2018

Evaluation of speed limit policy impacts on rural interstate fatalities

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Evaluation of speed limit policy impacts on rural interstate fatalities

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Transportation Engineering)

Program of Study Committee:
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Iowa State University

Ames, Iowa

2018

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

AADT	Annual Average Daily Traffic
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
HPMS	Highway Performance Monitoring System
IIHS	Insurance Institute for Highway Safety
NCHRP	National Cooperative Highway Research Project
NHTSA	National Highway Traffic Safety Administration
NMSL	National Maximum Speed Law
PDO	Property Damage Only
VMT	Vehicle-Miles Traveled

ACKNOWLEDGMENTS

I would like to thank my committee chair, Dr. Peter Savolainen, and my committee members, Dr. Chris Day and Dr. Michael Perez, for their guidance and support throughout the course of this research.

In addition, I would also like to thank the members of the Technical Advisory Committee for formulating and advising this project, including Tim Crouch, Jan Laaser-Webb, and Elijah Gansen from the Iowa Department of Transportation and John Shaw from the Institute for Transportation.

Finally, I would like to thank my colleagues and the department faculty and staff for making my time at Iowa State University a wonderful experience. I want to also offer my appreciation to my friends and family; without their continued support, this thesis would not have been possible.

ABSTRACT

The topic of raising maximum statutory speed limits has been a subject of debate for many decades. Supporters of high speed limits cite travel time savings and lower crash risk due to lower variances in speed as reasons to increase a speed limit, while opponents point to increases in crash and fatality rates that have followed speed limit increases in the past. As recently as February 2017, legislators in the state of Iowa have discussed increasing the maximum speed limit on rural interstates from 70 mph to 75 mph, an increase that would make Iowa the 19th state to have a speed limit of at least 75 mph.

The primary goal of this study is to assess the degree to which recent increases in maximum speed limits across the United States have impacted the number of traffic fatalities on rural interstates. To this end, the research includes two separate investigations of state-level fatality trends. These investigations include a state-level aggregate analysis, as well as a disaggregate road segment-level analysis, each of which uses information from federal highway and traffic safety agencies from 2001 to 2016 to examine the effects of rural interstate speed limit on traffic fatalities.

A series of negative binomial models are estimated, with the results showing significantly higher rates of fatal crashes in states with higher maximum limits. In the state-level analysis, the results show that increasing the statewide percentage of rural interstates posted at 70, 75, or 80 mph by one percent is associated with fatality increases of 0.2%, 0.5%, and 0.6% respectively. Likewise, the results from the road-level analysis indicate that raising the speed limit on a road segment from 65 to 70, 70 to 75, or 75 to 80 mph is likely to increase the fatal crashes by 29.7%, 2.9%, and 53.3%, respectively. In

addition, the segment-level analysis estimated quantities of fatal crashes related to distractions and speeding. The results of this study provide important insights to inform subsequent policy discussions related to speed limit increases.

CHAPTER 1. INTRODUCTION

Maximum statutory speed limits have been an issue of longstanding debate. Following the introduction of the National Maximum Speed Law (NMSL) in 1974, which set maximum speed limits to 55 mph nationwide, a series of longitudinal studies showed significant decreases in traffic fatalities (Borg, 1975; Enustun, Hornbeck, Lingeman, & Yang, 1974). Because the NMSL represented a reduction in speed limit on many roads, including interstates in most states, the results from these studies suggest that traffic fatalities tend to increase with maximum speed limits. In 1987, states were given the authority to increase 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, Lund, & Wells, 1989; Baum, Wells, & Lund, 1991). In 1995, the NMSL was repealed, giving states full autonomy to establish maximum limits. When lower limits were in place under the NMSL, speed limit compliance has generally been poor on rural interstates in particular (Lam & Wasielewski, 1976; McKnight & Klein, 1990), leading to a number of states increasing their maximum speed limits to 70 or 75 mph immediately following the repeal. However, the states that increased their maximum speed limits after the NMSL repeal generally observed higher fatality rates (National Highway Traffic Safety Administration, 1998). The two observations (i.e., high fatality rates with high speed limits and poor compliance with low speed limits) are the primary reason that the topic of raising speed limits has been debated for decades.

As recently as February 2017, the Iowa legislature has discussed potential increases to speed limits on rural interstates to 75 mph (S.F. 289, 2017). While the maximum speed limit on rural interstates remains 70 mph, there has been continuing discussion as to increased speed limits in Iowa, as well as other states across the country. To that end, it is necessary that the safety impacts of increasing the speed limit be thoroughly examined to allow state lawmakers to make an informed decision that is in the best interests of the state of Iowa.

Since 2001, 25 states, including Iowa, have raised their maximum statutory speed limits on rural interstates, and as of 2018, there are 18 states that have a maximum posted interstate speed limit of 75 or 80 mph, including Iowa's neighboring states of Nebraska, South Dakota, and Kansas. Separate maps illustrating these recent speed limit increases from 2001 to 2018 are shown in Figure 1.

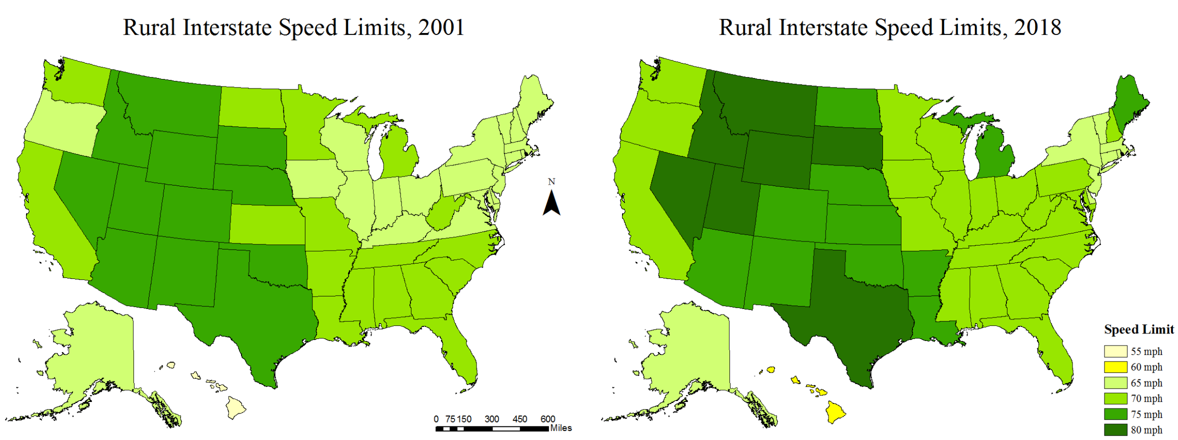

Figure 1. Maximum Rural Interstate Speed Limits in 2001 and 2018.

Because of the varied public perception about the safety benefits or concerns to raising maximum speed limits, it is necessary to examine the potential safety impacts to an increased limit. There are two main considerations that need to be balanced when agencies consider raising speed limits: the variance of driver speed under a higher limit, and the crash and fatality rates that occur as a result from increased speed limits. The primary objective of this research is to examine the latter consideration, by examining how speed limit changes have affected fatality rates nationwide. This was done by utilizing fatality data from 2001 to

2016 and examining the relationship between fatalities and maximum speed limit at both the state level and at the road segment level.

The research study is summarized in this thesis. The introductory chapter outlines the study, providing a background, overview, and objectives for the study. The remaining four chapters are summarized as follows:

- Chapter 2 presents the results of an extensive literature review of prior research on safety effects on speed limit changes.
- Chapter 3 details the data collection process and shows the different methods used to gather and compile these data.
- Chapter 4 outlines the statistical methods used in analyzing the data and provides the results of the statistical analysis.
- Chapter 5 summarizes the key findings from the research and provides recommendations based on the findings.

CHAPTER 2. LITERATURE REVIEW

Many studies have been performed to determine the effects of a change in speed limit on the number of crashes on roadways. In response to the speed limit reductions due to 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 of the three previous years (Borg, 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).

As the 55-mph requirement for rural interstates was being phased out in the 1980s to allow for speed limits as high as 65 mph, research on the effects of speed limit on crash rates continued. 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 they were to remain at 55 mph (Baum, Lund, & Wells, 1989). However, among the states that retained the 55-mph speed limit, the number of fatalities were observed to be 6 percent lower than expected. A subsequent follow-up study using FARS data from 1982 to 1989 found that the likelihood of a fatality was 29 percent higher on rural interstates in 1989 than expected based on the data from 1982 to 1986 (Baum, Wells, & Lund, 1991).

Additional analyses of national fatality data showed that 19 out of 40 states experienced a significant increase in fatal crashes when speed limits were increased on rural interstates in 1987, and 10 out of 36 states saw fatal crashes increase with a speed limit increase on rural interstates in 1996 (Balkin & Ord, 2001). Also in this study, 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 to show 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, more than double the expected rate of 22.0 fatalities if the speed limit were not increased (Ossiander & Cummings, 2002). A 1990 study took a deeper look at the effects of the speed limit increase in Michigan in 1987, and found that there was a 19.2 percent increase in fatalities, 39.8 percent increase in serious injuries, 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 (i.e., 1988) against the trends from the ten years prior to the increase (i.e., 1978-1987) (Wagenaar, Streff, & Schultz, 1990).

A similar study was performed in Michigan in 1990, and results of the monthly time-series intervention analyses estimated the rates of fatalities, major injuries, and minor injuries to increase by 28.4 percent, 38.8 percent, and 24.0 percent, respectively over the 25-month study period (Streff & Schultz, 1990). In Iowa, a study was performed to examine the safety impact of the increased speed limit (i.e., to 65 mph) on rural interstates with an analysis period from 1981 to 1991. Researchers concluded that higher speed limits led to a higher fatality rate, and the speed limit change brought approximately 20 percent more fatal crashes statewide. However, the number of major injury crashes turned out to be unaffected (Ledolter & Chan, 1994). This study was later expanded using more selective sample locations, including 18 locations along interstates, primary roads, and secondary roads in rural areas, as well as urban interstates. While this study made the same conclusion about fatal crashes as the previous study, this study determined that the adverse effect of increasing speed limits to 65 mph was more prevalent on rural interstates, where a 57 percent increase in the number of fatal crashes was determined to occur due to the speed limit increase (Ledolter & Chan, 1996). An additional study on rural interstate highways in Iowa used fatal crash data from 1980 to 1993, and used a dynamic model to show an average increase of four fatal crashes per quarter due to the increase in speed limit to 65 mph (Raju, Souleyrette, & Maze, 1998).

The relationships between speed limit, operating speed, 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 metro Detroit. The roadway sampled in that study experienced a decrease in speed limit from 70 to 55 mph for passenger cars, and the proportion of cars exceeding 60 mph dropped from 64 to 27 percent following the decrease in speed limit. However, only approximately 30 percent of vehicles in the study traveled below 55 mph after the speed limit decrease (Lam & Wasielewski, 1976). Another study used 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 from that study 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 for which the speed limit remained at 55 mph, the number of fatal crashes still increased by 10 percent for rural interstates and 13 percent for other non-interstate 55-mph highways (McKnight & Klein, 1990). A National Cooperative Highway Research Program (NCHRP) study examined the impacts of a raised speed limit to 65 mph on high-speed roads in Washington State. The results suggested 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 crash rate and a 24 percent increase in probability of an occupant being fatally injured in a crash (Kockelman, 2006).

A number of studies have supported the trends between speed limit, travel speed, and crash rates. One 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 speed limit was associated with a 0.3- 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 from the same time frame (1986 to 1989 in this case) utilized interstate speed data and fatal crash data to assess the effects of increasing the speed limit from 55 mph 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 & Lynn, 1991). Another 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, Stenzel, & Lee, 1991). However, the increase of crash rates was not found to be statistically significant.

While numerous studies have shown that fatality rates have increased when speed limits increased, several studies have also indicated positive effects of speed limit increases. Upon the nationwide speed limit increase to 65 mph, a few studies found that the growth of

VMT on rural interstate highways was significantly greater than the overall VMT growth. This implies that interstates with higher speed limits divert traffic away from more dangerous highway types, such as two-lane roads, that maintained a speed limit of 55 mph. When aggregating the fatality rates from 1986 to 1988 in all states that raised their speed limits versus all that did not, the states that increased their speed limit experienced a 3.62 percent higher decrease in fatality rate than states that did not increase their speed limit. Furthermore, a linear regression curve was fitted using fatality rate per VMT from 1976 to 1990, demonstrating 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 & Elias, 1994; Lave & Elias, 1997).

Mixed results have been found in several studies regarding the speed limit increase from 55 mph to 65 mph. One study employed a state-by-state analysis using FARS data from 1976 to 1988, and researchers asserted that the new 65-mph speed limit had disparate effects on rural highway fatalities. Most states observed 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 (Garber & Graham, 1990). The study also believed the new 65-mph speed limit contributed to traffic diversion as well as speed spillover effects on rural non-interstate highways, and they found that the median effect of the new speed limit on rural non-interstate fatalities was an increase in fatalities by approximately 5 percent.

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. Thus, researchers concluded that the severity of crashes on Illinois' 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 65-mph speed limit on the entire Alabama roadway system using two years before and one year after the speed limit change. The authors pointed out that the proportion of PDO, injury, and fatal crashes did not change, but the total crash frequency was found to have increased by 18.88 percent on rural interstates in the first year of the new speed limit (Brown, Maghsoodloo, & McArdle, 1990).

Some studies observed the different effects of speed limit increases to 65 mph on different road types. For example, an Ohio study used three years of crash data before and after the implementation of the new speed limit and claimed that the fatal crash rate did not significantly change on rural interstate highways with interstates and non-interstate highways. However, the injury and PDO crash rates increased on rural interstates by 16 percent and 10 percent, respectively, and they decreased on non-interstate highways, which did not experience a speed limit change, by 5 percent and 3 percent, respectively (Pant, Adhami, & Niehaus, 1992).

A 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 (Delaware, Alaska, 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 decayed after approximately one year. Fatality rates in larger states, such as Texas, California, Florida, and Illinois were found to be insensitive to the speed limit increase, while smaller states had more dramatic reactions to the speed limit increase (Chang, Chen, & Carter, 1993).

In addition to the speed limit changes brought by the NMSL, numerous studies have occurred in reaction to speed limit changes that have happened more recently. A study by the National Highway Traffic Safety Administration (NHTSA) compiled speed data from 1991 to 1996 in 10 states that increased their speed limits immediately following the NMSL repeal. The report that was submitted to Congress found that the interstate fatalities in these states increased by about 9 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 following the increases in speed limit from 55 to 65 mph ten years prior. It should be noted that this study had limited data available, both due to the relatively short study period after the speed limit change for which data was used and the unavailability of supplementary data such as VMT (National Highway Traffic Safety Administration, 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 speed limit on crash frequency. It found a 52 percent increase in nighttime fatal crashes and a 25 percent increase in severe cross-median crashes. The increases varied more than normal, but were not statistically significant. There was found to be a 25 percent increase in the total crashes in the state after the speed limit increase, which was significant at a 90 percent confidence level (Souleyrette & Cook, 2010).

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 6-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 & Mussa, 2006).

When speed limits on rural interstates in Indiana increased from 65 to 70 mph in 2005, it was found that socioeconomic variables, such as age, gender, and income, correlate 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 was performed in response to the speed limit increase to 70 mph, both of which examined crash risk versus speed limit. The study found that there was not 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 & Mannering, 2008).

After the state of Michigan increased its speed limit on freeways in 1997 from 65 to 70 mph for cars only, several studies examined the effects of that change. One study found that fatal crashes increased by 5 percent and total crashes increased by 10.5 percent after the 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 amount of truck crashes after the speed limit change (Taylor, 2000).

Another study in Michigan examined the results of the speed limit change on crash frequency. This study observed a 16.4 percent increase in crashes in sites 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 in sites where the speed limit did not change (Taylor & Maleck, 1996). Additionally, a continuation of this study was performed in 1998 that examined drivers' speeds in the three months after the speed limit increase in Michigan. It did not find significant speed changes for sites where the speed limit did not change, nor a spillover effect of increased speeds for locations near sites where the speed limit increase was applied. In sites where the change was applied, it was found that the median speed increased by 1 mph and the 85^{th}-percentile speed increased by 0.8 mph (Binkowski, Maleck, Taylor, & Czewski, 1998).

There have been many studies that have examined the effects of multiple speed limit changes at once. A California study defined three groups of highways: roadways with speed limits that increased from 55 to 65 mph, roadways that increased from 65 to 70 mph, and roadways that had a speed limit of 55 throughout the study period. It was found that for groups that experienced a speed limit increase, there was a significant increase in fatal collisions, although the 65 to 70 mph group had a level of significance less than 10 percent (Haselton, Gibby, & Ferrara, 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 asserted 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 had increased sharply. Meanwhile, other statistics, including fatal crash rates and total crash rates on rural interstates, remained stable after a speed limit change (Vernon, Cook, Peterson, & Dean, 2004).

Another study examined roads from 1993 to 2013 in 41 states that had at least 10 billion VMT in each year in 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 types of roadway. The study results revealed that the fatality rate generally decreased over the study period; however, increased maximum speed limit was associated with higher fatality rates. On all roads, a 1-mph increase in maximum speed limit resulted in a 0.9 percent increase in fatality rate, while this positive relationship was almost doubled to 1.6 percent on freeways and interstates. On roads other than freeways and interstates, fatality rates increased by 0.8 percent for each 1-mph increase in speed limit (Farmer, 2016).

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 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, it was found that in general, high speed limits are correlated with higher fatality counts at both the road level and the state level (Castillo-Manzano, Castro-Nuño, López-Valpuesta, & Vassallo, 2019).

Table 1 below shows a summary of results from selected studies outlined previously. Despite the extensive coverage of this topic in the extant 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 as to potential impacts of these increases while controlling for other pertinent factors.

Table 1. Summary of Literature Review Results

State(s)	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, 1975
Michigan	1971-1974	65	55	1974	-17%	Enustun et al., 1974
Nationwide	1982-1989	55	65	1987	29% increase in probability	Baum, Wells, & Lund, 1991
Washington	1970-1994	55	65	1987	110% compared to expected values	Ossiander & Cummings, 2002
Michigan	1978-1988	55	65	1987	+19.2%	Wagenaar, Streff, & Schultz, 1990
Iowa	1981-1991	55	65	1987	+20%	Ledolter & Chan, 1994
Nationwide	1982-1988	55	65	1987	+22%	McKnight & Klein, 1990
Nationwide	1976-1988	55	65	1987	+15% (Median statewide change)	Garber & Graham, 1990
Alabama	1985-1988	55	65	1987	No significant change	Brown, Maghsoodloo, & McArdle, 1990
Ohio	1984-1990	55	65	1987	No significant change	Pant, Adhami, & Niehaus, 1992
10 states	1991-1996	65	Varies	1996	+9%	National Highway Traffic Safety Administration, 1998
Michigan	1994-1999	65	70	1997	+5%	Taylor, 2000
Iowa	1991-2009	65	70	2005	+52% at night	Souleyrette & Cook, 2010
41 states	1993-2013	Varies	Varies	Varies	+0.8% per 1-mph increase	Farmer, 2016

CHAPTER 3. DATA COLLECTON AND METHODOLOGY

This study involved two different analyses, each of which required assembly of a different dataset. These analyses are outlined in the subsequent sections.

3.1 State-Level Fatality Analysis

The analyses for this study required assembly of a dataset from a variety of sources. The data used includes 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 was aggregated to the state-year level. This results in a longitudinal dataset where each state, as well as the District of Columbia, has one record per year for each of these variables. The data for this study is obtained over the 16-year period from 2001 through 2016.

The fatality data used for this study came from the NHTSA's annual Fatality Analysis Reporting System (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; and,
- person-level information such as type (e.g., driver or passenger), position within the vehicle, age, race, gender, and alcohol or drug use.

For this analysis, the pertinent fatal crashes are all of the crashes that occurred on an interstate highway between 2000 and 2016. To obtain this, all crashes where the roadway functional system 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 fields for latitude and longitude, available for most crashes occurring in 2001 or later.

Upon examining the locations of the fatal crashes, it was determined that there existed many errors in coding, resulting in some crashes appearing in the dataset that occurred on a road that is not an interstate highway. In addition, there were many cases where the geocoding of a crash was nowhere near the physical interstate, such as in Figure 2, where such crashes are denoted with a lighter color. Still other crashes were included in the dataset that occurred on a ramp, a cross street, or a nearby frontage road, such as in Figure 3, which shows an example of a crash on a ramp on Interstate 80 near Des Moines, Iowa. Because many of these crashes could not easily have been linked to the characteristics of the nearest roadway, the dataset needed to be refined.

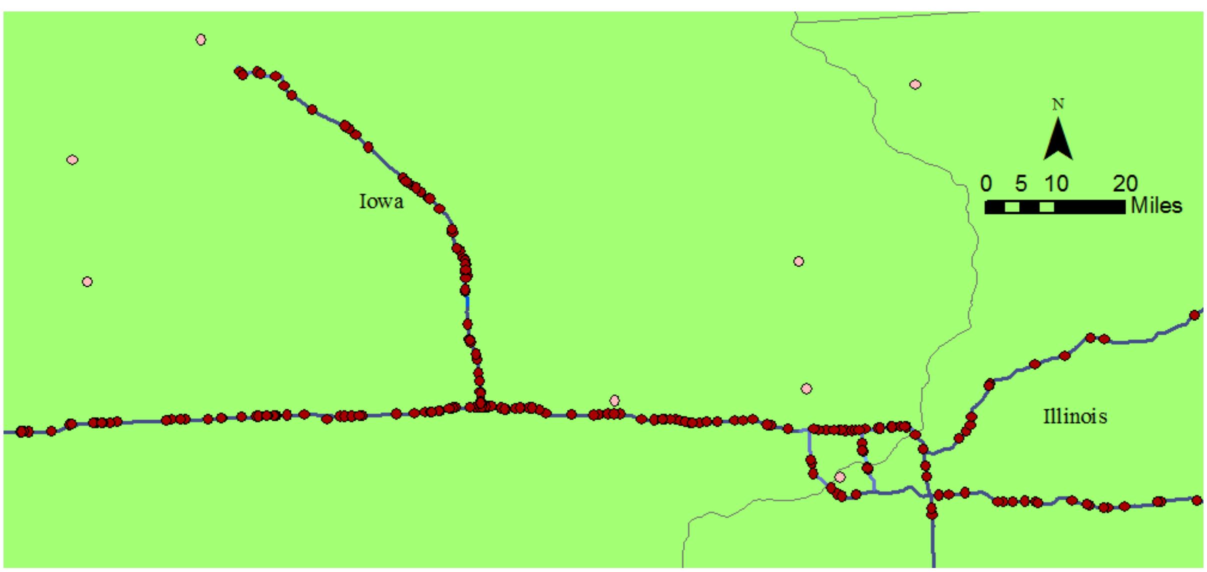

Figure 2. Example of Crashes not along Interstate.

Imagery Source: ESRI ArcGIS Online and data partners
Figure 3. Example of Crash on a Ramp.

The goal of the refined crash dataset was to only include 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. In order to achieve this goal, a manual review a subset of the crashes was undertaken. This subset consisted of all crashes that were 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 Interstate 24 northwest of Chattanooga, Tennessee, where the directions of travel are separated by nearly a mile to navigate through a mountain pass. In this case, the shapefile only shows the southbound direction of travel (shown in blue).

Imagery Source: ESRI ArcGIS Online and data partners

Figure 4. Example of a Roadway with a Wide Median.

In addition to the crash points found outside the buffer that belong in the dataset, there were also many crashes found inside the buffer that do not belong in the dataset. Specifically, the crashes that occurred along a ramp within 200 feet of a mainline 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 Interstate 290 in suburban Chicago. In this case, the crash falls within the 200-foot buffer (denoted in white), but was located along the eastbound off-ramp. Because there was no guarantee that any given crash in the subsets needed to be eliminated, each crash in the subsets had to be manually reviewed.

Imagery Source: ESRI ArcGIS Online and data partners

Figure 5. Example of Crash on Ramp within 200-foot Buffer.

After the manual reviews of the crash dataset, the number of crashes useful for this study was decreased to 57,493. This dataset was then linked with the shapefiles from the FHWA HPMS shapefiles that were compiled in the state-level fatality analysis. This was performed using the Spatial Join feature in ArcGIS.

Upon initial examination of the fatality data aggregated by state, general trends could be seen that indicate that states with higher speed limits tend to have more fatalities, even when normalized by VMT. Figure 6 shows four scatter plots of the number of rural interstate fatalities in a state in a year versus the state's amount of rural interstate VMT in that year, broken down by maximum speed limit. The figure on the bottom-left shows the graph of states with 75- or 80-mph speed limits; the points that appear in black indicate those where the maximum speed limit is 80 mph. Based on the trendlines and data shown on the bottom-right graph, it is shown that states with higher speed limits typically are associated with higher fatality rates. Additionally, Figure 7 indicates the general trends of fatalities per 100 MVMT per year over the course of the study period. Because these are just results from preliminary examinations of the dataset and don't include other potential factors that could affect fatality rates, further analysis is required.

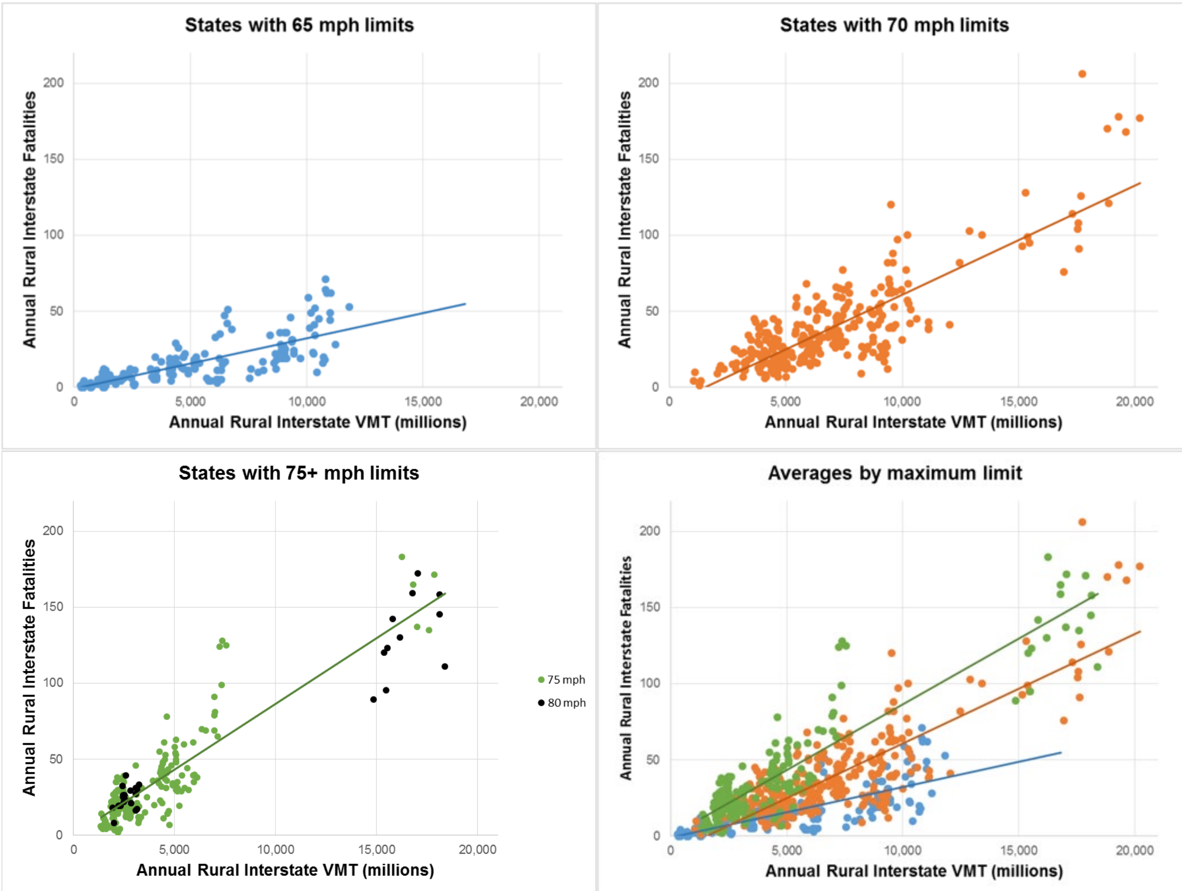

Figure 6. State-Level Fatalities vs. MVMT.

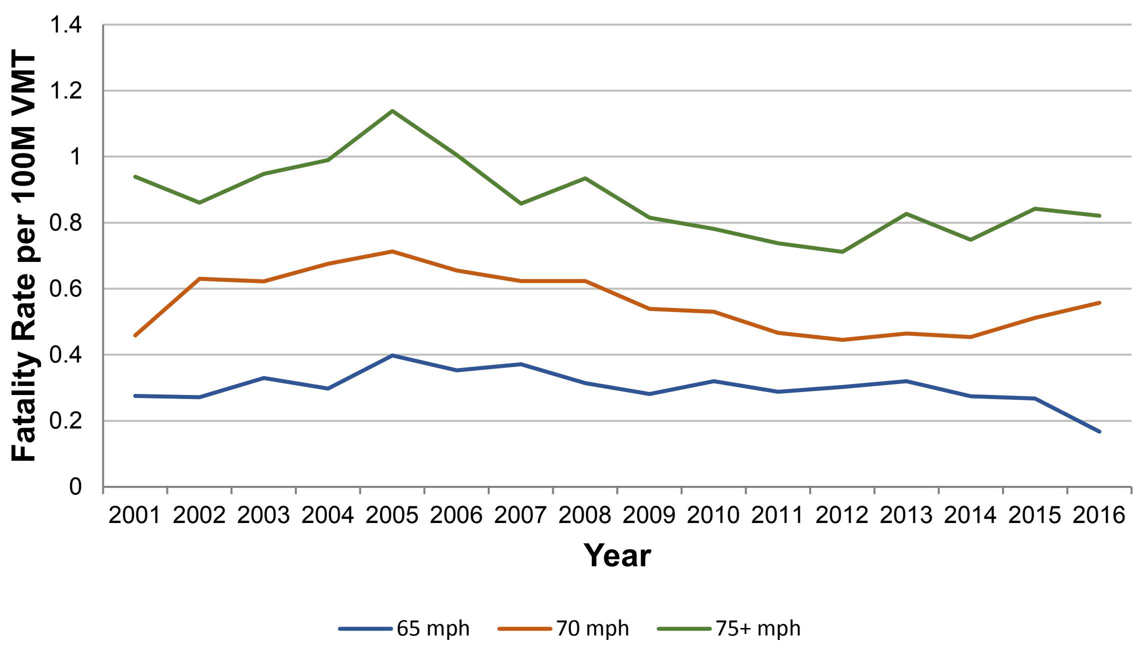

Figure 7. Fatalities per HMVMT over time.

Most of the roadway information for the analyses came from the Federal Highway Administration's (FHWA) Highway Statistics series (FHWA Office of Highway Policy Information, 2017), which provides annual information about the 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 data specific to rural interstates. Additionally, the FHWA Highway Statistics series provides information about motor vehicle registration and licensed drivers by state. The 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, where the ages are displayed in ranges of 5-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 in ranges of 5-year increments. This data was largely collected to confirm the states that 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 NHTSA Traffic Safety Fact sheets (National Highway Traffic Safety Administration, 2017).

Data were also collected for several other factors that may be expected to be associated with fatality rates. This includes air temperature, total precipitation, and average fuel prices. The temperature and precipitation information is from the National Oceanic and Atmospheric Administration's 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 are only used as general estimates for weather, and not necessarily the actual weather conditions of the entire states. The fuel price information came from the Energy Information Administration (U.S. Energy Information Administration, 2017), and displays 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 dataset includes the maximum rural interstate speed limit in each state, as well as the total values and percent at the maximum limit for mileage, VMT, and lane-mileage. This was collected from a number of different sources. The current maximum limits can be found from several sources, including the Insurance Institute for Highway Safety (IIHS) (IIHS Highway Loss Data Institute, 2018), and the maximum speed limits in 2000 were outlined in an FHWA Highway Information Quarterly Newsletter from April 2002 (FHWA Office of Highway Policy Information, April 2002). The dates of any speed limit change since then were found by searching press bulletins and news articles.

The total mileage of urban and rural interstate and the percentage of mileage at each speed limit in each state were calculated by the FHWA's Highway Performance Monitoring System (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 an 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 was 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; instead, the 2014 shapefiles were used for these three states. An image of the speed limits of interstates across the country is found in Figure 8. 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 fields were filled in. To determine any mileage that has 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 fill in the speed limits in years prior to 2015, assumptions were made that the speed limit of any given roadway had not changed unless the state's maximum limit has changed, and that a road segment with the maximum speed limit in 2015 also had the maximum speed limit prior to a statewide change. Additionally, due to unavailability of historic records, it was assumed that the urban area boundaries outlined in the HPMS had not changed over the course of the study period.

As the data in the FHWA Highway Statistics were given in terms of lane-mileage and VMT, the percentages of lane-mileage and VMT at the maximum speed limit in each state were also calculated. This provided a better estimate of the risk of speed limit-related crashes than percentage of mileage. However, due to time constraints and availability of the FHWA shapefiles, only the percentages for the most recent year (i.e., 2015 or 2014) were recorded. The values for these fields in the remaining years are estimates based on the percentages of total miles for the record and the trends of lane-mileage and VMT from year to year within the state. Table 2 presents summary statistics (i.e., minimum, maximum, average, and standard deviation) for each of the data sources presented in this section.

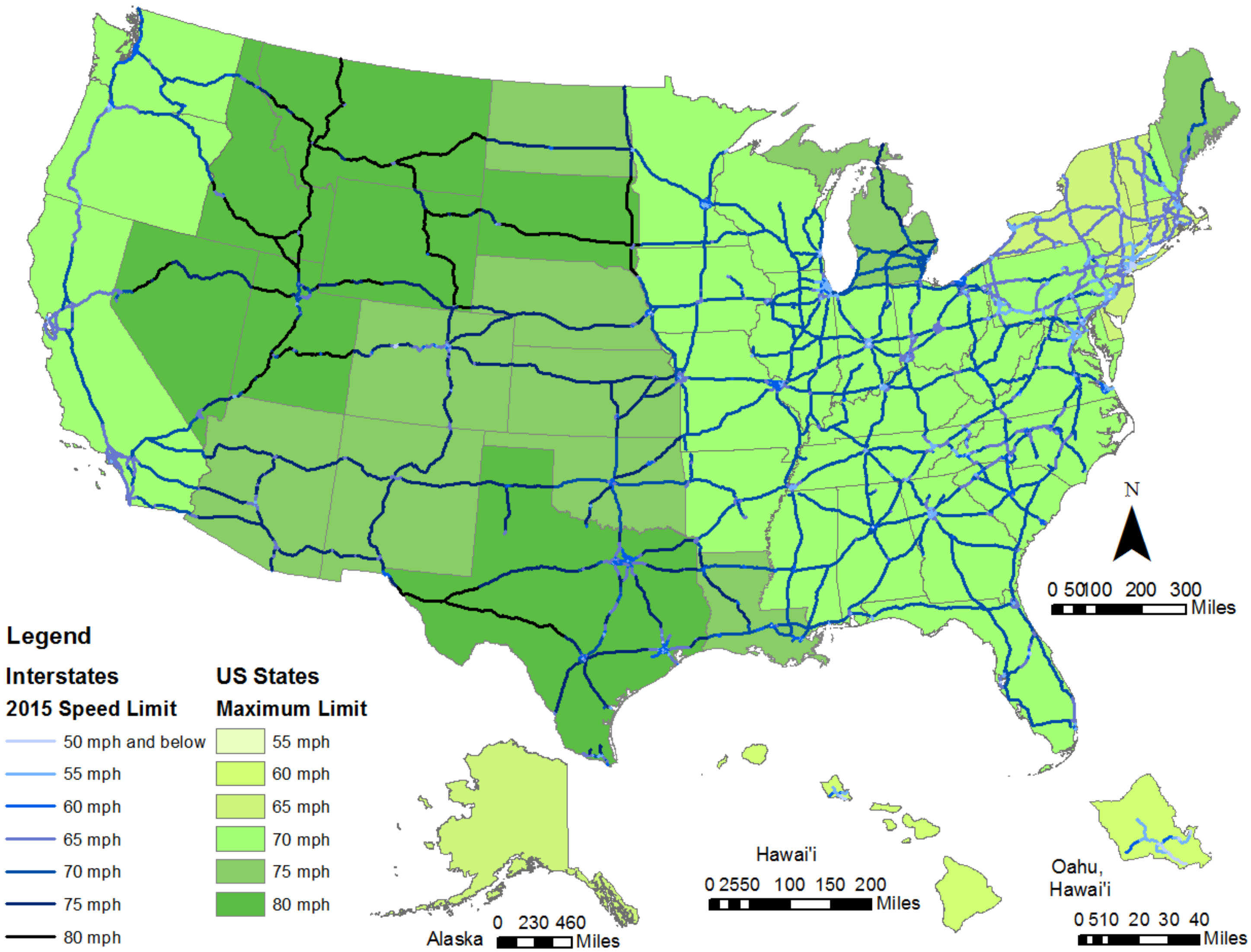

Figure 8. Map of Interstates with Speed Limits.

Because all crash data from before 2001 were eliminated due to lack of geographic information, it was decided to begin the study period of the state-level analysis at 2001. The total number of observations is comprised of 16 years of data for 47 states for the rural model. Data for Alaska were not recorded due to the lack of interstate freeways in that state (the interstate highways are unsigned and not necessarily designed to the same standards in the remaining 49 states), and all of the interstates in Delaware, Hawai'i, and the District of Columbia are located in an urban area.

Table 2. Summary Statistics for State-Level Rural Models (n=752 state-years)

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/sq. mi.)	190.67	262.14	5.09	1216.24
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	1998.44
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

3.2 Road-Level Fatality Analysis

Once the state-level information was all collected, there was still some work to perform in order to prepare for the road-level analysis. For this analysis, the goal was to create a dataset for a regression model where each data point corresponds to a segment-year combination with information about traffic volumes, number of lanes, speed limit, and number of fatal crashes. Because the original dataset from the HPMS included hundreds of thousands of segments, the research team decided it would be easier to work with a dataset that combined adjacent segments with identical characteristics. To achieve this, a MATLAB code was formulated and run to automatically combine adjacent segments that have the same route number, urban code, speed limit, traffic volume, and number of lanes. Before the code was run, the original dataset 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 dataset. The text of 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 were combined when the MATLAB code was run, there were some short segments where at least one of the four parameters were different from the adjacent segments. If the difference between the adjacent segments was traffic volume or number of lanes, the new segment was the combination of the short segment and the adjacent segment, and the new volume or number of lanes was the weighted average of values of the original segments. If the difference was the urban area, the urban code of the short segment was changed to the urban code of the longer segment and subsequently combined. Since there were only approximately 50 segments for which this was the case, it was not estimated that the model results would be affected significantly by this change. After these changes were made to the dataset, all segments that were shorter than 0.1 miles had been combined into longer segments. The final dataset consisted of 23,065 segments ranging in length from 0.1 miles to over 37 miles.

That roadway dataset consisted of all interstate segments in the HPMS shapefiles, but it only consisted of data for one year. Since the goal of the regression model was to include one data point for each segment-year combination, the dataset was copied once for every year in the study period. Because the crash dataset covers the years 2001 to 2016, the size of the roadway dataset increased sixteenfold to 369,040 segments. To ensure accuracy of the dataset, the crashes were broken down by year. Because data was now broken down by year, data from the state-year dataset could be incorporated into this dataset. When a state's maximum speed limit increased at some point over the study period, some of the speed limits in the original dataset would be higher than what was legally allowed in the state at the time. Therefore, in all of those cases, the speed limit was updated to reflect the 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 it was increased.

The final change that was made to the roadway dataset was the elimination of segments of roads that didn't exist at the year of study. Since 2001, there have been nearly 1,500 miles of new interstate designation, by either new construction or upgrading existing roadways. To ensure accuracy of the dataset, segments from years before the road became an interstate were deleted, 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 interstates at the time of the crash. In the final dataset, there were 57,408 fatal crashes on interstates. When considering only rural interstate segments, the dataset contains 102,140 segments, with 22,733 crashes occurring during the study period. Table 3 displays the numbers of segments, miles, and crashes on rural interstates in the dataset, 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 crash dataset, there were a number of crash subsets that could have been affected by the speed limit. In addition to the total number of fatal crashes and fatalities, these include crashes where at least one of the vehicles was traveling at a high rate of speed (for the purposes of this study, a high rate of speed is defined as greater than the speed limit of the road), crashes where speeding is coded, and crashes where a distraction is coded. For crashes where speeding is coded, data were only available from 2009 onward, and data from the distraction 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 less than 65 mph, those segments were not included in the analysis or the summary statistics table.

Table 5 shows the summary statistics of the variables used from the roadway dataset. The dataset also incorporated many variables from the state-level dataset; for the sake of space, those variables are omitted from this table. The final field, the number of years since speed limit changed, was included with the intent of accounting for driver confusion. The concept was that in the first few months and years after a speed limit is changed, drivers would travel with a high variance of speed for a period of time until it gradually becomes more consistent. A cap was arbitrarily placed on this variable at five years, because by that time, it was thought that drivers would generally be used to the new speed limit. For this reason, most of the data points for this variable are five years.

Table 4. Summary Statistics of Crash Types

Year	Total Fatal Crashes	Total Fatalities	Crashes with High Rate of Speed	Crashes with Coded Speeding	Crashes with Coded Distraction
2001	1,226	1,474	625	N/A	N/A
2002	1,417	1,735	691	N/A	N/A
2003	1,449	1,773	745	N/A	N/A
2004	1,597	1,988	834	N/A	N/A
2005	1,825	2,211	1,016	N/A	N/A
2006	1,647	1,977	877	N/A	N/A
2007	1,544	1,848	912	N/A	N/A
2008	1,463	1,714	860	N/A	N/A
2009	1,266	1,486	795	348	N/A
2010	1,301	1,536	768	377	191
2011	1,211	1,393	707	316	163
2012	1,196	1,417	753	312	182
2013	1,251	1,485	799	357	190
2014	1,185	1,387	761	303	182
2015	1,378	1,602	905	365	228
2016	1,525	1,769	1,046	347	236
Total	22,481	26,795	13,094	2,725	1,372

Table 5. Summary Statistics for Road-Level Rural Models (n=102,140 segment-years)

Variable	Average	Std. Dev.	Minimum	Maximum
Segment Length (mi)	4.29	3.89	0.10	37.29
Traffic Volume (Veh/day)	26856	19338	327	189000
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

CHAPTER 4. STATISTICAL METHODS AND RESULTS

4.1 Statistical Methods

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 total numbers 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, and 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 1,

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!} \quad (1)$$

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 2,

$$\lambda_i = EXP(\beta X_i) \quad (2)$$

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 overdispersion that is common in fatality data. Consequently, a Poisson-gamma model (more commonly known as a negative binomial model) is 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 3,

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \tag{3}$$

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 4:

$$VAR[y_i] = E[y_i] + \alpha E[y_i]^2 \tag{4}$$

Because this dataset features multiple data points that occur in each state, there could be 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 5:

$$\beta_{0j} = \beta_0 + \omega_{ij} \tag{5}$$

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 correspond to the percent change in fatalities associated with a one-unit change in a predictor variable. These elasticities can be determined as shown in Equation 6:

$$E_{x_{ik}}^{\lambda_i} = 100 \times EXP(\beta_k) - 1, \tag{6}$$

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

4.2 State-Level Analysis Results and Discussion

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 time-invariant (e.g., terrain, design practices, enforcement practices). This acknowledges the fact that specific states experience fatality rates that are higher or lower than other states due to factors that could not be 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 difference between the two models is 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 6.

- One limitation to this approach is that these maximum limits, particularly at the higher values of 75 and 80 mph, have generally been applied to only a subset of the rural interstate system. Consequently, the true effect 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, a series of variables are included that represent the proportion of rural interstate mileage that is posted at each limit (70, 75, and 80 mph). The results from this model are presented in Table 7.
- In each of these models, the speed limit variables are treated as random parameters. This is an important consideration as the states where speed limits have been increased to the higher range of limits (i.e., 75-80+ mph) have some inherent differences that are not explicitly captured in the dataset. 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 6 below) indicate that states with maximum speed limits 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 limit serve as the baseline scenario, and the parameter estimates indicate the average change in fatalities for states with higher limits as compared to the 65 mph limit. Based on these results, a state with an 80 mph limit can expect 61.3 percent more fatalities than a state with 65 mph limit.

Table 6. 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

States with a maximum speed limit of 75 mph experienced annual fatalities that were 36.2 percent higher 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 as only two states had an 80-mph speed limit prior to 2014, and this 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.

Table 7. Regression Model Results Considering the Proportion of Mileage at Each 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			

The second analysis, detailed by the model results in Table 7, addresses this concern by including the proportion of mileage in the rural interstate network in each state that is posted at each limit. Interestingly, these parameter estimates are significantly larger in magnitude than those of the maximum speed limit variables discussed previously. In interpreting these results, a state with all rural interstate mileage at 70 mph would experience

18.9 percent more fatalities than a state with all 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 these results. Speed limit increases to these higher bounds generally occur at a significantly smaller scale, rather than on a statewide basis. To this end, considering the effects of a one percent increase is likely to provide a more reasonable approximation of impacts on fatalities. If the percentage of rural interstates posted at 70, 75, or 80 mph are 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 limit provides better performance when considering the log-likelihood, AIC, and 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 limit in each state. Collectively, the evidence suggests that examining speed limit policy changes in consideration of the proportion of the system over which these changes are applied provides a more robust analytical framework than the traditional analyses that have considered only the maximum limit in each state.

4.3 Roadway-Level Analysis Results and Discussion

To perform roadway-level analysis, there were five alternate regression models that were estimated. Each of these models shares the following similarities:

- Average Annual Daily Traffic (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 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 the state-level analysis to account for effects that vary from state to state irrespective of time (e.g., terrain, design practices, enforcement practices). This accounts 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 to 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 five 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, and the different ways are outlined as follows:

- The first model examines the total number of fatal crashes on a rural interstate segment, assuming its speed limit is 65 mph or greater. Throughout the dataset, there were 22,481 such crashes. The results of this model are presented in Table 9.
- The second model is similar to the first, except it considers the total number of fatalities. This framework inherently places more weight on crashes that result in multiple fatalities. In the dataset, there were 26,795 fatalities on rural interstate highways with a speed limit of at least 65 mph. The results of this model are presented in Table 10.
- The third model filters the number of fatal crashes to only include those where the maximum travel speed indicated by the FARS database exceeded the speed limit of the road. This includes 13,094 crashes on rural interstates with a speed limit of at least 65 mph, and the results of this model are presented in Table 11.
- The fourth model only includes the fatal crashes where the "speeding" field in the FARS database indicates that speeding was involved with the crash. This field was only available from 2009 to 2016, so the dataset was cut to only include those years. For an unknown reason, there happened to be fewer of these crashes than those captured by the third model, even accounting for the difference in study period. 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 12.

- The final model only includes the fatal crashes where a distraction is coded. This field was introduced in the 2010 database, so the dataset was cut to only include data from 2010 to 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 13.

First of all, the parameter estimates of all five models are shown in Table 8 below, in order to show the different effects side by side. Most of the parameters have effects that are consistent across the models in terms of the direction of the relationships with each predictor variable.

The results from the first model (total fatal crashes, found in Table 9 below) indicate that roads with higher speed limits are expected to have a higher risk of fatal crashes. 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 a 75- and 80-mph road 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 a speed limit by 15 mph, and a rural interstate that currently has a speed limit of 65 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.

Table 8. Summary of Regression Model Results

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	0.169	8.905[c]	-48.490[c]	-32.370[c]	-0.818
Std. Dev(Intercept)	0.392	0.370	0.396	0.502	0.599
Year 2001 (1=yes, 0=no)	-0.773[c]	-0.627[c]	-1.252[c]	N/A	N/A
Year 2002 (1=yes, 0=no)	-0.640[c]	-0.495[c]	-1.174[c]	N/A	N/A
Year 2003 (1=yes, 0=no)	-0.523[c]	-0.374[b]	-0.970[c]	N/A	N/A
Year 2004 (1=yes, 0=no)	-0.306[c]	-0.142	-0.712[c]	N/A	N/A
Year 2005 (1=yes, 0=no)	-0.003	0.133	-0.255[b]	N/A	N/A
Year 2006 (1=yes, 0=no)	0.055	0.161	-0.121	N/A	N/A
Year 2007 (1=yes, 0=no)	0.088	0.192[a]	0.039	N/A	N/A
Year 2008 (1=yes, 0=no)	0.240	0.308[a]	0.293	N/A	N/A
Year 2009 (1=yes, 0=no)	-0.230[c]	-0.140[a]	-0.321[c]	-0.124	N/A
Year 2010 (1=yes, 0=no)	-0.034	0.044	-0.097	-0.134	-0.195
Year 2011 (1=yes, 0=no)	0.193	0.233	0.231	-0.548	0.270
Year 2012 (1=yes, 0=no)	0.237	0.268	0.389	-0.617	0.581
Year 2013 (1=yes, 0=no)	0.266	0.317[a]	0.426[a]	-0.380	0.665
Year 2014 (1=yes, 0=no)	0.175	0.206	0.323	-0.477	0.579
Year 2015 (1=yes, 0=no)	-0.018	-0.009	-0.035	-0.045	0.092
Year 2016 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A	N/A
Log (AADT)	1.000	1.000	1.000	1.000	1.000
Log (Segment Length, mi)	1.000	1.000	1.000	1.000	1.000
Speed Limit 65 (1=yes, 0=no) (baseline)	N/A	N/A	N/A	N/A	N/A
Speed Limit 70 (1=yes, 0=no)	0.260[c]	0.258[c]	0.393[c]	-0.007	0.094
Speed Limit 75 (1=yes, 0=no)	0.289[c]	0.324[c]	0.408[c]	0.139	0.588[c]
Speed Limit 80 (1=yes, 0=no)	0.716[c]	0.747[c]	0.768[c]	0.447[b]	0.615[b]
Number of Lanes	-0.133[c]	-0.142[c]	-0.117[c]	-0.073[b]	-0.133[c]
Proportion of State's Vehicles that are Autos	-9.947[c]	-19.230[c]	41.020[c]	16.690[c]	-9.825
Proportion of State's Vehicles that are Motorcycles	-15.540[c]	-24.550[c]	40.110[c]	15.490[c]	-8.988
Proportion of State's Vehicles that are Trucks	-10.140[c]	-19.180[c]	40.970[c]	17.300[c]	-11.120
Proportion of State's Drivers under 25 years	-3.998[c]	-4.242[c]	-10.710[c]	4.054	-7.455
Proportion of State's Drivers over 65 years	-4.777[c]	-3.829[c]	-8.863[c]	-2.837	-14.960[c]
State's Population Density (persons/sq. mi)	-0.001[b]	-0.001[b]	-0.001[b]	0.000	0.000
State's Seat Belt Usage (proportion)	-0.350[b]	-0.344[b]	-0.544[b]	-1.157	-0.287
State's Maximum monthly average temp. (°F)	-0.008	-0.004	-0.051[b]	0.058	0.098[a]
State's Minimum monthly average temp. (°F)	0.010	0.012	0.060[b]	-0.058	-0.106[a]
State's Annual Precipitation (inches)	-0.002	-0.002	-0.006[a]	0.005	0.012
State's Average Gas Price ($/gallon)	-0.409[c]	-0.399[b]	-0.629[c]	0.302	-0.914
Years since State's Max Limit Changed	0.047[c]	0.051[c]	0.075[c]	0.025	0.043
Overdispersion parameter	1.187	1.568	1.167	1.105	0.996

Dependent Variables	
Model 1	Total Fatal Crashes
Model 2	Total Fatalities
Model 3	Speed-related fatal crashes
Model 4	Fatal crashes with coded speeding
Model 5	Fatal crashes with a coded distraction

[a]Significant to 95% confidence; [b]Significant to 99% confidence; [c]Significant to 99.9% confidence

Table 9. 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	-49953			
AIC	99974.5			
BIC	100298.0			

Within this model, the variable indicating the number of years that the state has had its maximum limit was found to have a positive relationship with the fatal crash count. This variable's parameter estimate indicates that for every year since the state has changed their speed limit, the number of fatal crashes increases by 4.8 percent. However, it would be expected for the number of fatal crashes to decrease every year after a state's speed limit changes because it gives more time for drivers to become familiar with the new limit and adjust their driving habits accordingly. This variable only includes values up to 5 years (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 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 apply for when the variable increases by a value of one. Because these variables can only take values between zero and one, and increase of one is not possible. Rather, it is necessary to calculate how the expected crashes are affected by a more manageable change in these variables (e.g., one percent). In this case, a one percent increase in proportion of autos correlates to a 9.5 percent decrease in fatal crashes. The corresponding expected fatal crash decreases for a one percent increase in motorcycle and truck ownership are 14.4 percent and 9.6 percent, respectively. Furthermore, an increase in value of one of these three variables is likely to coincide with a decrease of at least one of the other two.

There were five additional variables used in this model that displayed negative correlations with fatal crashes that were statistically significant to 99 percent: 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 proportion variables like the vehicle type variables, and the parameter estimate indicates that when the proportion of young drivers increases by one percent, the expected number of fatal crashes will decrease by 3.9 percent, and if 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 these demographics of drivers being generally 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 get 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.

The binary indicators for each year were included to account for temporal changes in crash rates. From this model, it could be expected to have seen increased fatal crashes from 2001 to 2008, then they remain relatively constant until they steadily decrease from 2013 to 2016. Despite being statistically insignificant, these general trends are expected, as they match those found in the summary statistics of the original dataset (Table 4 on page 29). Finally, the three variables indicating weather trends were found to have a low coefficients that were insignificant. This indicates that the model shows temperature and precipitation not having a strong influence on fatal crashes.

The model that considers total fatalities (Table 10 below) is similar to the previous model in that it uses the entire dataset of rural roads with a speed limit greater than or equal to 65 mph, and all of the fatal crashes are considered rather than the subsets that are used in the final three models. The difference between this model and the previous model, which considers total fatal crashes, is particularly relevant when considering crashes with multiple fatalities. Since the majority of fatal crashes only involved one fatality, the parameter estimates are not very different between the two models, and nearly all of the variables that were featured in both models were consistent in having positive or negative relationships with the dependent variable.

The speed limit variables follow similar trends in the two models: A road with a speed limit of 70 is expected to see 29.4 percent more fatalities than an identical road with a speed limit of 65. Likewise, 75- and 80-mph roads are expected to experience 38.3 percent and 111.1 percent increases of fatalities, respectively, compared to 65-mph roads. Again, a 15-mph speed limit increase is unlikely, so it is necessary to examine the relative fatality risk between adjacent speed limits. According to this model, a 75-mph road is expected to see 6.8 percent more fatalities than a 70-mph road, and an 80-mph road is expected to see 52.7 percent more fatalities than a 75-mph road.

As mentioned previously, nearly all of the variables that were included in the first two models retained their positive or negative relationships with the dependent variable, as well as their levels of statistical significance.

Table 10. Regression Model Results Considering Total Rural Interstate Fatalities

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	8.905	1.126	7.909	<0.0001
Std. Dev(Intercept)	0.370			
Year 2001 (1=yes, 0=no)	-0.627	0.130	-4.807	<0.0001
Year 2002 (1=yes, 0=no)	-0.495	0.134	-3.688	0.0002
Year 2003 (1=yes, 0=no)	-0.374	0.116	-3.230	0.0012
Year 2004 (1=yes, 0=no)	-0.142	0.093	-1.525	0.1273
Year 2005 (1=yes, 0=no)	0.133	0.077	1.726	0.0844
Year 2006 (1=yes, 0=no)	0.161	0.082	1.957	0.0503
Year 2007 (1=yes, 0=no)	0.192	0.096	1.991	0.0465
Year 2008 (1=yes, 0=no)	0.308	0.139	2.220	0.0264
Year 2009 (1=yes, 0=no)	-0.140	0.071	-1.963	0.0496
Year 2010 (1=yes, 0=no)	0.044	0.094	0.462	0.6442
Year 2011 (1=yes, 0=no)	0.233	0.166	1.408	0.1592
Year 2012 (1=yes, 0=no)	0.268	0.173	1.547	0.1217
Year 2013 (1=yes, 0=no)	0.317	0.161	1.962	0.0497
Year 2014 (1=yes, 0=no)	0.206	0.146	1.413	0.1577
Year 2015 (1=yes, 0=no)	-0.009	0.055	-0.162	0.8716
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)	0.258	0.032	8.058	<0.0001
Speed Limit 75 (1=yes, 0=no)	0.324	0.045	7.140	<0.0001
Speed Limit 80 (1=yes, 0=no)	0.747	0.071	10.499	<0.0001
Number of Lanes	-0.142	0.011	-12.783	<0.0001
Proportion of State's Vehicles that are Autos	-19.230	1.109	-17.341	<0.0001
Proportion of State's Vehicles that are Motorcycles	-24.550	1.301	-18.861	<0.0001
Proportion of State's Vehicles that are Trucks	-19.180	1.092	-17.565	<0.0001
Proportion of State's Drivers under 25 years	-4.242	1.006	-4.218	<0.0001
Proportion of State's Drivers over 65 years	-3.829	1.121	-3.417	0.0006
State's Population Density (persons/sq. mi)	-0.001	0.000	-2.680	0.0074
State's Seat Belt Usage (proportion)	-0.344	0.125	-2.746	0.0060
State's Maximum Monthly Average Temp. (°F)	-0.004	0.016	-0.279	0.7804
State's Minimum Monthly Average Temp. (°F)	0.012	0.017	0.684	0.4941
State's Average Annual Precipitation (in.)	-0.002	0.002	-0.800	0.4238
State's Average Gas Price ($/gallon)	-0.399	0.127	-3.158	0.0016
Years since State's Max Limit Changed	0.051	0.008	6.399	<0.0001
Overdispersion parameter	1.568			
Goodness-of-fit statistics				
Log-likelihood at convergence	-56134.6			
AIC	112337.1			
BIC	112660.7			

For the only positively-related variable in these models, the number of years since the speed limit has changed, the magnitude of the parameter estimate was not much different either: for every year since the state has last increased its maximum limit (with a maximum of 5 years), the number of fatalities is expected to increase by 5.2 percent.

The magnitudes of the parameter estimates for most of the variables that were negatively related to the dependent variable also did not change much between the two models. Based on the results from the model that considers total fatalities, it was found that when gas price increases by one dollar per gallon in a state, fatalities are expected to decrease by 32.9 percent, and fatalities are expected to decrease by 0.3 percent for every one percent increase in a state's seat belt usage. When the proportion of licensed drivers over 65 or under 25 increases by one percent, then the expected number of fatalities is expected to decrease by 3.8 percent or 4.2 percent, respectively. Additionally, the population density of a state was found to have a very slight effect on fatalities, just like its slight effect on fatal crashes. When population density increases by one person per square mile, the number of fatalities is expected to decrease by 0.1 percent. One of the largest differences between the parameter estimates in the two models were the relationships between different vehicle types and the dependent variables. In the model considering total fatalities, a one percent increase in the proportion of registered autos, motorcycles, or trucks in a state was correlated with decreases in fatalities by 17.5 percent, 21.8 percent, and 17.5 percent, respectively, all of which are much higher than their estimates from the model considering total fatal crashes.

The results from the model considering speed-related fatal crashes (Table 11 below) indicate the likelihood of a fatal crash where at least one of the vehicles was traveling faster than the speed limit. Based on these results, it is more likely to experience a speed-related fatal crash on a road with a higher speed limit. Specifically, a road with a speed limit of 70 mph can expect to see a 48.1 percent higher crash rate than a road with a speed limit of 65 mph. The expected crash rate increases for 75- and 80-mph roads as compared to 65-mph roads are 50.4 percent and 115.6 percent, respectively. In other words, a road with a speed limit of 80 mph can expect more than twice as many speeding-related fatal crashes than an identical road with a speed limit of 65 mph. This could be the case for a number of reasons: first, a crash occurring at or above 80 mph is more likely to result in a fatality than a crash occurring just above 65 mph. Additionally, the general characteristics of roads have an effect on how agencies set their speed limits: roads that ultimately receive an 65-mph designation generally have high traffic, which leads to drivers being more attentive to their surroundings as well as making it more difficult for drivers to exceed the speed limit. On the other hand, roads that generally have speed limits set at 80 mph have lower traffic volumes, which could result in drivers dozing off or exceeding the speed limit to a level they deem as safe.

In this model, the variables regarding the state's composition of registered vehicles all had strong positive relationships with the number of speed-related fatal crashes. When the proportion of a state's motor vehicles that are autos, motorcycles, or trucks increase by one percent, the expected number of speed-related fatalities increases by 50.7 percent, 49.3 percent, and 50.6 percent, respectively. These estimated increases are large, but it is important to remember that when the parameter value for autos increases, for example, it will be accompanied by a decrease in at least one of the other two variables.

The additional variables that were found to have a negative relationship with speed-related fatal crashes were proportion of the state's drivers under 25 or over 65, state's population density, and state's seat belt usage. The age-related variables have strong parameter estimates, but because the data is presented as a proportion, the relationships are not obvious by simply examining the parameter estimates.

Table 11. Regression Model Results Considering Crashes with High Rates of Travel

Parameter	Estimate	Std. Dev.	t-stat	p-value
Intercept	-48.490	1.458	-33.259	<0.0001
Std. Dev(Intercept)	0.693			
Year 2001 (1=yes, 0=no)	-1.252	0.161	-7.771	<0.0001
Year 2002 (1=yes, 0=no)	-1.174	0.167	-7.041	<0.0001
Year 2003 (1=yes, 0=no)	-0.970	0.143	-6.804	<0.0001
Year 2004 (1=yes, 0=no)	-0.712	0.113	-6.291	<0.0001
Year 2005 (1=yes, 0=no)	-0.255	0.093	-2.732	0.0063
Year 2006 (1=yes, 0=no)	-0.121	0.101	-1.197	0.2315
Year 2007 (1=yes, 0=no)	0.039	0.119	0.327	0.7436
Year 2008 (1=yes, 0=no)	0.293	0.173	1.690	0.0910
Year 2009 (1=yes, 0=no)	-0.321	0.086	-3.727	0.0002
Year 2010 (1=yes, 0=no)	-0.097	0.117	-0.833	0.4047
Year 2011 (1=yes, 0=no)	0.231	0.208	1.111	0.2665
Year 2012 (1=yes, 0=no)	0.389	0.216	1.799	0.0720
Year 2013 (1=yes, 0=no)	0.426	0.203	2.102	0.0356
Year 2014 (1=yes, 0=no)	0.323	0.183	1.771	0.0766
Year 2015 (1=yes, 0=no)	-0.035	0.064	-0.552	0.5806
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)	0.393	0.041	9.707	<0.0001
Speed Limit 75 (1=yes, 0=no)	0.408	0.052	7.841	<0.0001
Speed Limit 80 (1=yes, 0=no)	0.768	0.079	9.717	<0.0001
Number of Lanes	-0.117	0.013	-8.832	<0.0001
Proportion of State’s Vehicles that are Autos	41.020	1.392	29.455	<0.0001
Proportion of State’s Vehicles that are Motorcycles	40.110	1.460	27.467	<0.0001
Proportion of State’s Vehicles that are Trucks	40.970	1.388	29.517	<0.0001
Proportion of State’s Drivers under 25 years	-10.710	1.160	-9.227	<0.0001
Proportion of State’s Drivers over 65 years	-8.863	1.399	-6.337	<0.0001
State’s Population Density (persons/sq. mi)	-0.001	0.000	-3.100	0.0019
State’s Seat Belt Usage (proportion)	-0.544	0.173	-3.143	0.0017
State’s Maximum Monthly Average temp. (°F)	-0.051	0.019	-2.687	0.0072
State’s Minimum Monthly Average temp. (°F)	0.060	0.021	2.802	0.0051
State’s Annual Precipitation (inches)	-0.006	0.003	-2.349	0.0188
State’s Average Gas Price ($/gallon)	-0.629	0.159	-3.970	0.0001
Years since State’s Max Limit Changed	0.075	0.009	8.000	<0.0001
Overdispersion parameter	1.167			
Goodness-of-fit statistics				
Log-likelihood at convergence	-34401			
AIC	68870.6			
BIC	69194.2			

When the proportion of a state’s drivers under 25 years of age increases by one percent, the speed-related fatal crash rate is expected to decrease by 10.2 percent, and the fatal crash rate is expected to decrease by 8.5 percent for every one percent increase in a state's driver population over 65 years of age. The population density variable has an extremely weak effect (as the state's population density increases by one person/sq mi, speed-related fatal crashes are expected to decrease by less than 0.1 percent), and according to the model, increased seat belt usage in a state predictably leads to a decrease in fatal crashes; the magnitude of this decrease is approximately 0.5 percent for every one percent increase in seat belt usage rate.

The weather variables all had slight significant effects on the speed-related crash rate, indicating that roads in states with more extreme temperatures (e.g. higher maximum and lower minimum temperatures) as well as higher precipitation had a lower likelihood of speed-related fatal crashes. This is possibly due to drivers' enhanced sense of caution in inclement weather.

The results from the model considering crashes that were coded as speeding-related by FARS (Table 12 below), like those of the model considering speed-related crashes, indicate that the likelihood of a speeding-related fatal crash generally increases as the speed limit increases. Specifically, a roadway with a speed limit of 75 mph would expect a 14.9 percent increase in fatalities where speeding is coded compared to an identical roadway with a speed limit of 65 mph, and an 80-mph segment would experience an expected 56.4 percent fatal crash increase. Interestingly, this model indicates that a 70-mph road segment would experience a lower speeding-related fatal crash rate than a 65-mph segment by approximately 0.7 percent; however, this parameter's p-value greater than 0.9 indicates that it is not statistically significant.

Table 12. Regression Model Results Considering Crashes with Coded Speeding

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	-9533.6			
AIC	19119.3			
BIC	19348.9			

This model features variables for the statewide proportions of registered motor vehicles that are automobiles, motorcycles, and trucks. Like in the previous models, all three of these parameter estimates are uncommonly high; however, after considering a one percent increase in proportion rather than a variable increase of one, it can be found that a one percent increase in proportion of autos correlates to an 18.2 percent increase in fatal crashes.

The corresponding expected fatal crash increases for a one percent increase in motorcycle and truck ownership are 16.8 percent and 18.9 percent, respectively. As is the case in other models, an increase in one of these three variables is likely to coincide with a decrease in at least one of the other two.

There are a number of variables in this model that are not statistically significant to 95 percent confidence, and most display similar trends to the other models in which they were significant. There are four notable exceptions to this: statewide proportion of young drivers, state maximum temperature, precipitation, and gas price. All four of these variables had negative correlations with the dependent variable in the other three models, but a positive correlation in this model. This could be because there is a lower sample size of fatal crashes coded by FARS as speed-related than any other subset of crashes used thus far, which could lead to a bias towards parameter values that could be overrepresented with speeding-coded 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, it would be expected to see the rate decrease from 2009 until approximately 2012, and then rise again towards 2016. However, there is no such trend in this model, and the parameter estimates were nearly all statistically insignificant. Part of the reason behind this is that the trends of fatal crashes where speeding was recorded did not follow this pattern (see Table 4 on page 29), which can likely be attributed to differences in reporting over time and geographical areas.

The final model run for the roadway-level analysis (Table 13 below) considers the number of fatal crashes that are related to a driver distraction of some sort, including distractions by cellular phones, eating, drinking, or smoking, among others. 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 70-mph segment than an identical segment with a speed limit of 65 mph. The expected increases of fatal crashes on a 75- or 80-mph segment as compared to a 65-mph segment are 80.0 percent and 85.0 percent, respectively.

Table 13. 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	-5359
AIC	10768.0
BIC	10985.5

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, there were a handful of additional variables that were found to be statistically significant to 95 percent confidence. This includes 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 variable had a strong negative correlation with distraction-related fatal crashes, which could be because the elderly population is less likely to be tempted with a cell phone-related distraction, or because the elderly driving population composes 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 opposite the trends displayed in the first three models.

The other variables in this model were not statistically significant to 95 percent confidence, but nearly all of them displayed trends consistent with those in the first three 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 the distraction information was only available between 2010 and 2016, nine fewer years of data than the total fatal crash dataset.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Ultimately, 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 interstate posted at the maximum limit, as well as other lower limits. A comparison of the results from companion models of each form show that the more detailed, disaggregate-level analysis considering the proportion of mileage posted at each limit provides significantly better fit.

From a practical standpoint, the results provide additional empirical support of prior research, which has consistently shown that states with higher rural interstate speed limits experience a higher number of traffic fatalities. When considering the degree to which these higher limits have been applied in various states, the effects are larger than would be concluded from analyses that consider only maximum statutory limits. However, it appears that these increases may begin to taper off at the highest limits, which may be due to the fact that drivers tend to decrease their speeds by lesser amounts when speed limit increases occur at the upper ranges of 75 to 80 mph or above.

Upon examining the road-level analysis, claims that roads with higher speed limit experience a higher number of fatalities and fatal crashes is even further supported. Additionally, the analysis indicates that fatal crashes relating to a distraction are affected by speed limit at a higher degree than total fatalities or fatal crashes. Fatal crashes where speeding is involved appears be more strongly affected by speed limit on roads with a limit of 70 or 75 mph than roads with a limit of 80 mph, suggesting one of two things: that drivers are generally more hesitant to exceed the speed limit when it is as high as 80 mph, or that drivers who do exceed the speed limit when it is higher are more cautious about their driving, decreasing the likelihood to be involved in a fatal crash.

It is important to acknowledge several caveats and limitations with respect to the results of the state-level analysis. The higher speed limits, particularly at 75 and 80 mph, have been applied selectively. Consequently, there are potential arguments that estimates of the effects on fatality risks may be either overstated or understated. First, since these higher 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 as fatalities may naturally increase in the years subsequent to the speed limit change if no policy change had been implemented.

Alternately, it can also be argued that the effects of speed limit increases may be understated because the limits have been increased on segments that are the most inherently safe on these road networks. It is tenuous to suggest that the same increases in fatalities would be experienced on 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 provide motivation for the additional disaggregate-level investigations presented in the road-level analysis, comparing road segments where speed limit increases have occurred with similar segments that did not experience a speed limit change. Unfortunately, this also presents challenges as the manner in which limits are increased introduces challenges as these segments may have inherent differences that make it difficult to find an appropriate comparison group for an empirical Bayes evaluation, for example. While the road-level dataset 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 applied a new maximum speed limit on a small proportion of the interstate network, it is not unreasonable to assume that driver behavior on roads that do not experience a speed limit increase would be different than 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, which could affect crashes and fatalities due to curves becoming substandard under 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 perspective. In some states, non-interstate freeways may not be eligible to sign the same maximum speed limit as interstates. On the other hand, inclusion of non-interstate freeways would introduce to the dataset even more high-speed roadways such as Texas State Highway 130, a toll road that famously has a speed limit of 85 mph.

The state-level analysis incorporated aggregate weather information to determine if general trends in temperature and precipitation have any additional effect on fatal crashes. In the road-level analysis, the weather information was also used in some of the models, but it was left aggregated at the state level. If weather data was gathered at the regional or local level for the road-level analysis, it might have shown a stronger or more significant effect on the fatal crash rate.

Moving forward, the analysis of maximum speed limits' effects on fatalities and fatal crashes provides agencies a snapshot of some of the potential ramifications to increasing the speed limit on a road. However, limiting the study to fatalities only gives a partial view of the effects; a fuller picture would be provided if all crash data were able to be used to draw conclusions on the safety impacts of increasing speed limits. Unfortunately, such an analysis at a national scale is unlikely due to the limited availability of non-fatal crash data. Numerous state-level analyses have been performed in the past studying 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
```