highways have been added, representing either new construction or the upgrading of existing roadways. To ensure the accuracy of the roadway data set, segments on roadways that became interstates at some point during the study period were deleted in the years before the upgrade, reducing the number of segments to 361,391. In this process, approximately 30 crashes were also deleted because they occurred on roads that were not interstate highways at the time of the crash.

The final roadway-level data set included 57,408 fatal crashes on the 361,391 interstate segments. The data set contains 102,140 rural interstate segments, with 22,733 fatal crashes on these segments during the study period. Table 3 displays the numbers of segments, miles, and fatal crashes on rural interstates in the data set, broken down by speed limit.

Table 3. Summary of rural interstate segments

Speed Limit (mph)	Number of Segments	% of Total	Total Length (mi)	% of Total	Number of Fatal Crashes	% of Total
60 or less	1,911	1.87%	5,851	1.33%	252	1.11%
65	29,664	29.04%	106,054	24.17%	4,204	18.49%
70	42,296	41.41%	176,279	40.17%	11,501	50.59%
75	25,889	25.35%	134,611	30.67%	6,175	27.16%
80	2,380	2.33%	16,054	3.66%	601	2.64%
Total	**102,140**	**100.00%**	**438,849**	**100.00%**	**22,733**	**100.00%**

Within the roadway-level crash data set, there were a number of crash subsets that may have been affected by speed limit. These included not only the total number of fatal crashes and fatalities but also crashes where speeding is coded as a contributing factor as well as those indicated to have involved driver distraction. For crashes coded as involving speeding, data were only available from 2009 onward, and data from distraction-related fields were only available beginning in 2010. A breakdown of crashes by year and crash type is found in Table 4. Because of the low mileage of rural interstates with a speed limit of less than 65 mph, these segments were not included in the analysis or the summary statistics in Table 4.

Table 4. Summary statistics of crash types

Year	Total Fatal Crashes	Total Fatalities	Crashes Coded as Involving Speeding	Crashes Coded as Involving Distraction
2001	1,226	1,474	N/A	N/A
2002	1,417	1,735	N/A	N/A
2003	1,449	1,773	N/A	N/A
2004	1,597	1,988	N/A	N/A
2005	1,825	2,211	N/A	N/A
2006	1,647	1,977	N/A	N/A
2007	1,544	1,848	N/A	N/A
2008	1,463	1,714	N/A	N/A
2009	1,266	1,486	348	N/A
2010	1,301	1,536	377	191
2011	1,211	1,393	316	163
2012	1,196	1,417	312	182
2013	1,251	1,485	357	190
2014	1,185	1,387	303	182
2015	1,378	1,602	365	228
2016	1,525	1,769	347	236
Total	**22,481**	**26,795**	**2,725**	**1,372**

Table 5 shows the summary statistics of the variables from the roadway data set used in the road-level analysis. While the roadway data set incorporates many variables from the state-level data set, these variables are omitted from Table 5 for the sake of space.

Table 5. Summary statistics for the national road-level rural interstate model

Variable	Average	Std. Dev.	Minimum	Maximum
Segment Length (mi)	4.29	3.89	0.10	37.29
Traffic Volume (vpd)	26,856	19338	327	189,000
Speed Limit	69.78	4.48	40	80
Speed Limit 80 (1=yes, 0=no)	0.023	0.151	0.00	1.00
Speed Limit 75 (1=yes, 0=no)	0.253	0.435	0.00	1.00
Speed Limit 70 (1=yes, 0=no)	0.414	0.493	0.00	1.00
Speed Limit 65 (1=yes, 0=no)	0.290	0.454	0.00	1.00
Number of Lanes	4.27	0.81	2	12
Number of years since speed limit changed	4.57	1.23	0	5

n=102,140 segment-years, vpd=vehicles per day

The final field in Table 5, the number of years since speed limit changed, was included with the intent of accounting for driver confusion due to the change in speed limit, the idea being that in the first few months and years after a speed limit change, drivers would travel with a high variance of speed for a period of time until their speeds gradually become more consistent. A cap was arbitrarily placed on this variable at five years, because it was thought that by that time drivers would generally be used to the new speed limit. For this reason, most data points for this variable are five years.

4. DATA COLLECTION AND SUMMARY FOR IOWA-SPECIFIC ANALYSES

In addition to the national-level data sets, an Iowa-specific data set was developed to allow for a comparison of trends in traffic crashes, injuries, and fatalities with a particular emphasis on changes since the 2005 speed limit increases in Iowa.

4.1 Iowa-Specific Segment-Level Crash Analysis

The Iowa-specific crash analysis relies on several different datasets, which are outlined in the following sections.

4.1.1 Roadway Information

The interstate roadway network used in the Iowa-specific analysis was obtained from the Iowa DOT's online Geographic Information Management System (GIMS) portal, which provides traffic control and geometric characteristics for state-maintained roadways. Each roadway segment is assigned a unique identifier in the MSLINK field.

To evaluate the potential impacts of the speed limit policy on Iowa highways, various roadway geometric and traffic characteristics were extracted from the GIMS database. To obtain Iowa's interstate segments, the ROAD_INFO_2015 file, which had the most current data at the time of study, was imported into ArcMap.

Several fields from the file, such as INTERSTATE and FUNCTION, were utilized to identify the interstate segments. The INTERSTATE field indicates whether a road system is classified as an interstate. However, solely relying on this attribute would result in the inclusion of unwanted road segments such as ramps. Therefore, the FUNCTION field was introduced to distinguish mainline and non-mainline road segments. The following values were selected by applying a filter to the attribute FUNCTION:

- mainline normal (00)
- mainline - 1st innerleg (09)
- mainline - 2nd innerleg (10)
- mainline - 3rd innerleg (11)
- mainline - 4th innerleg (12)
- mainline - 5th innerleg (13)
- mainline - 6th innerleg (14)
- mainline - 7th innerleg (22)
- mainline - 8th innerleg (23)
- mainline - 9th innerleg (24)
- mainline - 10th innerleg (25)

After this process, some redundant segments remained. These were removed manually using ArcMap's Editing tool. Eventually, a total of 4,164 interstate segments were selected.

Because the GIMS database is updated annually, the information collected was disaggregated by year so that multiple years of data could be included. The MSLINK field was used as a unique identifier to link roadway and traffic characteristics. The following information was obtained from the GIMS database for this study:

- Segment length
- Data year
- Indicator for urban/rural area
- Median type, presence of median barrier, and median width
- Number of lanes, lane type, and acceleration/deceleration lane
- Annual average daily traffic (AADT)
- Shoulder width
- Presence of rumble strips
- Speed limit

Some variables of interest were not provided by GIMS directly and required additional processing to obtain. For example, the indicator for urban/rural area was derived from the URBANAREA attribute, which identifies whether the road segment is within a specific urban area assigned by the FHWA. Segments with predefined codes were treated as urban segments and were given a value of "1" to indicate an the urban area, while segments with code "9999" were given a value of "0" to indicate a rural area. The presence of median barriers was identified by the median type attribute, which categorizes medians into different groups. Segments with acceleration/deceleration lanes were identified by the lane type attribute, which specifies the type of each lane from the left side of the road segment to the right side.

Since the information was disaggregated by year, new construction or resurfacing of roadway segments might have taken place at some point during the study period, at which point a new MSLINK value would have been assigned to the roadway segment where work had been done. Therefore, 208 out of 4,164 segments had missing values in 2008, which was the start of the study period and the year with the largest number of missing values. To verify whether these road segments had previously existed or were newly constructed, quality assurance/quality control (QA/QC) was conducted for those segments using Google Street View. It was found that no completely new interstate segments had been constructed. Therefore, to add the missing values to the data set, ArcMap was used to locate the nearest segment on either side of the null segments; the values were filled in by averaging the values of the data from the two adjacent segments. The same process was repeated for each of the nine years of data.

Additionally, a large number of short segments had lengths of less than 0.1 miles. To eliminate the potential bias that these short segments might introduce when developing crash prediction models, segments shorter than 0.095 miles (i.e., those whose lengths do not round up to 0.1 miles) were merged with the nearest adjacent segments. Given that the two segments to be merged might have different characteristics, the characteristics of the newly combined segments were represented using weighted average values by length for all corresponding variables. By merging the short segments (<0.095 miles) with adjacent segments, the number of interstate segments was reduced from 4,164 to 2,578. Of these, 1,843 segments had the 70 mph speed limit.

Summary statistics for these interstate segments are given in Table 6.

Table 6. Summary statistics for average interstate bidirectional mileage and vehicle miles traveled, 2008 to 2016

Interstate Type	Mileage (bidirectional)	Vehicle Miles Traveled (100 M)
55 mph	55	5.129
60 mph	32	4.083
65 mph (urban)	190	15.735
65 mph (rural)	34	1.365
70 mph (urban)	65	4.043
70 mph (rural)	1,187	45.272

Note that all of the low-speed interstate roadways with speed limits of 55 or 60 mph are in urban areas. It was found that only 22% of interstate miles are within urban areas, while the average annual VMT on urban interstates accounts for 38% of the total VMT on all interstates.

4.1.2 Crash Information

Another essential database used in this study was the Iowa statewide crash database maintained by the Iowa DOT, which includes information regarding crashes that have occurred on the Iowa roadway network, such as vehicle characteristics, driver characteristics, crash environment, roadway characteristics, injury/protective devices, etc. For the purpose of this study, crash information was collected from 2008 to 2016. Aggregate data for years prior to 2008 were obtained from an earlier short-term evaluation of the 2005 speed limit increases (Souleyrette et al. 2009, Souleyrette and Cook 2010).

The variables of interest in the crash database included crash key, crash location, identifier for type of roadway/ramp, crash severity, weather/road surface conditions, year of crash, manner of collision, and first harmful event. To obtain only crashes that occurred on a mainline interstate, the interstate network layer described above and the crash layer were both added into ArcMap. A 100-foot buffer on both sides of the roadway was created along the interstate network to include only crashes that occurred within the buffer. This method resulted in the inclusion of some crashes that occurred on interstate ramp segments. To remove ramp crashes, the ramp identifier in the crash database was used. The crash severities for individual crashes were also collected to investigate the severity-specific crash rates.

4.1.3 Weather Data

Weather data were requested from the Iowa Environmental Mesonet (IEM). IEM provides access to the raw observations from the National Weather Service Cooperative Observer Program (NWS COOP) network in the form of downloadable daily reports. The requested data set included observations from 115 stations across Iowa between January 2008 and December 2016. The variables included latitude and longitude coordinates, daily high temperature, daily low temperature, daily precipitation, and daily snowfall.

After the weather data were downloaded, data cleaning was performed by eliminating the data gathered from stations where the yearly total for any of the variables of interest had a value of zero or a value that was three standard deviations away from the average of all observed stations. Such values were counted as outliers, and the data from stations with outliers were removed from the data set. Yearly average values for temperature, precipitation, and snowfall for each of the remaining stations were then calculated, and the data were imported into ArcMap.

Since the weather stations provide only point data and can only represent the weather conditions in their respective surrounding regions, stations within 20 miles of the interstate network were first selected to accurately represent the weather characteristics on the interstate network. A 25-mile buffer was then created around each of these weather stations, which provided total coverage of the interstate network.

The data from weather stations with an interstate within the 25-mile buffer were joined to the nearest interstate segments. Because some weather stations are close to one another and the 25-mile buffer created some overlap, an average was taken for overlapping stations when the weather data were joined to the interstate segments. Because different weather stations were eliminated in each of the nine years of weather data due to missing records or outlier values, the joining process was repeated for each of the nine years of weather data. Figure 7 illustrates the selected weather stations and buffers for 2016.

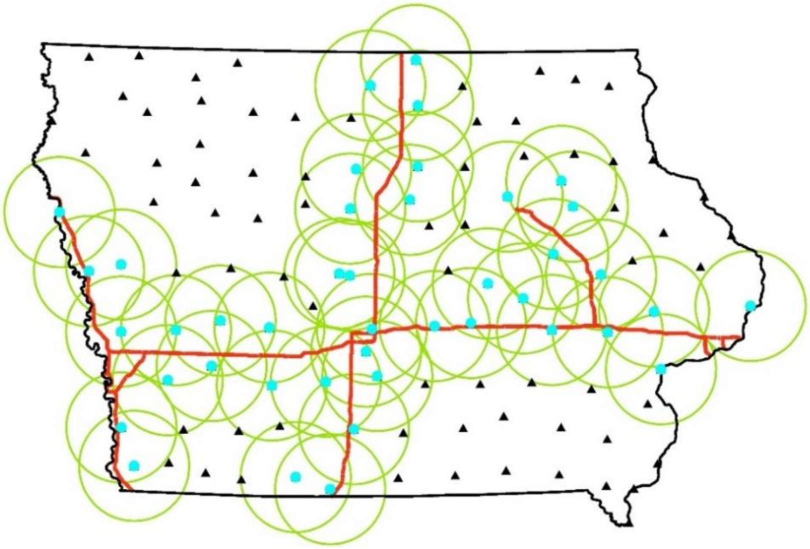


Figure 7. Selected weather stations and buffers along Iowa interstates for 2016

4.1.4 Automatic Traffic Recorder (ATR) Data

The Iowa DOT collects vehicle speed data using automatic traffic recorder (ATR) equipment at permanent sites across Iowa’s highway system. Speed reports for Iowa’s highways are generated on a quarterly basis. The quarterly speed reports from 2013 to 2016 were requested from the Iowa DOT; however, three quarterly reports were missing during this four-year period, namely the second quarter of 2014 and the second and third quarters of 2015.

Forty ATR locations are identified in the reports, ten of which are on interstates and seven of which are on rural interstates. The estimated locations of the interstate ATR stations were mapped out manually in ArcMap according to the location description provided with the reports. Figure 8 shows the Iowa interstate network in relation to these ATR stations.

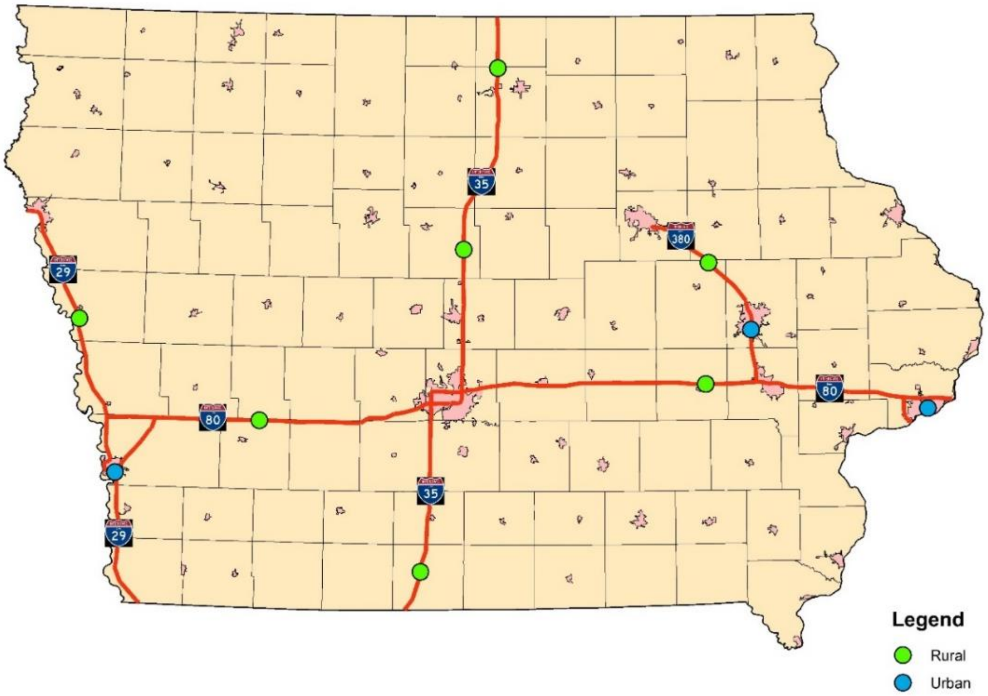


Figure 8. ATR stations on Iowa Interstates

Since the quarterly speed reports only record the count of vehicles that fall within each speed range, it was necessary to estimate the average speeds as well as the percentile speeds. To estimate average speeds, a midpoint was applied to each speed range. For the speed ranges of 40 mph and below and 86 mph and above, the midpoints were established at 37.5 mph for the lower speed boundary and 87.5 mph for the upper speed boundary. That is, because the quarterly reports present speed ranges in increments of 5 mph, 2.5 mph was deducted from the higher speed boundary and added to the lower speed boundary. The number of vehicles traveling at speeds higher or lower than these two speed boundaries was generally low; therefore, the midpoint calculations for the highest and lowest speed ranges were not expected to significantly alter the average speed estimation.

The average speeds were then calculated by multiplying the count of vehicles in each of the speed ranges by the corresponding midpoints, adding up all of the products, and dividing the sum of the products by the total number of vehicles. To estimate the 85th percentile speed, the percentage of traffic exceeding the lower bound of all speed ranges was calculated, and logical functions were applied to locate which speed range contained the 85th percentile speed. The proportion was then taken to estimate the 85th percentile speed.

4.1.5 INRIX Data

Conventionally, freeway traffic data are collected through fixed location detectors by state DOTs and transportation agencies. In recent years, several companies have started to collect traffic data through probe vehicle technology. These data are obtained through the collection of vehicle position data from fleet navigation services, smartphone apps, and other sources. The raw vehicle position data are aggregated to yield average speeds for predefined road segments. Compared to data from traditional fixed-location sensors, probe data can provide more comprehensive coverage of roadway systems and forgo the costs of sensor deployment and maintenance.

INRIX is a key provider of probe data. INRIX provides speed data at a one-minute reporting intervals and two segment formats: traffic message channel (TMC) and XD segments. TMC segments are defined by an industry consortium. On controlled-access highways, TMC segments generally span the distances between interchanges and can be several miles long. Many shorter TMC segments exist as well, particularly for roadways involving complex interchange geometry. XD segments are defined by INRIX. These segments are more consistent in length, mostly 1 to 1.5 miles long. For this study, TMC data were used because more years of data are available for this segment format.

INRIX provides both real-time and historical data. Generally, INRIX provides excellent coverage of interstate highways, with real-time data consistently available for the entire interstate system in Iowa.

INRIX TMC real-time data were acquired for Iowa interstates from 2013 to 2016. The quality of the data was evaluated by extracting and analyzing one month of raw data (July 2016) for a sample segment of each segment type: urban 55 mph (TMC: 118+04661), urban 60 mph (TMC: 118+04643), urban 65 mph (TMC: 118+04644), urban 70 mph (TMC: 118+04859), rural 65 mph (TMC: 118+05030), and rural 70 mph (TMC: 118+04815). Table 7 summarizes these data.

Table 7. Summary statistics of sample INRIX operational speed for one month (July 2016)

	Min	Max	Mean	Std. Dev.	Percentage Below Speed Limit (%)
Urban 55 mph	10	75	58.65	3.79	6
Urban 60 mph	13	75	60.47	3.64	42
Urban 65 mph	7	75	61.26	3.99	82
Urban 70 mph	5	75	67.39	3.7	75
Rural 65 mph	43	75	66.72	2.55	16
Rural 70 mph	37	75	67.28	2.41	83

Examination of the INRIX speed data revealed that the maximum reported speed was 75 mph. The standard deviation of the raw speed data was higher in urban areas than in rural areas. The percentages of one-minute raw speeds that were below the speed limit during the one-month period were high, especially on urban 65 mph, urban 70 mph, and rural 70 mph segments. Similarly, the mean speeds were much lower than the actual speed limits. A likely reason for this is that the INRIX data contain many freight and other commercial vehicles. These vehicles have more consistent driving behavior because they tend to travel the same routes on a regular basis (Travers 2010), but they also tend to travel at a lower speed than other traffic. The trends illustrated in Table 7 are representative of the overall data set.

Additional investigation was performed to assess the upper bound of speeds for the INRIX data. Five segments were selected, all rural interstates with a speed limit of 70 mph: one from I-29 (TMC: 118-04967), two from I-80 (TMC: 118+04747 and 118+04815), one from I-35 (TMC: 118-04843), and one from I-380 (TMC: 118N04932). These specific segments were chosen because they have little curvature and are far from urban areas. Figure 9 indicates the locations of the selected segments.

Figure 9. Selected 70 mph rural interstate segments

Five probability density functions (Figure 10) were plotted for the selected 70 mph segments to assess the stability of the speed distribution over the course of one month (July 2016).

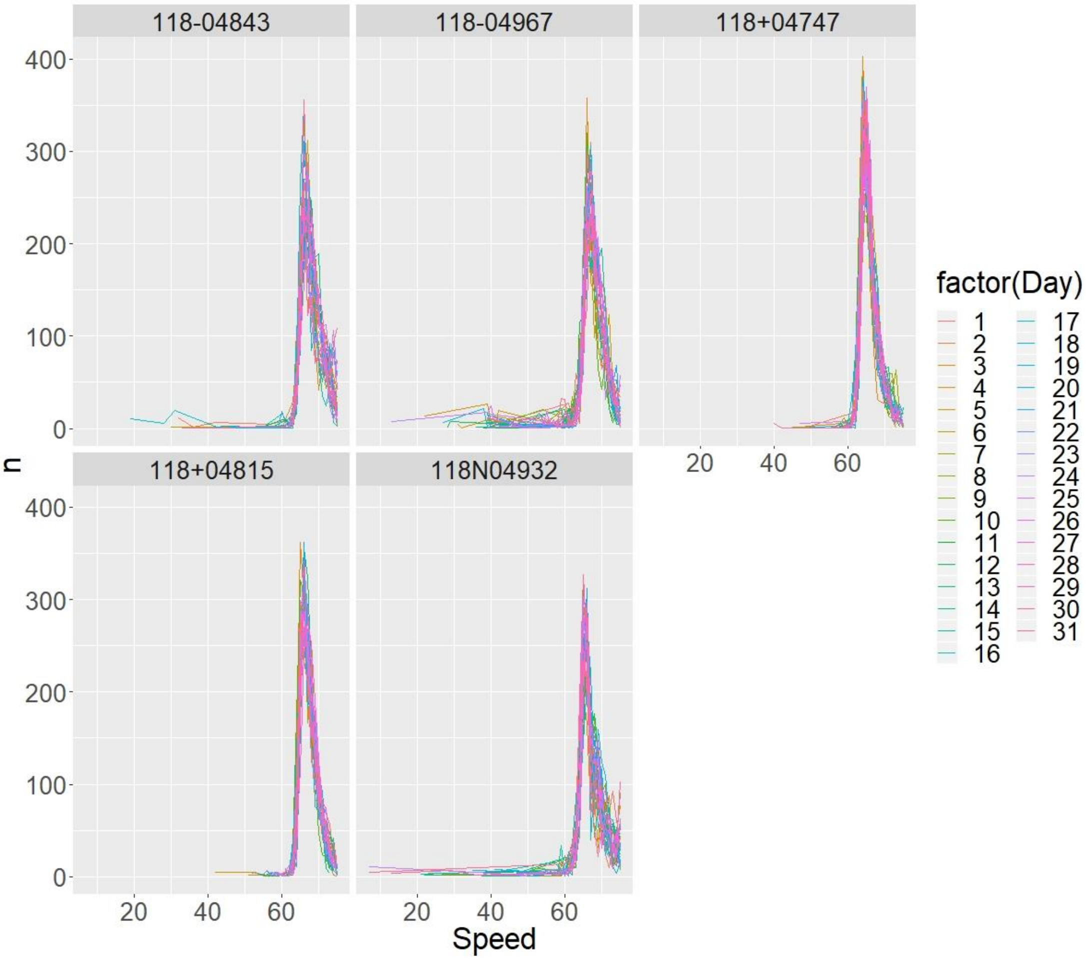


Figure 10. Probability density function plots for one month

The graphs shown in Figure 10 indicate that the speed with the highest frequency falls between 62 mph and 65 mph. The speed distributions are generally consistent between the days of the month. However, traffic patterns typically vary between weekdays and weekends because of the greater proportion of recreational traffic on weekends (Pigman et al. 1978). Therefore, filters were applied to the raw data to exclude weekends and holidays. Speed profiles also vary by time of day. To study this variation, modified box plots were created for the selected segments to visualize the speed data using the filtered data. Figure 11 shows box plots that indicate the minimum, 15th percentile, 50th percentile, 85th percentile, and maximum speeds for each hour of the day. The red horizontal line indicates the speed limit, which is 70 mph.

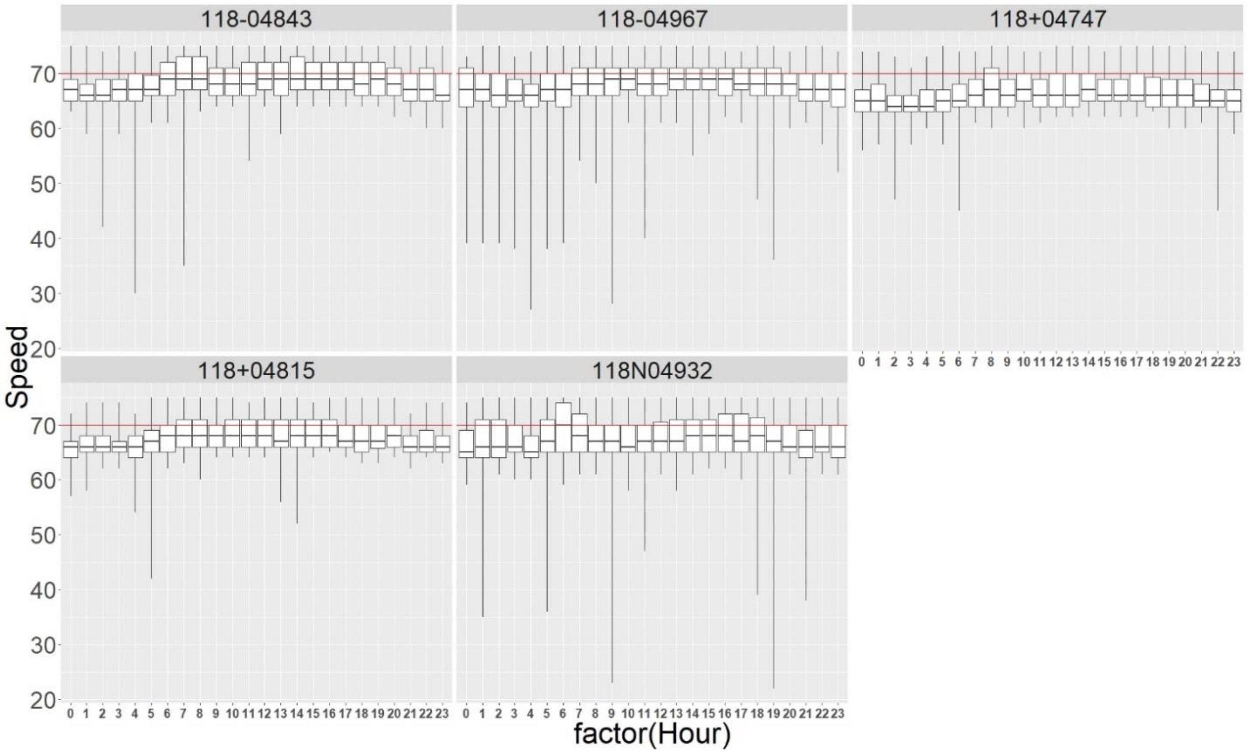


Figure 11. Modified box plots by time of day

Overnight periods (9 p.m. to 5 a.m.) tended to have lower speeds than other times of day. This may be due to the higher proportion of trucks traveling during that time period. A previous study also claimed that the speed bias was higher during the overnight period compared to other times of day (Sharma et al. 2017).

To better represent the typical speed characteristics of interstate segments, it was decided to select data only on weekdays from 6 a.m. to 8 p.m. Monthly average values of percentile speeds, average speed, and the standard deviation and variance of speed for all interstate TMC segments were obtained from 2013 to 2016.

Standard methods of calculating the statistical properties of speed are not directly applicable to INRIX data because of its format (i.e., one-minute average speeds on a segment). Instead, each individual one-minute speed record is typically treated as though it is a speed measurement, following common practice in the use of probe data (see, for example, the National Performance Measures required by the U.S. DOT).

Mean speeds were calculated per month for each segment by averaging all available one-minute speed records for that segment within each month. The standard deviations of the speeds were also calculated for the samples comprising the mean. For each month, the 85th percentile speed was calculated for the sample of one-minute average speed measurements for each segment. The speeds were ordered from lowest to highest, and 85th percentile rank was calculated using Equation 1.

$$Rank_{85} = \frac{85}{100} * n + 0.5 \tag{1}$$

The number calculated in Equation 1 was used to locate each data point in the ranking. If the number was an integer, the corresponding data point was the 85th percentile speed. If the number was a decimal, the integers immediately below and above the number were selected, and Equation 2 was applied to calculate the 85th percentile speed.

$$Percentile_{85} = (1 - d) * X_{below} + d * X_{above} \tag{2}$$

where d is the decimal from the result of Equation 1, and X_{below} and X_{above} are the data points corresponding to the whole numbers below and above the rank calculated in Equation 1, respectively.

4.1.6 Comparison of ATR and INRIX Data

The speeds measured by INRIX were compared to those measured by ATR for Iowa rural interstates to better understand how the two data sets varied from each other. Seven ATR stations are located on rural interstates: one on I-29, two on I-80, three on I-35, and one on I-380. The nearest corresponding INRIX TMC segments were identified for comparison purposes. Since ATR data are only reported quarterly, the INRIX data were averaged by quarter. Figure 12 and Figure 13 show the ATR and INRIX quarterly average speeds and 85th percentile speeds, respectively, for the combination of all rural interstate segments.

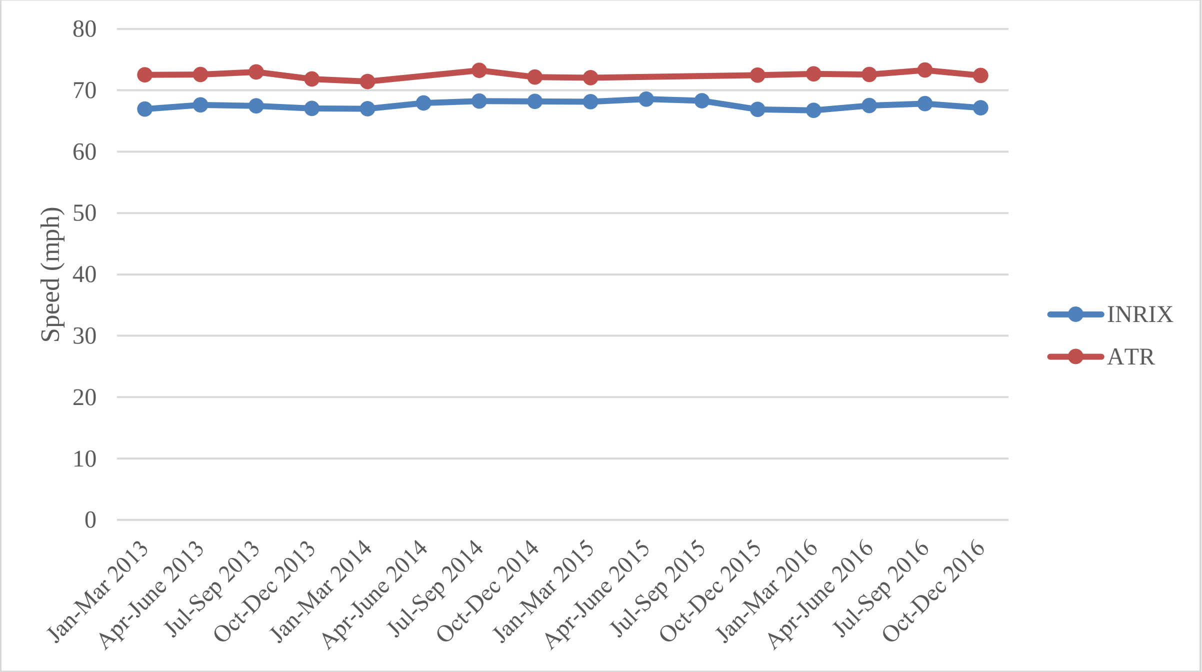


Figure 12. Average speed comparison between INRIX and ATR

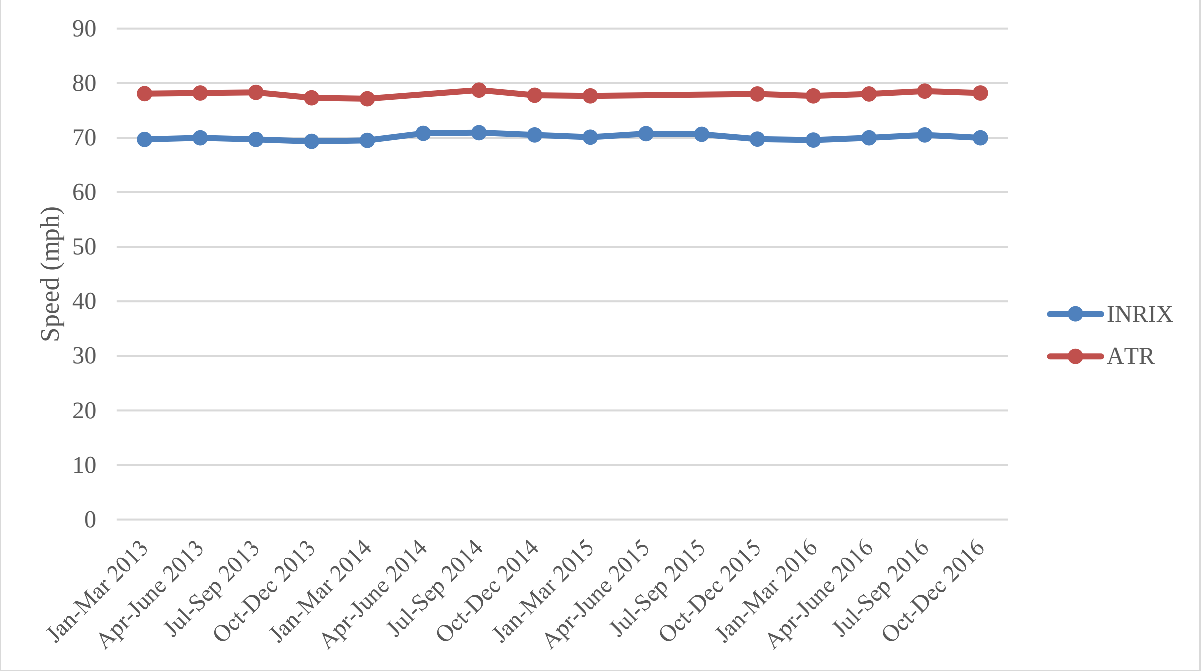


Figure 13. 85th percentile speed comparison between INRIX and ATR

The comparison shows that the INRIX-reported speeds are consistently lower than the ATR-reported speeds at these selected sites. The average speeds measured by INRIX are about 5 mph lower, while the 85th percentile speeds are about 8 mph lower. These differences are relatively stable over the study period for both measures. Here again, the differences likely reflect the distinct mechanisms of how the data are collected by each source. Probe data are provided as the average speed of vehicles over a one-minute interval within a segment, whereas the fixed-location sensors calculate average speed within a segment by averaging spot speeds. In a previous study, researchers compared the speed data from probes and traditional sensors and noted a consistent difference between the two sources (Sharma et al. 2017). Other research has compared INRIX speeds against loop detector speeds and also found a consistent difference of around 5 mph between the two reported speeds (Kim and Coifman 2014). The lower speeds reported by INRIX are likely affected by the lower speeds of freight vehicles, whereas the ATR speeds reflect all traffic. Both data sets indicate that the speeds peaked in summer months and declined in winter months. This is typically true for Iowa.

Figure 14 and Figure 15 compare the INRIX and ATR speed records for each rural interstate route individually.

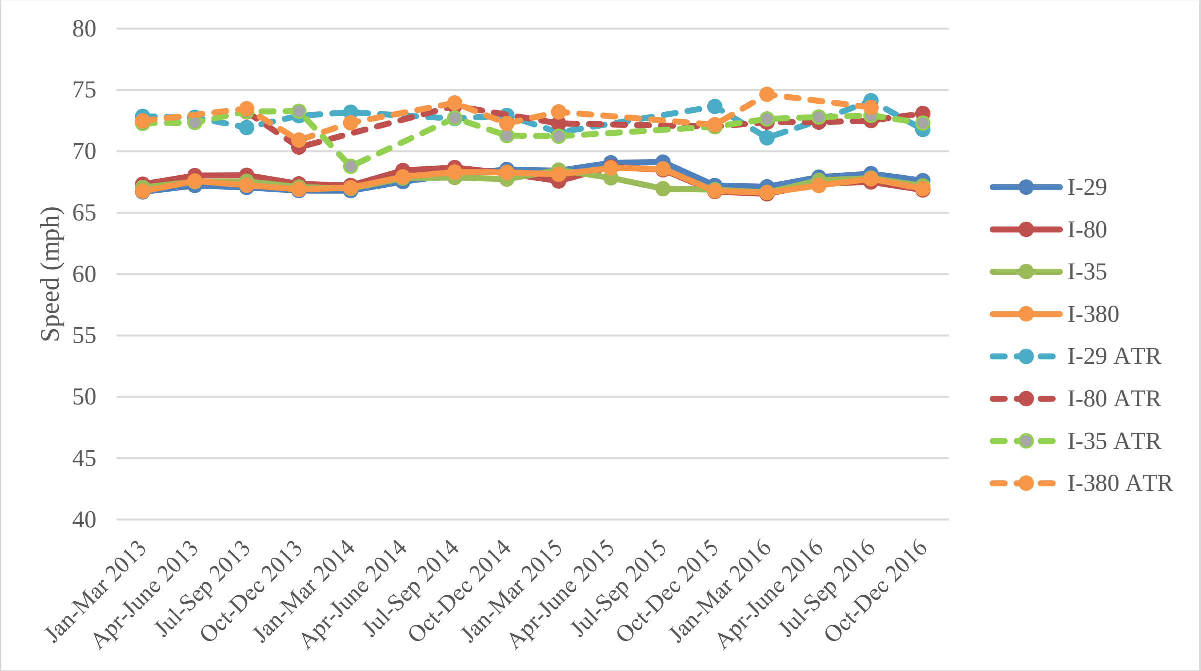


Figure 14. Average speed comparison by interstate between INRIX and ATR

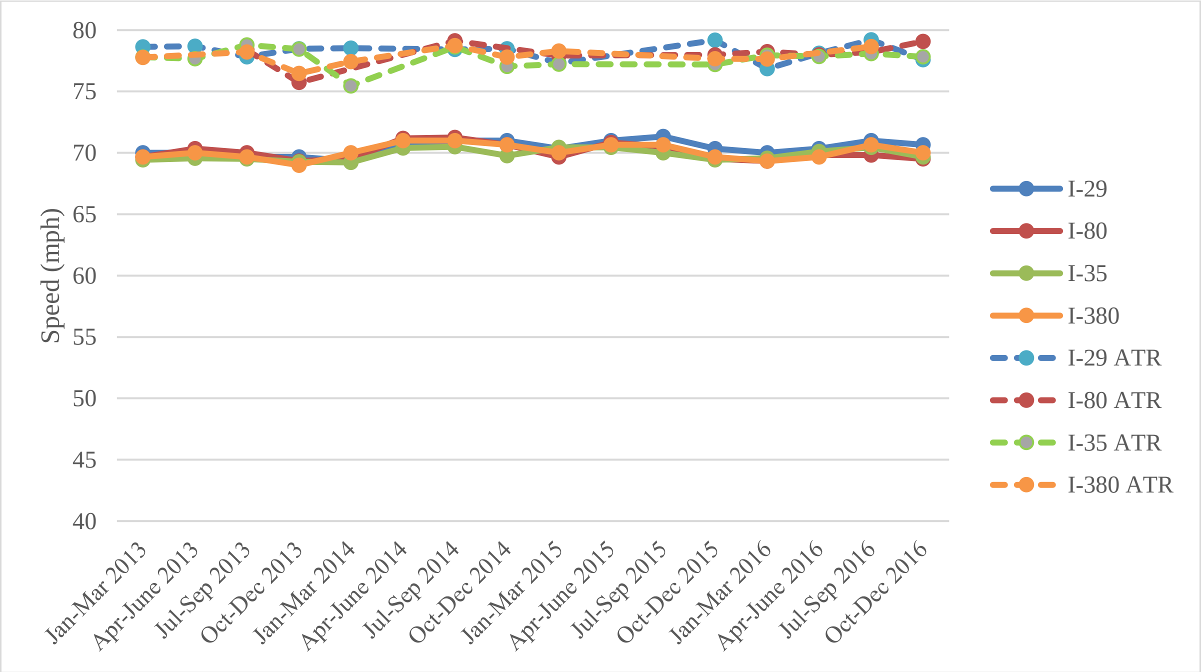


Figure 15. 85th percentile speed comparison by interstate between INRIX and ATR

An average was taken for the interstates that had multiple ATR stations. As expected, the discrepancies between the ATR and INRIX data persist comparably. The abrupt jumps of speeds evident in the ATR data may be caused by the absence of data for several months. In contrast, the INRIX-reported speeds show more consistency across all rural interstates throughout the study period.

4.1.7 Data Integration

The *Highway Safety Improvement Program Manual* developed by the FHWA recommends using at least three years of historical/observed crash data (Herbel et al. 2010) for crash data analysis. For this study, nine years of data (2008 through 2016) were obtained from the Iowa DOT's GIMS.

Two combined data sets were assembled using ArcMap. The first data set was developed to assess how roadway geometric characteristics vary with crash, injury, and fatality rates across the 70 mph limited-access highway network. The geospatial data for the Iowa interstate network, crash data, and weather station data from 2008 through 2016 were imported into ArcMap as layers. Crashes were spatially joined onto the nearest Iowa interstate segments, and the 25-mile buffers around the selected weather stations were joined into the roadway segments that they intersected. In the final data set, each row represents one segment in a particular year with all of the associated geometric, traffic, and weather information. As previously mentioned, a total of 1,843 interstate segments with the 70 mph speed limit were examined over the nine-year study period, resulting in 16,553 segment-years of data from Iowa interstates. Table 8 shows the summary statistics for these segments.

Table 8. Summary statistics for 70 mph Iowa interstates

	Min	Max	Mean	Std. Dev
Presence of Median Barrier (1=yes, 0=no)	0	1	0.13	0.33
Median Width (ft)	30	100	55.2	13.07
Four Lanes (1=yes, 0=no)	0	1	0.77	0.42
Five Lanes (1=yes, 0=no)	0	1	0.14	0.35
Six Lanes (1=yes, 0=no)	0	1	0.09	0.29
Acceleration/Deceleration Lane (1=yes, 0=no)	0	1	0.22	0.42
Presence of Rumble Strips (1=yes, 0=no)	0	1	0.38	0.48
Right Shoulder Width	6	12	9.88	0.51
Left Shoulder Width	4	10	5.97	0.61
AADT	2257.7	58400	20610.4	8883
ln(AADT)	7.72	10.98	9.84	0.45
Urban Area Indicator (1=yes, 0=no)	0	1	0.07	0.26
Annual Average High Temperature (°F)	51.81	66.56	59.59	2.81
Annual Average Low Temperature (°F)	32.28	44.06	38.02	2.24
Annual Average Temperature (°F)	42.05	55.21	48.8	2.45
Annual Precipitation (in.)	20.5	57.87	38.48	7.89
Annual Snowfall (in.)	8.78	63.49	31.29	11.11
Total Crashes	0	20	1.21	1.82
KA-Injury Crashes	0	3	0.04	0.2
B-Injury Crashes	0	4	0.10	0.33
C-Injury Crashes	0	6	0.12	0.38
O-Injury Crashes	0	16	0.96	1.52

n = 16,553 segment-years
KA = fatal (K) or serious injury (A), B = minor injury, C = possible injury, O = no injury

The shoulder width for each segment was averaged across the left (inside) and right (outside) shoulders. Median width was also determined, and 43 out of 1,843 segments had extremely large median widths (over 100 feet). For analysis purposes, the median width was capped at 100 feet.

Other data sets were assembled that incorporated operational speed data from INRIX. Since INRIX data were only available after 2013, the new data sets were reduced to four years of data (2013 through 2016). Additional operational speed data were added into the data sets to capture the speed characteristics of each interstate segment. The speed data from INRIX were aggregated by month; therefore, the new data sets were created to include INRIX speed data as well as all traffic, weather, and geometric characteristics variables. In the final data sets, each row represents one segment in a specific month with all of the associated geometric, traffic, weather, and speed data.

Because GIMS data are not broken down by direction but INRIX speed data are for directional segments, the speed data were averaged across opposing directions of travel. The INRIX TMC segments were separated into two layers based on the directions of travel: one layer containing northbound or eastbound segments and the other layer containing southbound or westbound segments.

In ArcMap, two line data sets cannot be spatially joined to one another, so additional work was required to integrate INRIX data with GIMS and crash data. It was found that, in general, INRIX segments were longer than GIMS segments. The center point of each GIMS roadway segment was computed, and the two directional INRIX TMC segment layers were joined into the GIMS roadway centers separately. The average across the two directions of travel was then taken to calculate the speed characteristics of the GIMS segments. Table 9 presents the descriptive statistics for the resulting data set.

Table 9. Summary statistics for 70 mph interstate speed model

Variable	Min	Max	Mean	Std. Dev
Presence of Median Barrier	0	1	0.25	0.43
Median Width	30	100	55.31	13.11
Right Shoulder Width	6	11	9.89	0.47
Left Shoulder Width	4	10	5.98	0.63
AADT	2954	58400	21373.42	9317.33
Ln AADT	7.99	10.98	9.87	0.45
Urban Indicator	0	1	0.07	0.25
Total Crashes	0	9	0.1	0.37
KA-Injury Crashes	0	2	0.003	0.05
B-Injury Crashes	0	3	0.01	0.09
C-Injury Crashes	0	3	0.01	0.1
O-Injury Crashes	0	8	0.08	0.33
85th Percentile Speed	59	73.5	69.76	1.4
Speed Standard Deviation	1.37	10.19	2.91	0.72
Average Speed	58.02	70.49	67.24	1.32

n = 88,212 segment-months
KA = fatal (K) or serious injury (A), B = minor injury, C = possible injury, O = no injury

5. ANALYSIS RESULTS FOR NATIONWIDE DATA SETS

5.1 Statistical Methodology for Nationwide Analyses

To determine the effects of different rural interstate speed limits on fatality rates, regression models were created to estimate how fatality risk changes based on different factors, including speed limit. To estimate fatality risk, the dependent variable was related to the total number of fatalities: In the state-level fatality analysis, the dependent variable was the number of fatalities on rural interstate highways in a state in a given year. In the road-level fatality analysis, the dependent variable was the number of fatalities along a given interstate segment in a given year. Because the fatality data were made up of non-negative integers, a Poisson regression model was used as a starting point for these analyses. In the Poisson model, the probability of state or road segment *i* experiencing y_i fatalities in a given year is given by Equation 3:

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!} \tag{3}$$

where $P(y_i)$ is the probability of state or road segment *i* experiencing y_i fatalities, and λ_i is the Poisson parameter for state *i*, which is equal to the state's expected number of fatalities per year, $E[y_i]$. The Poisson parameter is estimated as a function of explanatory variables, the most common functional form being given by Equation 4:

$$\lambda_i = EXP(\beta X_i) \tag{4}$$

where X_i is a vector of explanatory variables and β is a vector of estimable parameters, the latter of which is estimated directly in the statistical model.

A limitation of the Poisson model is the underlying assumption that the mean and variance of the distribution are equal to each other. The Poisson model cannot handle the overdispersion that is common in fatality data. Consequently, a Poisson-gamma model (more commonly known as a negative binomial model) was introduced to allow for additional heterogeneity across states or roadway segments. The negative binomial model modifies the Poisson parameter to include an error term as shown in Equation 5:

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \tag{5}$$

where $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean 1 and variance α, where α is an overdispersion parameter. The addition of this term allows the variance to differ from the mean, as shown in Equation 6:

$$VAR[y_i] = E[y_i] + \alpha E[y_i]^2 \tag{6}$$

Because this data set features multiple data points in each state, there could be a temporal correlation between observations within a state. To address this, random effect models were estimated, which allow the constant term to vary across states, as shown in Equation 7:

$$\beta_{0j} = \beta_0 + \omega_{ij} \qquad (7)$$

where ω_i is a randomly distributed random effect for state j and β_0 is the constant term from the negative binomial model. In addition to including random effects to account for correlation within states, a binary indicator variable was added for each year to account for correlation within years (i.e., general nationwide safety trends).

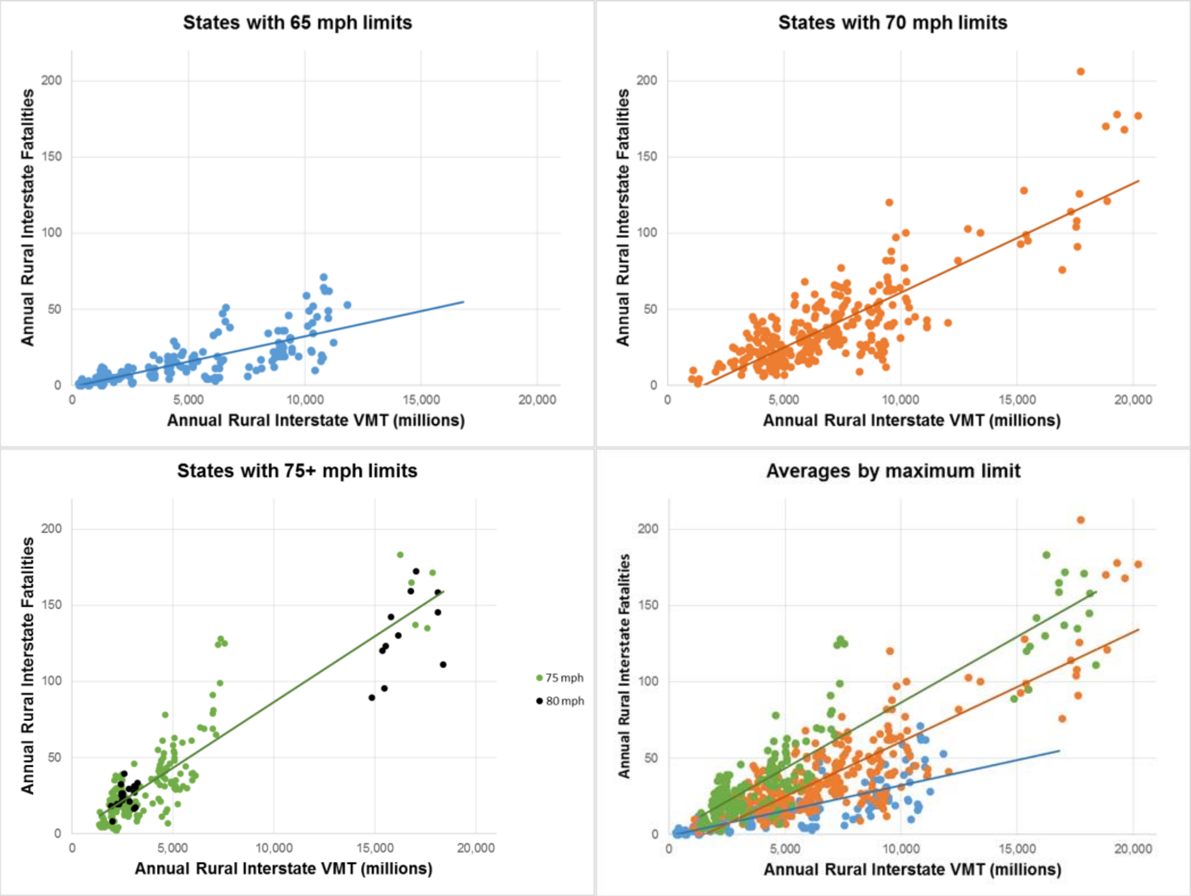
The average effects of the parameter estimates from these models can be determined by calculating the elasticities, which are the percentage change in fatalities associated with a one-unit change in a predictor variable. These elasticities can be determined as shown in Equation 8:

$$E_{x_{ik}}^{\lambda_i} = 100 \times EXP(\beta_k) - 1 \qquad (8)$$

where β_k is the corresponding estimated coefficient for the k^{th} independent parameter. Negative parameter estimates indicate that the number of fatalities decreases when the parameter increases, and positive estimates indicate that the number of fatalities increases as the associated parameter increases.

5.2 State-Level Analysis Results and Discussion

Upon initial examination of the fatality data aggregated by state, general trends could be seen that indicated that states with higher speed limits tend to have more fatalities, even when the data are normalized by VMT. Figure 16 presents four scatter plots, with each data point in each graph representing the number of rural interstate fatalities in a given state in a given year versus the state’s total amount of rural interstate VMT in that year. The first three graphs group states according to maximum speed limit, and the fourth graph presents all data together.



States with 65 mph limits

States with 70 mph limits

States with 75+ mph limits

Averages by maximum limit

Figure 16. State-level fatalities versus VMT

The graph on the bottom-left shows states with 75 mph or 80 mph speed limits; the points in black indicate states where the maximum speed limit is 80 mph. The trends in the bottom-right graph indicate that states with higher speed limits are typically associated with higher fatality rates. In this chart, the 75+ mph trendline is entirely above the 70 mph trendline, which is mostly above the 65 mph trendline.

Figure 17 shows the general trends of fatalities per hundred million VMT (HMVMT) per year over the course of the study period, which shows similar trends associating higher speed limits with higher fatality rates per HMVMT.

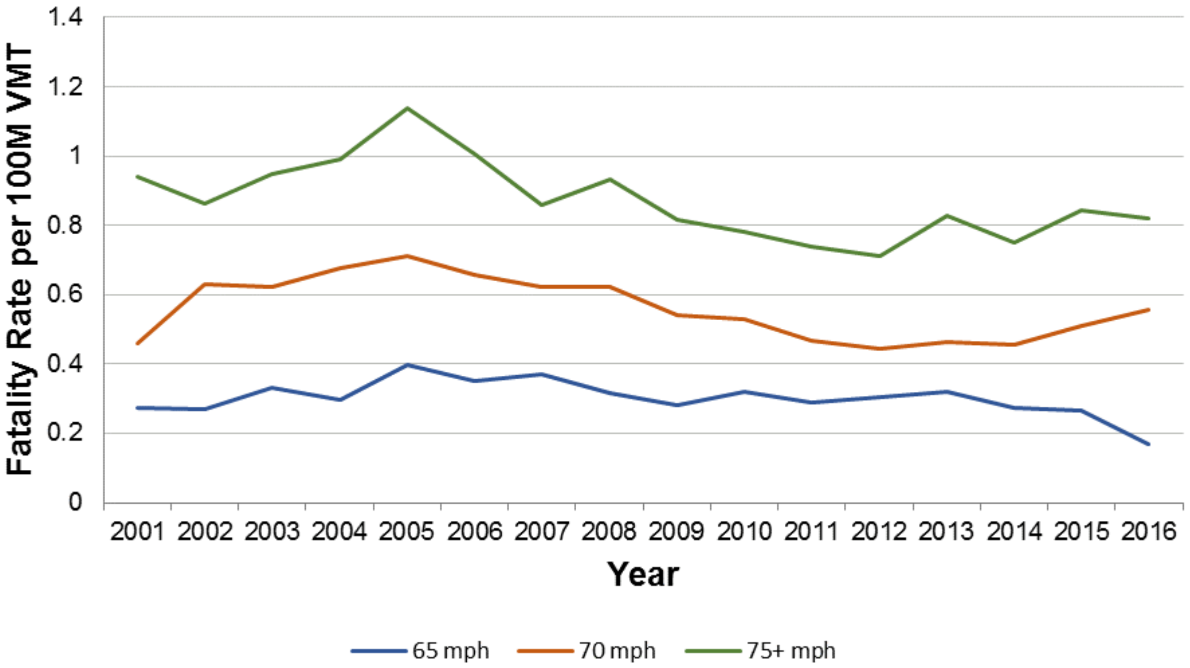


Figure 17. Fatalities per HMVMT over time

These results show the general trends in fatality rates at a high level without consideration of any of the factors that might affect fatality rates. Additional analysis is needed to make more conclusive observations about the impacts of speed limits on fatality rates.

As part of the state-level analysis, two regression models were estimated to compare alternate means of capturing the rural interstate speed limit policies in each state. Each model is generally similar in the following respects:

- Yearly binary indicator variables are included to capture the effects of contemporaneous changes that occur across states (e.g., economic climate, improvements in vehicle technology). These terms capture the general decline in overall traffic fatalities that occurred over much of the study period.
- A state-level random effect term is introduced to account for within-state effects that are assumed to be time-invariant (e.g., terrain, design practices, enforcement practices). This term reflects the fact that specific states experience fatality rates that are higher or lower than other states due to factors that could not be directly accounted for in the model.
- Other variables not related to speed limit, such as temperature, precipitation, seat belt use rate, and proportion of truck traffic, are also included as covariates. The effects of these variables are relatively consistent across the models.

The primary differences between the two models are as follows:

- The first model, which is consistent with prior longitudinal studies that have leveraged data from FARS, includes a series of binary indicator variables to distinguish the maximum rural interstate speed limit in a given state during a particular year. These results are presented in Table 10.
- One limitation to this approach is that these maximum speed limits, particularly at the higher values of 75 and 80 mph, have generally been applied to only a subset of the rural interstate system in each state. Consequently, the true effects of the speed limit increases are likely to be dampened since the increases occurred on only a subset of the system. To address this concern, the second model includes a series of variables that represent the proportion of rural interstate mileage in each state that is posted at each limit (70, 75, and 80 mph). The results from this model are presented in Table 11.
- In each of these models, the speed limit variables are treated as random parameters. This is an important consideration because the states where speed limits have been increased to the higher range of limits (i.e., 75 to 80 mph or higher) have some inherent differences that are not explicitly captured in the data set. Consequently, it is reasonable to expect significant variability in the effects of the speed limit due to the resulting unobserved heterogeneity.

The results from the analysis that considers maximum speed limits (Table 10) indicate that states with a maximum speed limit of 75 or 80 mph experience significantly more fatalities than states with a maximum speed limit of 65 or 70 mph. States with a 65 mph speed limit serve as the baseline scenario, and the parameter estimates indicate the average change in fatalities for states with higher speed limits compared to the 65 mph speed limit.

Table 10. Regression model results considering maximum speed limit

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	-16.6419	0.7967	-20.889	<0.0001
Std. Dev(Intercept)	0.2984	0.0160	18.650	<0.0001
Year 2001	-0.2557	0.1159	-2.206	0.0351
Year 2002	-0.1219	0.1213	-1.005	0.2406
Year 2003	-0.0221	0.1199	-0.184	0.3921
Year 2004	0.0818	0.1132	0.723	0.3071
Year 2005	0.2146	0.1236	1.736	0.0884
Year 2006	0.0747	0.1252	0.597	0.3337
Year 2007	0.0584	0.1236	0.472	0.3566
Year 2008	0.0791	0.1210	0.654	0.3220
Year 2009	-0.0393	0.1418	-0.277	0.3838
Year 2010	-0.0164	0.1392	-0.118	0.3960
Year 2011	-0.1578	0.1119	-1.410	0.1475
Year 2012	-0.2900	0.1309	-2.215	0.0344
Year 2013	-0.1018	0.1272	-0.800	0.2894
Year 2014	-0.1361	0.1492	-0.912	0.2630
Year 2015	-0.0578	0.1312	-0.441	0.3619
Year 2016 (baseline)	N/A	N/A	N/A	N/A
Log (rural interstate VMT)	0.7888	0.0333	23.688	<0.0001
Average monthly temp. (°F)	0.0271	0.0032	8.469	<0.0001
Range in average monthly temp. (°F)	0.0259	0.0106	2.443	0.0203
Monthly Precipitation (in.)	0.0014	0.0021	0.667	0.3193
Proportion of truck traffic	0.4027	0.3458	1.165	0.2024
Maximum speed limit 65 (baseline)	N/A	N/A	N/A	N/A
Maximum speed limit 70 (1 if yes; 0 otherwise)	0.1525	0.0500	3.050	0.0039
Maximum speed limit 75 (1 if yes; 0 otherwise)	0.3091	0.0695	4.447	<0.0001
Maximum speed limit 80 (1 if yes; 0 otherwise)	0.4780	0.0956	5.000	<0.0001
Overdispersion Parameter	0.0696			
Goodness-of-fit statistics				
Log-likelihood at convergence	-2598.47			
AIC	5258.94			
BIC	5402.25			

Based on these results, a state with an 80 mph speed limit can expect 61.3 percent more fatalities than a state with a 65 mph speed limit. States with a maximum speed limit of 75 mph experienced annual fatalities that were 36.2 percent higher than states with lower maximum speed limits, while states with a 70 mph maximum limit experienced 16.5 percent more fatalities than the 65 mph states. Interestingly, the effects at 75 and 80 mph are not significantly different from one another. It is important to note that 80 mph speed limits are relatively new. Only two states had an 80 mph speed limit prior to 2014, and this speed limit was not in place in any state until 2006. Furthermore, since these increases were only applied to small proportions of these respective interstate systems, the actual differences in fatalities with respect to the speed limit differences may be understated.

The second analysis, whose results are shown in Table 11, addresses this concern by including the proportion of mileage in the rural interstate network in each state that is posted at each speed limit.

Table 11. Regression model results considering the proportion of mileage at each speed limit

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	-17.0441	0.8027	-21.233	<0.0001
Std. Dev(Intercept)	0.2951	0.0159	18.560	<0.0001
Year 2001	-0.2687	0.1171	-2.295	0.0288
Year 2002	-0.1346	0.1244	-1.082	0.2220
Year 2003	-0.0317	0.1270	-0.250	0.3866
Year 2004	0.0744	0.1126	0.661	0.3205
Year 2005	0.2095	0.1254	1.671	0.0989
Year 2006	0.0659	0.1308	0.504	0.3512
Year 2007	0.0511	0.1221	0.419	0.3653
Year 2008	0.0720	0.1264	0.570	0.3390
Year 2009	-0.0437	0.1461	-0.299	0.3813
Year 2010	-0.0191	0.1417	-0.135	0.3952
Year 2011	-0.1680	0.1170	-1.436	0.1423
Year 2012	-0.2989	0.1362	-2.195	0.0361
Year 2013	-0.1082	0.1304	-0.830	0.2826
Year 2014	-0.1389	0.1519	-0.914	0.2625
Year 2015	-0.0625	0.1372	-0.456	0.3595
Year 2016 (baseline)	N/A	N/A	N/A	N/A
Log (Rural Interstate VMT)	0.8073	0.0333	24.243	<0.0001
Average monthly temp. (°F)	0.0277	0.0034	8.147	<0.0001
Range in average monthly temp. (°F)	0.0268	0.0108	2.481	0.0185
Monthly Precipitation (in.)	0.0017	0.0021	0.810	0.2873
Proportion of truck traffic	0.3335	0.3508	0.951	0.2537
Proportion of rural mileage at Speed Limit 70	0.1733	0.0564	3.073	0.0036
Proportion of rural mileage at Speed Limit 75	0.4926	0.0833	5.914	<0.0001
Proportion of rural mileage at Speed Limit 80	0.6165	0.1487	4.146	0.0001
Overdispersion parameter	0.0704			
Goodness-of-fit statistics				
Log-likelihood at convergence	-2598.25			
AIC	5258.50			
BIC	5401.81			

Interestingly, these parameter estimates are significantly larger in magnitude than those of the maximum speed limit variables discussed previously. These results can be interpreted as indicating that a state with all rural interstate mileage posted at 70 mph would experience 18.9 percent more fatalities than a state with all rural interstate mileage posted at 65 mph or below. Similarly, if all rural interstates were posted at 75 or 80 mph, fatalities would be expected to be 63.7 percent and 85.2 percent higher, respectively. As in the preceding analysis, the effects at 75 and 80 mph are not significantly different from one another.

However, caution should be exercised in such large-scale extrapolation of the results of speed limit increases. Speed limit increases to these higher bounds generally occur at a significantly smaller scale than statewide. To this end, considering the effects on fatality rate of a one percent increase in rural interstate mileage posted at the higher speed limit is likely to provide a more reasonable approximation of the impacts on fatalities. If the percentage of rural interstates posted at 70, 75, or 80 mph is increased by one percent, fatalities are expected to increase by 0.2 percent, 0.5 percent, and 0.6 percent, respectively.

In considering the goodness of fit provided by the two analysis frameworks, several factors should be considered. First, the model that considers the proportion of mileage posted at each speed limit provides performs better in terms of the log-likelihood, Akaike information criterion (AIC), and Bayesian information criterion (BIC) values. In addition, the variability of the state-level random effect term is lower (0.2951 versus 0.2984) in the model that considers proportional mileage versus the maximum statutory speed limit in each state. Collectively, the evidence suggests that examining speed limit policy changes in terms of the proportion of the system over which these changes are applied provides a more robust analytical framework than the traditional analyses that consider only the maximum speed limit in each state.

5.3 Road-Level Analysis Results and Discussion

To perform a roadway-level analysis, three alternative regression models were estimated. Each of these models shares the following similarities:

- AADT and segment length were both treated as offset variables, where their parameter estimates were constrained to one. This was done to conform to implicit assumptions that fatalities increase proportionately with respect to segment length and traffic volume.
- The speed limit variables in the models were displayed as binary indicators. All of the models in this analysis are focused on rural interstates, and only segments where the speed limit was greater than or equal to 65 mph were considered due to the low mileage of rural interstates with lower speed limits.
- A binary indicator was included for each year within the study period to capture the effects of changes that occur across states, such as economic climate or general improvements to vehicle technology.
- Because some of the variables used in the analysis are statewide totals or averages, state-level random effect terms were introduced in this analysis as well as in the state-level analysis to account for effects that vary from state to state irrespective of time (e.g., terrain, design practices, enforcement practices). These variables account for the fact that specific states may experience fatality rates that differ from other states for reasons that cannot be captured by the model.
- Additional variables were used in the analysis that were found to be statistically significant at the 90 percent confidence in the individual models. The same variables were not necessarily significant in all of the models, but those that were generally had similar trends across the entire analysis. For example, all of the separate models indicate a negative correlation between number of lanes and fatality rate; that is, fewer lanes of travel is correlated with a higher rate of fatalities.

The way these three models differ is in how the dependent variable is presented. In all of the models, the dependent variable reflects a rate of fatal crashes in some way:

- The first model examines the total number of fatal crashes on rural interstate segments where the speed limit is 65 mph or greater. The data set included 22,481 such crashes. The results of this model are presented in Table 12.
- The second model only includes fatal crashes where the "speeding" field in the FARS database indicates that the crash involved speeding. This field was only available in the database from 2009 through 2016, so the data set was cut to only include those years. For an unknown reason, fewer fatal crashes were captured by this model than by the third model, even accounting for the shorter study period of the third model. In total, this model includes 2,725 crashes on rural interstates with a speed limit of 65 mph or greater, and the model results are presented in Table 13.
- The third model only includes fatal crashes where a distraction is coded in the FARS database. This field was introduced in the 2010 database, so the data set was cut to only include data from 2010 through 2016. This model includes 1,372 crashes on rural interstates with a speed limit of at least 65 mph, and the results of the model are presented in Table 14.

The results from the first model (total fatal crashes, found in Table 12) indicate that roads with higher speed limits are expected to have a higher risk of fatal crashes.

Table 12. Regression model results considering total rural interstate fatal crashes

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	0.169	1.607	0.105	0.9164
Std. Dev(Intercept)	0.392			
Year 2001 (1=yes, 0=no)	-0.773	0.122	-6.345	<0.0001
Year 2002 (1=yes, 0=no)	-0.640	0.125	-5.118	<0.0001
Year 2003 (1=yes, 0=no)	-0.523	0.108	-4.840	<0.0001
Year 2004 (1=yes, 0=no)	-0.306	0.087	-3.520	0.0004
Year 2005 (1=yes, 0=no)	-0.003	0.071	-0.036	0.9710
Year 2006 (1=yes, 0=no)	0.055	0.075	0.739	0.4602
Year 2007 (1=yes, 0=no)	0.088	0.087	1.016	0.3097
Year 2008 (1=yes, 0=no)	0.240	0.125	1.921	0.0548
Year 2009 (1=yes, 0=no)	-0.230	0.066	-3.499	0.0005
Year 2010 (1=yes, 0=no)	-0.034	0.085	-0.396	0.6922
Year 2011 (1=yes, 0=no)	0.193	0.150	1.289	0.1975
Year 2012 (1=yes, 0=no)	0.237	0.157	1.512	0.1305
Year 2013 (1=yes, 0=no)	0.266	0.147	1.815	0.0696
Year 2014 (1=yes, 0=no)	0.175	0.132	1.322	0.1861
Year 2015 (1=yes, 0=no)	-0.018	0.049	-0.367	0.7134
Year 2016 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A
Log (AADT)	1.000	(fixed)	N/A	N/A
Log (Segment Length, mi)	1.000	(fixed)	N/A	N/A
Speed Limit 65 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A
Speed Limit 70 (1=yes, 0=no)	0.260	0.030	8.750	<0.0001
Speed Limit 75 (1=yes, 0=no)	0.289	0.042	6.932	<0.0001
Speed Limit 80 (1=yes, 0=no)	0.716	0.066	10.915	<0.0001
Number of Lanes	-0.133	0.010	-13.646	<0.0001
Proportion of State’s Vehicles that are Autos	-9.947	1.617	-6.151	<0.0001
Proportion of State’s Vehicles that are Motorcycles	-15.540	1.769	-8.786	<0.0001
Proportion of State’s Vehicles that are Trucks	-10.140	1.608	-6.302	<0.0001
Proportion of State’s Drivers under 25 years	-3.998	0.937	-4.269	<0.0001
Proportion of State’s Drivers over 65 years	-4.777	1.073	-4.452	<0.0001
State’s Population Density (persons/sq. mi)	-0.001	0.000	-2.629	0.0086
State’s Seat Belt Usage (proportion)	-0.350	0.118	-2.969	0.0030
State’s Maximum Monthly Average Temp. (°F)	-0.008	0.015	-0.539	0.5902
State’s Minimum Monthly Average Temp. (°F)	0.010	0.016	0.615	0.5388
State’s Average Annual Precipitation (in.)	-0.002	0.002	-1.118	0.2636
State’s Average Gas Price ($/gallon)	-0.409	0.115	-3.548	0.0004
Years since State’s Max Limit Changed	0.047	0.008	6.230	<0.0001
Overdispersion parameter	1.187			
Goodness-of-fit statistics				
Log-likelihood at convergence	-4,9953			
AIC	99,974.5			
BIC	100,298.0			

Specifically, a road with a speed limit of 70 mph is expected to see a 29.7 percent higher fatal crash rate than a road with a speed limit of 65 mph. The corresponding values for 75 mph and 80 mph roads are increases of 33.5 percent and 104.6 percent, respectively. These appear to be exceptionally high values, especially the expected doubling of the crash rate between a 65 mph road and an 80 mph road. However, it is unlikely for an agency to raise the speed limit by 15 mph, and a rural interstate that currently has a speed limit of 65 mph is unlikely to have the right traffic levels and geometric characteristics to warrant an increase to 80 mph. Because of this, it is more practical to consider the relative increases in fatal crash risk for each of the 5 mph increases. A road with a speed limit of 75 mph is expected to see 2.9 percent more fatal crashes than a road with a speed limit of 70 mph, and an 80 mph road can expect to experience 53.3 percent more fatal crashes than a 75 mph road.

Within this model, the variable indicating the number of years that the state has had its maximum speed limit was found to have a positive relationship with the fatal crash count. This variable's parameter estimate indicates that for every year after a state changes its speed limit, the number of fatal crashes increases by 4.8 percent. However, it would be expected that the number of fatal crashes would decrease every year after a state's speed limit changes because drivers have more time to become familiar with the new speed limit and adjust their driving habits accordingly. This variable only includes values up to 5 years (i.e., if the speed limit changed more than 5 years prior to the data point, the value is still 5), so the model assumes that after the fifth year of a new speed limit, the number of fatal crashes does not change as a result of temporal proximity to the policy change.

Nearly all of the other variables display a negative relationship with fatal crash rates. Three variables that show statistically significant negative relationships are the state's respective proportions of registered vehicles that are automobiles, motorcycles, and trucks. All three of these parameter estimates are uncommonly high in magnitude; however, the parameter estimates reflect cases where the variable increases by a value of one. Because these variables can only take a value between zero and one, an increase of one is not possible. Rather, it is necessary to calculate how the expected crashes are affected by a more reasonable change in these variables (e.g., one percent). In this case, a one percent increase in the proportion of automobile registrations correlates to a 9.5 percent decrease in fatal crashes. The corresponding expected decreases in fatal crashes for a one percent increase in motorcycle and truck registrations are 14.4 percent and 9.6 percent, respectively. Furthermore, an increase in the value of one of these three variables is likely to coincide with a decrease of at least one of the other two.

Five additional variables used in this model displayed negative correlations with fatal crashes that were statistically significant at the 99 percent confidence level: proportion of licensed drivers under the age of 25, proportion of licensed drivers over the age of 65, population density of the state, annual average gas price within the state, and the state's seat belt usage. The younger driver and older driver variables are proportional variables similar to the vehicle type variables; the parameter estimates indicate that when the proportion of young drivers increases by one percent, the number of fatal crashes is expected to decrease by 3.9 percent, and when the proportion of old drivers increases by one percent, fatal crashes are expected to decrease by 4.7 percent. These decreases could be due to the fact that drivers in both of these demographics generally tend to be cautious about their driving. In this model, the population density variable has a slight negative effect on the number of fatal crashes, where an increase of one person per square mile in a state correlates with a 0.1 percent decrease in fatal crashes. While this parameter estimate is statistically significant, the estimate is so low that the effects are negligible. The gas price variable had a significant effect on fatal crashes, where a one dollar increase in price per gallon corresponds to a 33.6 percent decrease in fatalities, likely due to drivers' general reluctance to travel if the costs of doing so are too high. Finally, the seat belt usage rate predictably has a negative relationship with fatal crashes (i.e., fatal crashes decrease when seat belt usage increases). According to the model, for every one percent increase in statewide seat belt usage, the number of fatal crashes is expected to decrease by 0.3 percent.

A binary indicator for each year was included to account for temporal changes in crash rates. From this model, fatal crashes would have been expected to increase from 2001 to 2008 and then remain relatively constant until steadily decreasing from 2013 to 2016. Despite being statistically insignificant, these general trends are unsurprising because they match those found in the summary statistics of the original data set (see Table 4). Finally, the three variables indicating weather trends had coefficients that were insignificant. This result indicates that the model shows that temperature and precipitation do not have a strong influence on fatal crashes.

The results from the model considering crashes that were coded as speeding-related in FARS (Table 13) indicate that the likelihood of a speeding-related fatal crash generally increases as the speed limit increases.

Table 13. Regression model results considering crashes coded as speeding-related

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	-32.370	3.593	-9.012	<0.0001
Std. Dev(Intercept)	0.502			
Year 2009 (1=yes, 0=no)	-0.124	0.175	-0.709	0.4780
Year 2010 (1=yes, 0=no)	-0.134	0.209	-0.641	0.5216
Year 2011 (1=yes, 0=no)	-0.548	0.376	-1.458	0.1449
Year 2012 (1=yes, 0=no)	-0.617	0.408	-1.513	0.1302
Year 2013 (1=yes, 0=no)	-0.380	0.374	-1.016	0.3098
Year 2014 (1=yes, 0=no)	-0.477	0.337	-1.417	0.1564
Year 2015 (1=yes, 0=no)	-0.045	0.112	-0.398	0.6906
Year 2016 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A
Log (AADT)	1.000	(fixed)	N/A	N/A
Log (Segment Length, mi)	1.000	(fixed)	N/A	N/A
Speed Limit 65 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A
Speed Limit 70 (1=yes, 0=no)	-0.007	0.079	-0.086	0.9311
Speed Limit 75 (1=yes, 0=no)	0.139	0.102	1.365	0.1722
Speed Limit 80 (1=yes, 0=no)	0.447	0.145	3.083	0.0021
Number of Lanes	-0.073	0.028	-2.628	0.0086
Proportion of State’s Vehicles that are Autos	16.690	3.639	4.586	<0.0001
Proportion of State’s Vehicles that are Motorcycles	15.490	4.459	3.474	0.0005
Proportion of State’s Vehicles that are Trucks	17.300	3.579	4.833	<0.0001
Proportion of State’s Drivers under 25 years	4.054	2.964	1.368	0.1713
Proportion of State’s Drivers over 65 years	-2.837	3.092	-0.917	0.3590
State’s Population Density (persons/sq. mi)	0.000	0.000	-0.741	0.4587
State’s Seat Belt Usage (proportion)	-1.157	0.764	-1.515	0.1298
State’s Maximum Monthly Average temp. (°F)	0.058	0.034	1.683	0.0924
State’s Minimum Monthly Average temp. (°F)	-0.058	0.039	-1.480	0.1389
State’s Annual Precipitation (inches)	0.005	0.005	0.997	0.3188
State’s Average Gas Price ($/gallon)	0.302	0.309	0.979	0.3275
Years since State’s Max Limit Changed	0.025	0.019	1.319	0.1872
Overdispersion parameter	1.105			
Goodness-of-fit statistics				
Log-likelihood at convergence	-9,533.6			
AIC	19,119.3			
BIC	19,348.9			

Specifically, a roadway with a speed limit of 75 mph is expected to see a 14.9 percent increase in speeding-related fatal crashes compared to an identical roadway with a speed limit of 65 mph, and an 80 mph segment is expected to experience a 56.4 percent increase in speeding-related fatal crashes. Interestingly, this model indicates that a 70 mph road segment would experience a lower rate of speeding-related fatal crashes than a 65 mph segment by approximately 0.7 percent; however, this result is not statistically significant.

This model features variables for the statewide proportions of registered motor vehicles that are automobiles, motorcycles, and trucks. Like in the previous model, all three of these parameter estimates are uncommonly high; however, when a one percent increase in proportion is considered rather than a variable increase of one, it can be seen that a one percent increase in the proportion of automobile registrations correlates to an 18.2 percent increase in fatal crashes. The corresponding expected increases in fatal crashes for a one percent increase in motorcycle and truck registrations are 16.8 percent and 18.9 percent, respectively. As is the case in the previous model, an increase in the value of one of these three variables is likely to coincide with a decrease in at least one of the other two.

A number of variables in this model are not statistically significant at the 95 percent confidence level, and most display trends similar to those in the other models in which they are significant. There are four notable exceptions to this: statewide proportion of young drivers, state maximum temperature, state annual precipitation, and state average gas price. All four of these variables have negative correlations with the dependent variable in the other models but a positive correlation in this model. This could be because the sample size of fatal crashes coded in FARS as speeding-related is smaller than any of the other subsets of fatal crashes used thus far, which could lead to a bias towards parameter values that are overrepresented in speeding-related crashes.

This model is unique among the five road-level models in that the binary indicators for each year do not indicate a general trend in fatalities over time. Based on general fatality rates, the fatal crash rate would be expected to decrease from 2009 until approximately 2012 and then rise again through 2016. However, there is no such trend in this model, and the parameter estimates are nearly all statistically insignificant. Part of the reason behind this is that the trends for speeding-related fatal crashes do not follow this pattern (see Table 4), which can likely be attributed to differences in reporting over time and in different geographical areas.

The final model run for the roadway-level analysis (Table 14) considers the number of fatal crashes that are related to a driver distraction of some sort, including distractions due cellular phone use, eating, drinking, smoking, or other causes.

Table 14. Regression model results considering distraction-related fatal crashes

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	-0.818	6.135	-0.133	0.8940
Std. Dev(Intercept)	0.599			
Year 2010 (1=yes, 0=no)	-0.195	0.312	-0.624	0.5326
Year 2011 (1=yes, 0=no)	0.270	0.586	0.461	0.6451
Year 2012 (1=yes, 0=no)	0.581	0.635	0.915	0.3600
Year 2013 (1=yes, 0=no)	0.665	0.586	1.135	0.2562
Year 2014 (1=yes, 0=no)	0.579	0.525	1.104	0.2697
Year 2015 (1=yes, 0=no)	0.092	0.153	0.601	0.5478
Year 2016 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A
Log (AADT)	1.000	(fixed)	N/A	N/A
Log (Segment Length, mi)	1.000	(fixed)	N/A	N/A
Speed Limit 65 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A
Speed Limit 70 (1=yes, 0=no)	0.094	0.122	0.768	0.4427
Speed Limit 75 (1=yes, 0=no)	0.588	0.149	3.935	0.0001
Speed Limit 80 (1=yes, 0=no)	0.615	0.223	2.755	0.0059
Number of Lanes	-0.133	0.040	-3.291	0.0010
Proportion of State’s Vehicles that are Autos	-9.825	5.951	-1.651	0.0988
Proportion of State’s Vehicles that are Motorcycles	-8.988	6.550	-1.372	0.1700
Proportion of State’s Vehicles that are Trucks	-11.120	5.931	-1.876	0.0607
Proportion of State’s Drivers under 25 years	-7.455	4.094	-1.821	0.0686
Proportion of State’s Drivers over 65 years	-14.960	4.489	-3.332	0.0009
State’s Population Density (persons/sq. mi)	0.000	0.001	0.269	0.7879
State’s Seat Belt Usage (proportion)	-0.287	1.144	-0.251	0.8020
State’s Maximum Monthly Average temp. (°F)	0.098	0.045	2.156	0.0311
State’s Minimum Monthly Average temp. (°F)	-0.106	0.052	-2.040	0.0414
State’s Annual Precipitation (inches)	0.012	0.007	1.729	0.0839
State’s Average Gas Price ($/gallon)	-0.914	0.484	-1.886	0.0593
Years since State’s Max Limit Changed	0.043	0.029	1.488	0.1366
Overdispersion parameter	0.996			
Goodness-of-fit statistics				
Log-likelihood at convergence	-5,359			
AIC	10,768.0			
BIC	10,985.5			

Like the other models, higher speed limits are correlated with higher rates of fatal crashes. Specifically, the number of distraction-related fatal crashes is expected to be 9.9 percent higher on a segment with a speed limit of 70 mph than an identical segment with a speed limit of 65 mph. The expected increases in fatal crashes on a 75 or 80 mph segment compared to a 65 mph segment are 80.0 percent and 85.0 percent, respectively. These values seem high, but it is important to remember that reaction distance and braking distance both increase at higher speeds, meaning distracted drivers traveling faster have a higher likelihood of being involved in a crash.

In addition to the speed limit variables, a handful of additional variables were found to be statistically significant at the 95 percent confidence level. These include the proportion of the driving population over the age of 65 and the state’s maximum and minimum monthly average temperatures. The proportion of the state’s driving population over the age of 65 had a strong negative correlation with distraction-related fatal crashes, which could be because the elderly driving population is less likely to engage in a cell phone-related distraction or because the elderly driving population represents less than 20 percent of the total driving population in most states. Additionally, the parameter estimates from the temperature variables indicate that distraction-related crashes are expected to increase with higher maximum temperatures and lower minimum temperatures, which is the opposite of the trends displayed in the other models.

The other variables in this model were not statistically significant at the 95 percent confidence level, but nearly all of them displayed trends consistent with those in the other models. The one exception was the state annual precipitation variable, which showed a weak positive correlation with the dependent variable rather than a weak negative correlation. This difference is probably because distraction information was only available between 2010 and 2016, which means that the data set used in this model included nine fewer years of data than the total fatal crash data set.

6. ANALYSIS RESULTS FOR IOWA-SPECIFIC DATA SETS

Iowa most recently raised its maximum speed limit from 65 mph to 70 mph in 2005. A previous study evaluated the short-term impacts of this speed limit increase on traffic safety (Souleyrette and Cook 2010). In that study, annual fatal and serious injury crashes were examined from 1991 to 2009 across those interstate segments where speed limits were increased to 70 mph. As a continuation of that study, the present study extended these same plots 2017, the most current year for which data were available. There were two years of overlap between the previous study period and the current study period, 2008 and 2009. Data from these years were used to verify that the number of crashes was consistent across the two data sets.

The number of crashes was combined with VMT information collected from a 30-year historical VMT table provided on the Iowa DOT website (Iowa DOT 2018) to create plots of the rate of fatal and serious crashes per HMVMT, as shown in Figure 18 and Figure 19, respectively.

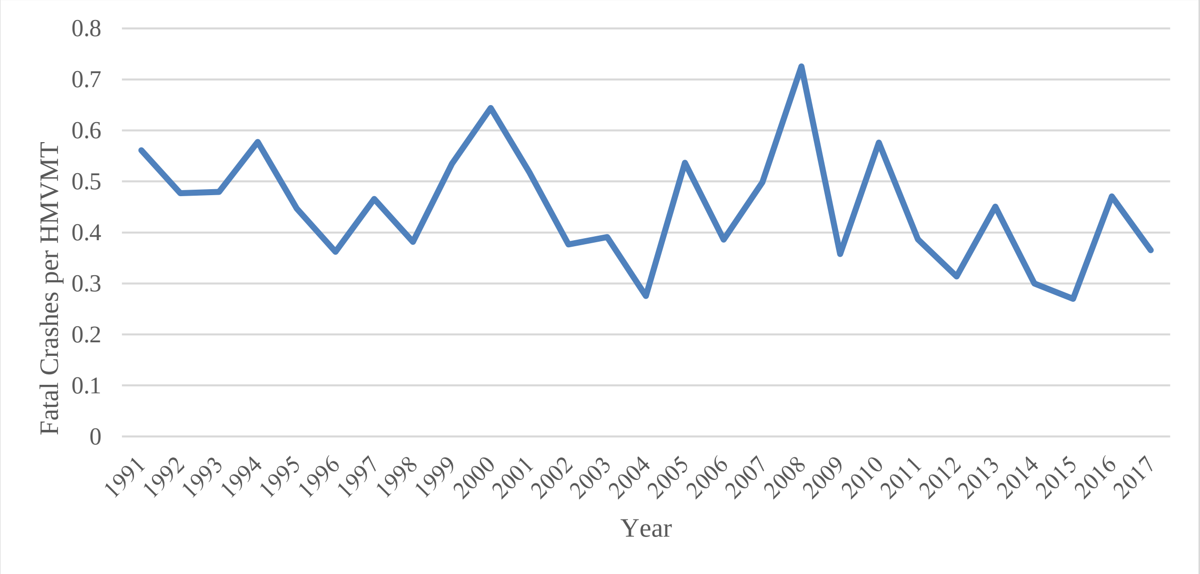


Figure 18. Fatal crash rate from 1991 to 2017 on interstate segments where the speed limit was increased to 70 mph

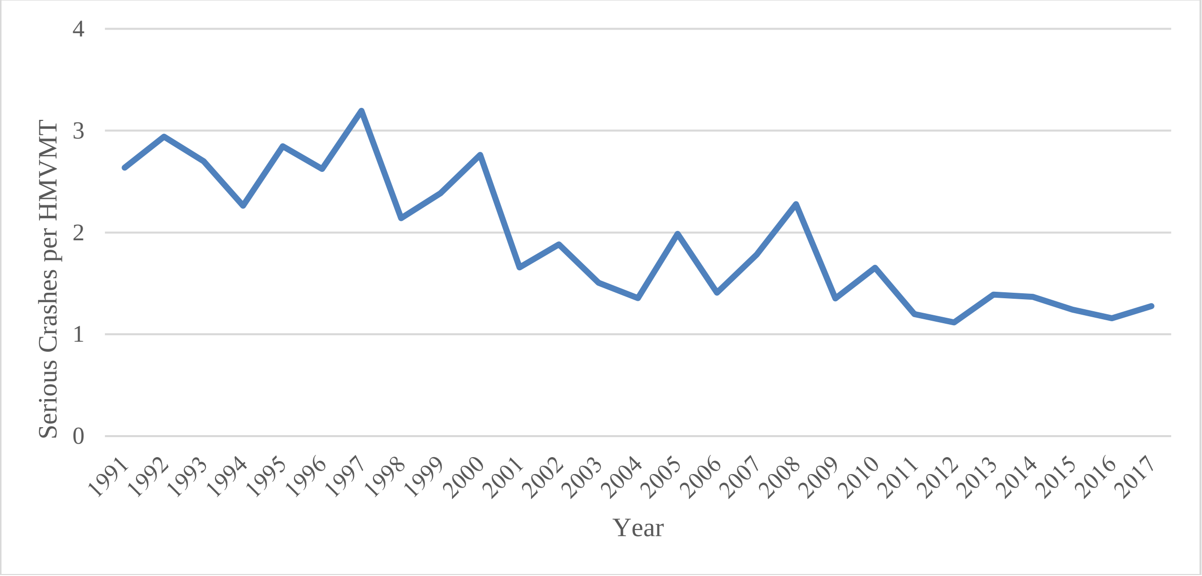


Figure 19. Serious crash rate from 1991 to 2017 on interstate segments where the speed limit was increased to 70 mph

These plots show that the fatal crash rate fluctuated significantly over the study period, ranging between 0.2 and 0.8 crashes per HMVMT. Between the periods before and after the speed limit change (excluding data from calendar year 2005), it was found that the average number of fatal crashes per year increased from 20.8 to 22.2, representing a 6.7 percent increase. However, when the data are normalized by VMT, the average crash rate declined by 8.3 percent, or from 0.46 to 0.42 fatal crashes per HMVMT. For serious crashes (i.e., fatal [K] or serious injury [A]), as Figure 19 shows, there was a general declining trend. The average number of serious crashes per year decreased from 104.1 to 74.9 (a decrease of 28 percent), while serious crashes per HMVMT dropped by 39 percent from 2.35 to 1.44.

In both the fatal and serious injury rates, a short-term increase occurred in the years immediately following the speed limit increase. Subsequently, crashes tended to trend downward over time, which is broadly reflective of national trends over this same time period. This declining trend is likely due to several factors, including traffic safety countermeasures that have been implemented on a large scale throughout the state as well as advances in motor vehicle technologies over the years.

The results of the national-level analyses suggest that increases in the maximum speed limit may have adverse effects on traffic fatalities. Additional investigations were conducted specific to Iowa's interstate freeway system. These sought to examine two fundamental questions:

- How do speeds vary across the Iowa interstate system?
- What is the relationship between speed and safety on the Iowa interstate system?

6.1 Statistical Methodology for Iowa-Specific Analysis

In considering potential changes to the maximum speed limit on the Iowa rural interstate system, it is important to understand how speeds vary across these freeways under current (i.e., 70 mph speed limit) conditions. To this end, three common speed measures, the mean speed, 85th percentile speed, and speed variance, were examined with respect to roadway geometry and traffic volumes on individual rural interstate segments. Typically, separate models are developed for various speed measures. However, the results of such models may be biased due to recursive or endogenous relationships among these measures. To account for these concerns, seemingly unrelated regression equations (SURE) model were used.

In this study, the SURE model consists of three single equations that simultaneously assess the effects of various parameters of interest on mean speed, 85th percentile speed, and speed variance, as follows:

$$MS_i = \beta_{1i}X + \varepsilon_{1i} \tag{9}$$

$$SP85_i = \beta_{2i}X + \varepsilon_{2i} \tag{10}$$

$$SDS_i = \beta_{3i}X + \varepsilon_{3i} \tag{11}$$

where MS_i is the mean speed on segment i; $SP85_i$ represents the 85th percentile speed on segment i; SDS_i is the calculated standard deviation of speeds on segments i; the β terms are the estimated regression coefficients; X is a vector of crash, traffic, roadway geometry, and weather characteristics; and the ε terms represent unobserved characteristics.

Although Equations 9, 10, and 11 are seemingly unrelated and do not directly interact with each other (e.g., the mean speed does not directly affect the 85th percentile speed or speed variance), there are some unobserved shared characteristics because all three values are calculated for the same segment. This cross-equation correlation is captured in the error term. SURE provides efficient parameter estimates by considering the contemporaneous correlation of disturbances, ε_1, ε_2, and ε_3. A detailed discussion of SURE can be found in Washington et al. (2010).

To understand how speed relates to traffic safety, a series of random effects negative binomial regression models were estimated to study how crash, injury, and fatality rates vary across the Iowa interstate network in consideration of mean speed, standard deviation of speed, and other geometric and traffic characteristics. In this analysis, given the fidelity of the available speed data, the dependent variable was the number of crashes experienced at different severity levels in a given month on interstate highways with a 70 mph speed limit.

6.2 Relationship between Speed and Roadway Characteristics

To examine the impacts of roadway geometric characteristics on speed measures and how drivers react to roadway features on average, SURE models were estimated using the speed data between 2013 and 2016. The analysis included variables related to geometric characteristics and traffic volume. Three speed measures were investigated: average speed, 85th percentile speed, and standard deviation of speed. Table 15 shows the results of the SURE models for interstates with a 70 mph speed limit.

Table 15. SURE results for all interstates (2013–2016)

	Mean Speed Model			
Parameter	**Estimate**	**Std. Error**	**t-stat**	**p-value**
Intercept	53.115	0.149	357.525	<0.001
ln(AADT)	1.096	0.012	94.888	<0.001
Urban Area (1=yes, 0=no)	-0.502	0.018	-28.567	<0.001
Presence of Median Barrier (1=yes, 0=no)	-0.257	0.011	-22.340	<0.001
Right Shoulder Width	0.260	0.010	27.262	<0.001
Left Shoulder Width	0.120	0.007	16.691	<0.001
Median Width	0.002	0.000	5.625	<0.001
	85th Percentile Speed Model			
Parameter	**Estimate**	**Std. Error**	**t-stat**	**p-value**
Intercept	53.917	0.155	347.951	<0.001
ln(AADT)	1.254	0.012	104.097	<0.001
Urban Area (1=yes, 0=no)	-0.287	0.018	-15.649	<0.001
Presence of Median Barrier (1=yes, 0=no)	-0.196	0.012	-16.326	<0.001
Right Shoulder Width	0.236	0.010	23.691	<0.001
Left Shoulder Width	0.190	0.008	25.247	<0.001
Median Width	0.001	0.0003	3.034	0.002
	Speed Standard Deviation Model			
Parameter	**Estimate**	**Std. Error**	**t-stat**	**p-value**
Intercept	2.333	0.084	27.628	<0.001
ln(AADT)	0.067	0.007	10.191	<0.001
Urban Area (1=yes, 0=no)	0.400	0.010	40.058	<0.001
Presence of Median Barrier (1=yes, 0=no)	0.043	0.007	6.536	<0.001
Right Shoulder Width	-0.033	0.005	-6.089	<0.001
Left Shoulder Width	0.039	0.004	9.445	<0.001
Median Width	-0.0004	0.0002	-2.359	0.018

The results show that both mean speed and 85th percentile speed are marginally lower in urban areas (0.5 and 0.3 mph lower, respectively) while the standard deviation of speed is higher in these areas by a similar magnitude. Drivers generally tend to select lower speeds in urban environments, which likely reflects increasing traffic congestion and a more complex roadway environment. The presence of traffic congestion in urban areas also helps to explain why there is greater speed variance in urban areas. In relative terms, location in an urban area appears to have a stronger effect on the variability of speeds than on the average speed.

Segments where a median barrier has been installed tend to have lower average and 85th percentile speeds and higher speed variance. On interstates with a 70 mph speed limit, median barriers are typically implemented on crash-prone segments where higher risks are observed (based on historical data) or predicted (based on the roadway geometry). Typical locations might include segments with horizontal curvatures or steep side slopes. In such areas, drivers may be more likely to reduce their speeds in response to such geometric characteristics, which may explain why segments with median barriers have lower average and 85th percentile speeds. In any case, the differences in these speed measures between segments with and without median barriers are quite small.

In contrast, vehicle speeds tend to be higher on segments with wider medians and wider shoulders. As the right shoulder width and median width increase, the average and 85th percentile speeds increase while the standard deviation of speed decreases. These results are generally consistent with prior research, including the speed-related predictive models from the *Highway Capacity Manual*. Interestingly, left shoulder width shows a positive relationship with all three speed measures, including standard deviation of speed. The reason for this result is unclear. One potential explanation is that passing occurs more frequently in these areas because drivers tend to be more comfortable passing when greater lateral clearance is available. Since a wider left shoulder makes it easier to overtake trucks or other slow-moving vehicles, this may explain the higher average and 85th percentile speeds, as well as the greater variability in speeds, along such segments.

Ultimately, the SURE models show that driver speed choice is impacted by roadway geometric characteristics. The mean speed and 85th percentile speed models show that drivers generally select a higher speed on interstates with 70 mph speed limits that have good geometric design standards, including wider shoulders and medians. As the models for standard deviation of speed indicate, the speed variance is typically highest on segments near urban areas and where the right shoulder and median are relatively narrow.

6.3 Relationship between Speed and Safety

To further study the relationship between operational speeds and crash frequencies, a series of random effects negative binomial models were estimated that incorporated speed measures, such as speed variance and average speed, as the explanatory variables. Additional variables, such as traffic and roadway geometry, were included in the model. These models used the segment-month data sets from 2013 to 2016. Three random effect terms, segment-level ID, year, and month, were introduced to account for spatial and temporal effects. These random effects accounted for the unobserved site-specific heterogeneity and allowed the fixed effects to vary for each segment in certain years. Since GIMS segments do not have a uniform length, segment length was included in the models as an offset term. This enabled the models to estimate the crash rate on a per-mile basis. Five random effects negative binomial models were developed for interstate roadways with 70 mph speed limits. One used the total number of crashes as the dependent variable, while the other four used different crash severity types.

Table 16 shows the model results. In interpreting the model results, a positive estimate indicates that crashes tend to increase with increases in that parameter. In contrast, negative coefficients reflect variables that exhibit an inverse relationship with crash frequency.

Table 16. Regression model results for monthly crashes with different severity types (2013–2016)

Severity	Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Total	Intercept	-10.268	0.895	-11.466	<0.001
	ln(AADT)	1.256	0.050	25.172	<0.001
	Speed Standard Deviation	0.245	0.016	15.522	<0.001
	Average Speed	-0.054	0.013	-4.207	<0.001
	Median Width	-0.002	0.001	-1.586	0.113
	Right Shoulder Width	-0.066	0.033	-1.978	0.048
	Presence of Median Barrier (1=yes, 0=no)	0.052	0.039	1.321	0.187
KA	Intercept	-7.275	4.237	-1.717	0.086
	ln(AADT)	0.166	0.214	0.776	0.438
	Speed Standard Deviation	0.388	0.075	5.211	<0.001
	Average Speed	-0.012	0.060	-0.196	0.844
	Median Width	-0.006	0.006	-0.947	0.344
	Right Shoulder Width	0.025	0.172	0.144	0.886
	Presence of Median Barrier (1=yes, 0=no)	0.176	0.182	0.963	0.336
B	Intercept	-11.939	2.496	-4.783	<0.001
	ln(AADT)	1.099	0.126	8.708	<0.001
	Speed Standard Deviation	0.302	0.047	6.462	<0.001
	Average Speed	-0.059	0.036	-1.623	0.105
	Median Width	-0.001	0.003	-0.378	0.706
	Right Shoulder Width	0.021	0.094	0.219	0.827
	Presence of Median Barrier (1=yes, 0=no)	-0.041	0.096	-0.426	0.670
C	Intercept	-19.895	2.691	-7.394	<0.001
	ln(AADT)	1.415	0.127	11.167	<0.001
	Speed Standard Deviation	0.357	0.044	8.122	<0.001
	Average Speed	0.022	0.039	0.549	0.583
	Median Width	-0.013	0.004	-3.439	<0.001
	Right Shoulder Width	0.011	0.091	0.124	0.901
	Presence of Median Barrier (1=yes, 0=no)	-0.109	0.091	-1.195	0.232
O	Intercept	-10.309	1.008	-10.224	<0.001
	ln(AADT)	1.294	0.054	24.055	<0.001
	Speed Standard Deviation	0.216	0.018	12.182	<0.001
	Average Speed	-0.059	0.014	-4.196	<0.001
	Median Width	-0.001	0.001	-0.766	0.444
	Right Shoulder Width	-0.082	0.035	-2.322	0.020
	Presence of Median Barrier (1=yes, 0=no)	0.076	0.042	1.817	0.069

KA = fatal (K) or serious injury (A), B = minor injury, C = possible injury, O = no injury

As expected, segments with higher traffic volumes (AADT) experience higher crash frequencies for all severity levels. This largely reflects the fact that the risk of crashes tends to increase proportionately with exposure. Research has also shown that crash risk tends to increase with higher traffic density (Kuang et al. 2017). Interestingly, the effect of traffic volume on fatal and severe (KA) injuries was not statistically significant. This suggests that these more severe crashes occur in a more random nature across the road network, which reflects the greater variability in severe injury crashes over both space (i.e., across locations) and time (at the same locations).

The results also show strong correlations between the number of crashes at all severity levels and the standard deviation of speed. The estimates indicate that a 1 mph increase in the standard deviation of speed would result in a 27.8 percent increase in the total number of crashes, a 47.4 percent increase in the number of serious (fatal and serious injury) crashes, a 35.3 percent increase in the number of B-level crashes, a 42.9 percent increase in the number of C-level crashes, and a 24.1 percent increase in the number of O-level crashes. It is important to emphasize that the increases are greatest for the most severe crashes. These results are generally consistent with prior research showing speed variance to be highly correlated with crash frequency (Lave 1985, Garber and Gadiraju 1989).

While higher speed variance is associated with more crashes, the absolute speed of traffic does not necessarily correspond to higher numbers of crashes. Total crashes tended to decrease marginally as average speed increased at most of the severity levels, except for possible injury (C-level) crashes. However, this result was only statistically significant for property damage-only (O-level) crashes. Beyond the speed measures, the other geometric characteristics had negligible impacts on crashes in general.

Ultimately, it is important to note that the effects of standard deviation in speed tend to be more pronounced than the effects of average speed. Furthermore, the variability in the standard deviation of speed from segment to segment tends to be more pronounced than the variability in mean and 85th percentile speeds. Consequently, in consideration of future speed limit policy discussions, it will be important to carefully examine the potential safety impacts of higher speed limits on those segments that have historically exhibited higher variability in speed. Overall, the results of these analyses provide some insights that can be used to help frame future decision-making in this area.

7. CONCLUSIONS, RECOMMENDATIONS, AND LIMITATIONS

7.1 Conclusions and Recommendations

This study provides important insights that can be used to help frame continuing speed limit policy discussions. In contrast to prior longitudinal studies, which have generally considered only maximum statutory speed limits, the state-level portion of this study leveraged state-specific details as to the number of miles of rural interstates posted at the maximum speed limit as well as at lower speed limits. A comparison of the results of the two state-level analysis models show that the more detailed, disaggregate-level analysis that accounts for the proportion of rural interstate mileage posted at each speed limit provides a significantly better fit for the fatal crash data.

From a practical standpoint, the results provide additional empirical support for prior research, which has consistently shown that states with higher rural interstate speed limits experience a higher number of traffic fatalities. This effect is even larger when the analysis accounts for the proportion of rural interstate mileage in each state posted at higher speed limits rather than only each state's maximum statutory speed limit. However, it appears that these increases in traffic fatalities may begin to taper off at the highest speed limits, which may be due to the fact that drivers tend to increase their speeds by lesser amounts when speed limits are increased to the upper ranges of 75 to 80 mph or above.

The road-level analysis further supports the claim that roads with higher speed limits experience a higher number of fatalities and fatal crashes. Additionally, the road-level analysis indicates that fatal crashes related to driver distraction are affected by speed limit to a higher degree than total fatalities or fatal crashes. The road-level analysis also suggests that fatal crashes where speeding is involved are more strongly affected by speed limit on roads with a speed limit of 70 or 75 mph than on roads with a speed limit of 80 mph, suggesting one of two things: (1) that drivers are generally more hesitant to exceed the speed limit when it is as high as 80 mph or (2) that drivers who do exceed the speed limit when it is higher are more cautious about their driving, reducing their likelihood of involvement in a fatal crash.

In addition to the findings from the national-level analysis, a simple before-and-after comparison of fatal and serious crash rates on Iowa interstates from 1991 to 2017 shows that crashes increased in the few years after the 2005 speed limit increase but have generally declined since that time.

Further analysis was conducted using Iowa-specific data sets to better understand the relationship between speed and safety. Analysis of speed data obtained from INRIX showed that speeds were generally lower near urban areas, while the standard deviation of speeds on urban interstates was greater. These results were obtained using the average and 85th percentiles of minute-by-minute average speed data. The speed measures were found to be influenced by roadway geometric characteristics.

The impacts of mean speed and speed variance on traffic crashes were discerned through the estimation of additional regression models while controlling for the effects of geometric conditions and traffic volumes. Ultimately, speed variance was found to be the primary factor affecting crash rate. The impacts of speed variance were most intense for the most severe crashes. Meanwhile, the mean speed showed statistically insignificant effects or a negative correlation with crashes, which was in line with some prior studies. The lower crash frequency on segments with higher speeds may reflect more accommodating roadway geometry in such areas.

7.2 Limitations

It is important to acknowledge several caveats and limitations with respect to the results of the state-level analysis. The higher speed limits, particularly 75 and 80 mph, have been applied selectively. Consequently, arguments can be made that estimates of the effects of these speed limits on fatality risk may be either overstated or understated. In one regard, since these higher speed limits have generally been applied at locations with low historical numbers of traffic fatalities, there are possible regression-to-the-mean effects that cannot be directly controlled for at this level of aggregation. This would result in the effects of the increases being overstated because fatalities may naturally have increased in the years subsequent to the speed limit change, even if no policy change had been implemented.

Alternatively, it can be argued that the effects of speed limit increases may be understated because the speed limits have been increased on the most inherently safe segments on a given state’s road network. It is tenuous to suggest that fatalities would increase by the same amount on both these segments and segments that have traditionally performed more poorly due to geometric constraints, weather conditions, or other site-specific factors that led to such segments not being selected for speed limit increases.

Both of these concerns provided motivation for the additional disaggregate-level investigations presented in the road-level analysis, that is, the comparison of road segments where the speed limit has been increased with similar segments that did not experience a speed limit change. Unfortunately, this type of analysis also presents challenges. For example, those segments that did not experience a speed limit change may have inherent differences from segments that did, which makes it difficult to find appropriate comparisons for an empirical Bayes evaluation. Moreover, while the road-level data set is robust in that it includes all rural interstate highways nationwide, it is limited in showing how statewide speed limit policies are put into practice and how they affect driver behavior. For example, if a state were to apply a new maximum speed limit on a small proportion of its interstate network, it is not unreasonable to assume that driver behavior on roads where the speed limit did not increase would be different compared to the situation if the state’s overall maximum limit had not changed at all. These effects cannot be captured in the road-level analyses conducted as a part of this study. Additionally, there is no way to account for segments where speed limits have been raised to or above the design speed of the roadway; in such cases, crashes and fatalities would be affected because existing curves would become substandard under the new speed limits.

Another limitation to this study is that it only considers interstate highways. In most states, there are some segments of non-interstate highways that are up to freeway standards (i.e., four-lane divided highways with access points limited to grade-separated interchanges). It is impossible to account for these roads in the state-level analysis because the FHWA Highway Statistics series makes no distinction between a non-interstate freeway and a major arterial. However, the road-level analysis would have benefitted from the additional data provided by non-interstate freeways that are no different from interstates from a driver's perspective. In some states, non-interstate freeways may not be eligible to post the same maximum speed limit as interstates. However, inclusion of non-interstate freeways would also introduce to the data set even more high-speed roadways such as Texas State Highway 130, a toll road that famously has a speed limit of 85 mph.

A limitation of the Iowa-specific analysis is that the GIMS database maintained by the Iowa DOT was used to integrate traffic, roadway, and crash data. The disadvantage of this database is that directional analysis is not supported. Therefore, all of the segment-specific characteristics had to be aggregated by averaging two directions of traffic. Additionally, it was challenging to integrate INRIX data into the GIMS roadway segments because INRIX not only provides directional speeds but also divides the interstate segments using a completely different segmentation scheme than that used by GIMS. Recently, the Roadway Asset Management System (RAMS) has been adopted by Iowa DOT. RAMS will allow for the collection and maintenance of roadway asset data on a directional basis. As more data become available over the years, future research should leverage this data set for directional analysis to examine the interrelationships among the variables examined in this study with better resolution. Lastly, the accuracy of the weather data was limited by the relatively large spatial buffers that had to be used around the weather stations to ensure total coverage of the interstate network.

Moving forward, analyzing the effects of maximum speed limits on fatalities and fatal crashes can provide agencies with a snapshot of some of the potential ramifications of increasing the speed limit on a road. However, limiting such studies to fatalities only gives a partial view of the effects; a fuller picture would be provided if all crash data were used to draw conclusions on the safety impacts of increasing speed limits. Unfortunately, such an analysis at a national scale is unlikely given the limited availability of non-fatal crash data. However, numerous state-level analyses have been performed to study the effects of speed limits on crashes of varying severities.

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APPENDIX: MATLAB CODE COMBINING ADJACENT ROADWAY SEGMENTS

```
clear all;
clc;
close;

%% Import Excel file
filename = 'C:\Users\Jacob Warner\Box\Theses\Jacob
Thesis\All_Interstates_2015.xlsx';
sheet = 1;
xlRange = 'A3:AB643118';
table = xlsread(filename,sheet,xlRange);

%% New import.
% This section defines each column of the Excel file to improve
% readability
ObjectID = table(:,1);
State_Code = table(:,2);
AADT = table(:,3);
Route_No = table(:,4);
Route_No_1 = table(:,5);
Speed_Lim = table(:,6);
Through_Lanes = table(:,7);
Urban_Code = table(:,8);
MP_Begin = table(:,9);
MP_End = table(:,10);
Segment_Len = table(:,11);
Crashes = table(:,12);
Crashes_01 = table(:,13);
Crashes_02 = table(:,14);
Crashes_03 = table(:,15);
Crashes_04 = table(:,16);
Crashes_05 = table(:,17);
Crashes_06 = table(:,18);
Crashes_07 = table(:,19);
Crashes_08 = table(:,20);
Crashes_09 = table(:,21);
Crashes_10 = table(:,22);
Crashes_11 = table(:,23);
Crashes_12 = table(:,24);
Crashes_13 = table(:,25);
Crashes_14 = table(:,26);
Crashes_15 = table(:,27);
Crashes_16 = table(:,28);

%% Create New Table
% The new table takes each segment in the existing Excel file and
% automatically combines the data with the next segment if and only if the
% state, route number, AADT, number of lanes, urban code, and speed limit
% are identical. If all of these criteria are met, the new segment retains
% the Object ID and beginning milepost of the first segment and the ending
% milepost of the second segment. The new crash fields are the sum of the
% two crashes in the segments that are combined, and all other information
% is defined to be the same.

new_table = table(1,:);
```

```
i=1;
j=1;
for i=1:(length(table)-1)
    if State_Code(i+1)==State_Code(i)
        if Route_No(i+1)==Route_No(i)
            if AADT(i+1)==AADT(i)
                if Through_Lanes(i+1)==Through_Lanes(i)
                    if Urban_Code(i+1)==Urban_Code(i)
                        if Speed_Lim(i+1)==Speed_Lim(i)
                        new_table(j,10)=MP_End(i+1);
                        new_table(j,11)=new_table(j,11)+Segment_Len(i+1);
                        new_table(j,12)=new_table(j,12)+Crashes(i+1);
                        new_table(j,13)=new_table(j,13)+Crashes_01(i+1);
                        new_table(j,14)=new_table(j,14)+Crashes_02(i+1);
                        new_table(j,15)=new_table(j,15)+Crashes_03(i+1);
                        new_table(j,16)=new_table(j,16)+Crashes_04(i+1);
                        new_table(j,17)=new_table(j,17)+Crashes_05(i+1);
                        new_table(j,18)=new_table(j,18)+Crashes_06(i+1);
                        new_table(j,19)=new_table(j,19)+Crashes_07(i+1);
                        new_table(j,20)=new_table(j,20)+Crashes_08(i+1);
                        new_table(j,21)=new_table(j,21)+Crashes_09(i+1);
                        new_table(j,22)=new_table(j,22)+Crashes_10(i+1);
                        new_table(j,23)=new_table(j,23)+Crashes_11(i+1);
                        new_table(j,24)=new_table(j,24)+Crashes_12(i+1);
                        new_table(j,25)=new_table(j,25)+Crashes_13(i+1);
                        new_table(j,26)=new_table(j,26)+Crashes_14(i+1);
                        new_table(j,27)=new_table(j,27)+Crashes_15(i+1);
                        new_table(j,28)=new_table(j,28)+Crashes_16(i+1);
                        else
                        j=j+1;
                        new_table(j,:)=table(i+1,:);
                        end
                    else
                        j=j+1;
                        new_table(j,:)=table(i+1,:);
                    end
                else
                    j=j+1;
                    new_table(j,:)=table(i+1,:);
                end
            else
                j=j+1;
                new_table(j,:)=table(i+1,:);
            end
        else
            j=j+1;
            new_table(j,:)=table(i+1,:);
        end
    else
        j=j+1;
        new_table(j,:)=table(i+1,:);
    end

end
```

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