Evaluating the Impacts of Speed Limit Policy Alternatives

MDOT Research Administration Project Number: OR 13-009

FINAL REPORT

Prepared for:

Michigan Department of Transportation
Research Administration Division
Lansing MI 48909

Prepared by:

Peter Savolainen, Timothy Gates, Elizabeth Hacker, Amelia Davis,
Sterling Frazier, Brendan Russo, and Emira Rista
Wayne State University
Detroit, MI

Martin Parker
Wade Trim
Detroit, MI

Fred Mannering
Independent Consultant

William Schneider
University of Akron
Akron, OH

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William Schneider
UNIVERSITY OF AKRON
AKRON, OH

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As of June 2014, Michigan is one of eight states with a differential speed limit in place on its rural freeways, which sets a maximum speed of 70 mph for passenger vehicles and 60 mph for trucks and buses. In select urban environments, these speed limits are both reduced to a uniform 55 mph limit. Legislation was introduced in early 2014 that proposed increases to these speed limits. In order to ascertain the potential impacts of these proposed speed limit increases, this research examined a broad range of traffic safety, operational, environmental, and economic data. This study involved a comprehensive state-of-the-art review of prior research on the relationships between traffic speed, safety, and crash risk. A survey was conducted of state agency practices with respect to speed limit establishment and another survey was conducted to obtain feedback on proposed changes from the trucking industry. National fatality data were collected and analyzed to ascertain the effects of speed limit policies on traffic fatalities, with specific emphasis on maximum speed limits and the effects of uniform vs. differential limits on urban and rural interstates. Further analyses were conducted at the disaggregate level to examine crash trends on Michigan freeways. These results were supplemented by the analysis of field speed data that were collected on freeways in Michigan, Indiana, and Ohio. Differences in mean speeds, 85th percentile speeds, and the standard deviation in speeds among passenger cars, trucks, and buses were examined with respect to the speed limit policies in place at each of 160 roadway locations. Based upon the results of the fatality and speed data analyses, a benefit-cost analysis of the proposed speed limit change was conducted in consideration of both road user and agency costs. Recommendations were presented to aid in decision-making related to speed limit policies.</td></tr>
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EXECUTIVE SUMMARY

The repeal of the National Maximum Speed Limit in 1995 returned all speed limit determination authority to the individual states. Since then, a wide variety of speed limit policies were enacted and modified, with nearly all states eventually choosing to raise maximum freeway speed limits beyond previous federal limits. Recently, further speed limit policy modifications have resulted in a general upward trend in many states, particularly for rural freeways and in western states. Between April 2011 and January 2014, at least 14 states have increased speed limits or are proposing to do so, with a majority of these increases involving rural freeways. The popularity of differential speed limits between passenger vehicles and heavy vehicles (trucks/buses) has also diminished over time, with eight states continuing to maintain such differentials, all but three of which are located in the western United States.

With the trend of increasing speed limits continuing to expand throughout the United States, the Michigan legislature proposed Senate Bill 896 in March of 2014. SB 896 proposed new legislation that would create a new “Rural Freeway General Speed Limit” of 80 mph (currently 70 mph) and a new “Urban Freeway General Speed Limit” of 70 mph (currently ranging from 55 to 70 mph). The legislation also proposes to increase the maximum speed limit for trucks and buses to 70 mph (currently 60 mph), thereby maintaining a differential speed limit between passenger vehicles and trucks/buses on rural freeways. Additional speed limit increases have been proposed for non-limited access roadways, as well.

PROBLEM AND OBJECTIVES

Research was necessary to determine the potential impacts of the speed limit changes proposed by SB 896 to assist the Michigan Department of Transportation (MDOT) and the State of Michigan with critical decisions related to the bill. Increasing the maximum speed limit on Michigan roadways is expected to potentially impact various measures including: mean and 85th percentile speeds, speed variance, fatality rates, road user costs, pavement condition, air quality, noise, and trucking industry economics. Thus, in order to fully understand the impacts of these proposed speed limit increases, a careful analysis was required, considering a broad range of traffic safety, operational, environmental, and economic data. These data were available from a variety of sources, including several states that have recently changed their passenger car speed limits, their truck/bus speed limits, or both.

The primary objective of this research was to examine available empirical evidence to estimate the impacts of proposed speed limit changes on traffic safety, mobility, economics, and environmental aspects in Michigan. To better understand the possible effects that may occur if the proposed speed limit policies are enacted, several tasks were performed, including:

- A comprehensive review of the literature and survey of state policy/practice;
- Collection and analysis of national freeway fatality data, as well as disaggregate level data for Michigan freeways, to determine speed limit policy impacts;
- Collection and analysis of speed data from Michigan, Indiana, and Ohio to ascertain the impacts of the different speed limit policies that exist between the three states; and
- Analysis of the expected economic impacts associated with the proposed speed limit changes, including both agency and road user costs.

CRASH EVALUATION

The comprehensive review of the literature and state agency policy/practices showed that higher maximum speed limits tend to result in increases in traffic fatalities. This is particularly true for rural freeways, which have the highest limits among all functional roadway classes in the United States, ranging up to as high as 85 mph on select facilities in Texas. The research on differential limits has generally been inconsistent, with some states demonstrating higher fatality rates and others exhibiting lower rates as compared to states with uniform limits. One of the reasons that many states have transitioned from differential to uniform limits has been due to the fact that uniform limits have been shown to reduce the variance in travel speeds, which may in turn reduce the risk of traffic crashes and resultant injuries/fatalities.

Fatal crash data from 1999 through 2011 were obtained and examined, with specific emphasis placed on assessing the fatal crash impacts of maximum speed limits, in addition to the effects of uniform vs. differential limits on urban and rural interstates. The results showed traffic fatalities to increase consistently with maximum speed limits in rural environments. Compared to interstates with 60 or 65 mph limits, fatalities increased by 31.0 percent in states with 70 mph maximum limits and by 54.0 percent in states with maximum limits of 75 mph or above. Unlike in rural areas, consistent trends between fatal crashes and maximum speed limits were not observed on urban interstates. Rural truck- and bus-involved interstate fatalities were 20 percent higher in states with uniform speed limits than in states with differential limits for such vehicles.

As in the case of maximum speed limits, fatality rates were not significantly different on urban interstates between states with uniform and differential truck and bus limits. Single-vehicle crashes were most prevalent on high-speed rural interstates. States with lower rural speed limits experienced a higher percentage of rear-end collisions. Rear-end collisions were also more prevalent on urban freeways.

To better understand differences in safety performance between urban and rural freeways, a longitudinal study of freeway crashes was conducted for Michigan freeways over the period from 2004 through 2012. Explicit comparisons were made between segments posted at a uniform 55 mph and those urban and rural segments that were posted at 70 mph for passenger vehicles and 60 mph for trucks and buses. The results showed that crash, injury, and fatality rates were significantly higher in urban environments, particularly on those segments that were posted at 55 mph. A review of crash data from urban freeways where speed limits had been increased from 55 mph to 65 or 70 mph (60 mph for trucks/buses) during the study period showed that total and injury crashes increased after these changes. These findings suggest that increased crash risks in urban areas are largely reflective of lower design standards and more challenging geometric conditions due to limited right-of-way.

SPEED EVALUATION

Spot speed studies were conducted at 160 freeway locations in Michigan, Indiana, and Ohio to provide a comparison between the 10-mph differential (Michigan), 5-mph differential (Indiana), and uniform speed limits (Ohio). These states provided an additional advantage of possessing several freeways that pass between bordering states, thereby allowing for a controlled comparison of speed limit impacts. These sites were split among urban and rural freeways and were selected from various regions to provide geographic diversity.

Analysis of these speed data show that mean and 85th percentile travel speeds for passenger vehicles were consistent among the three states at locations with a common limit of 55 mph or 70 mph. Conversely, truck and bus speeds were more variable, which is likely due to the existing differential limits in Indiana (5 mph) and Michigan (10 mph). However, the differences in mean and 85th percentile speeds were much less pronounced at 2.1 mph and 4.2 mph, respectively. While the mean and 85th percentile truck and bus speeds were above the posted limit of 60 mph in Michigan, compliance increased substantially in Indiana and Ohio.

The variability in travel speeds was also found to vary significantly based upon the posted speed limit. For all vehicles combined, the highest standard deviation in travel speeds was found on freeways posted at 70 mph for passenger vehicles and 60 mph for trucks and buses (6.9 mph on average). This was higher than the standard deviation at locations with a uniform 55-mph limit or with a 5-mph differential (70 mph/65 mph), which was 6.2 mph on average. Standard deviations in travel speeds were significantly less on those segments with uniform speed limits. Segments posted at 65/65 showed a standard deviation of 5.7 mph while those posted at 70/70 showed the lowest standard deviation at 5.4 mph. As crashes have been shown to decrease at lower speed variance, these findings present evidence in support of uniform speed limits.

ECONOMIC EVALUATION

The results of the fatality and speed data analyses were used to obtain estimates of the impacts of increasing Michigan's existing speed limits for trucks and buses, as well as for passenger vehicles. Using these estimates, an economic analysis was conducted to examine the following scenarios:

- Increasing the maximum freeway truck/bus speed limit to 65 or 70 mph
- Increasing rural freeway speed limits to 75 or 80 mph
- Increasing existing 55 mph urban speed limits to 70 mph
- Increasing speed limits on non-freeway facilities from 55 to 65 mph

This economic analysis considered road user costs and benefits, as well as installation cost for speed limit sign upgrades, and estimates of system-wide costs for necessary geometric upgrades associated with increasing posted speed limits above existing design speeds.

The benefit/cost results suggest that none of the proposed speed limit policy scenarios present a favorable economic condition compared to the current policy. The most favorable (albeit economically undesirable) of these proposed scenarios include cases where only the freeway truck speed limit is increased, either from 60 to 65 mph or 60 to 70 mph, while preserving the 70 mph maximum speed limit. This is largely due to the expected absence of any infrastructure upgrades aside from the speed limit signs, in addition to minimal expected impacts on fatal crashes. However, the benefit/cost ratio remains less than 1.0, largely due to the expectation that the increased fuel consumption costs associated with higher operating speeds will outweigh the resulting travel time savings.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study show that speed limit policies require careful consideration of a variety of factors. All proposed speed limit policy scenarios involving an increase in the maximum speed limit will result in substantial infrastructure costs for the geometric modifications necessary to increase the design speed to comply with state and federal requirements. The majority of the MDOT highway network is currently designed for compliance with posted speed limits of 70 mph on freeways and 55 mph on non-freeways and freeways in dense urban areas. Consequently, system-wide increases in the posted speed limit beyond these levels will result in geometric upgrade costs that will greatly outweigh any net user benefits, resulting in benefit/cost ratios well below 1.0. This is especially true for urban freeways and non-freeways currently posted at 55 mph where geometric modification costs are expected to be especially severe. With respect to truck/bus speed limits, the results of this study showed that rural truck/bus fatal crashes tended to be higher in states with uniform speed limits, though the speed studies conducted as part of this project showed that speed variance was higher where differential limits were in place.

Ultimately, increasing the maximum speed limits on freeways and non-freeways should only be considered for sections of roadway where design speed compliance is maintained after the increase to avoid costly geometric improvements. Furthermore, it is recommended that detailed engineering and safety analyses be performed prior to increasing the posted speed limit for any roadways under consideration.

CHAPTER 1:

INTRODUCTION

STATEMENT OF PROBLEM

Speed management has long been a concern of transportation agencies, dating back to research from the 1960's, which showed that vehicles traveling excessively below or above the average speed of traffic were overrepresented in crashes on rural highways and interstates [*1, 2*]. Historically, there have been three major legislative decisions that have influenced speed limit policies across the United States:

- Establishment of the National Maximum Speed Limit (NMSL) – A national maximum speed limit of 55 mph was established as part of the Emergency Highway Energy Conservation Act of 1974.
- Relaxation of the NMSL – In 1987, the NMSL was relaxed, allowing states to selectively increase speed limits up to a maximum of 65 mph on rural interstate highways.
- Repeal of the NMSL – In 1995, the NMSL was fully repealed, providing each state with full authority to determine appropriate speed limits on all roadways.

Following each of these policy changes, various research studies were conducted to ascertain the impacts of speed limits on traffic crashes and fatalities. In general, these studies showed higher speed limits to adversely impact traffic safety by increasing the number and/or rate of traffic fatalities [*3-28*]. Several studies suggested that speed limit increases did not consistently increase or decrease safety [*29-42*] while others have suggested that speed limit increases improved traffic safety and reduced traffic fatalities [*33-36*]. There remains considerable debate as to the true impacts of speed limit policies on traffic crashes and fatalities. Several states have recently enacted increases in speed limits on select segments of road facilities. This is in contrast to prior initiatives, which generally included large-scale increases in speed limits on a statewide basis.

A related issue that has generated considerable debate is the establishment of maximum speed limits for trucks and buses. States generally ascribe to one of two practices: the use of uniform speed limit (USL) policies that set the same maximum speed limit for both passenger vehicles and trucks; and the use of differential speed limit (DSL) policies that set a lower speed limit for trucks in comparison to passenger vehicles. As in the broader speed limit debate, a strong consensus has not emerged among whether USL or DSL policies are more appropriate, though currently there are only 8 states with differential speed limits. The principal philosophical arguments supporting uniform and differential speed limits are as follows:

- Support for DSL policies – Given their larger size, trucks require greater time and distance in order to come to a stop. This increased size also tends to result in more severe injuries when trucks are crash involved. Fuel economy tends to degrade at higher speeds and the environmental impacts tend to worsen.
- Support for USL policies – Varying speed limits for passenger vehicles and trucks could increase speed differences (i.e., variance) and thereby increase the potential for collisions. Higher speed limits also tend to reduce travel times, creating potential economic benefits to the freight industry.

The State of Michigan has used differential speed limits on freeways for many decades. Prior to 2006, on freeways with a maximum speed limit of 70 mph, the speed limit for trucks was 55 mph and the minimum speed was 45 mph. After consideration of available crash information, vehicle speed profiles, and economic impacts to the trucking industry and the State of Michigan, the Michigan legislature passed bills (Enrolled House Bill 5104 and 5240) raising truck speeds on 70 mph freeways from 55 to 60 mph. More recently, legislation has been introduced (SB 896) that proposes the creation of a new "Rural Freeway General Speed Limit" of 80 mph and a new "Urban Freeway General Speed Limit" of 70 mph. The legislation also proposes a maximum speed limit for trucks and buses of 70 mph.

In order to ascertain the impacts of these proposed speed limit increases, a careful analysis is required of a broad range of traffic safety, operational, environmental, and economic data. Such data are available from a variety of states, including several that have recently changed their passenger car speed limits, their truck/bus speed limits, or both.

STUDY GOAL AND OBJECTIVES

The purpose of the proposed work is to assist the Michigan Department of Transportation (MDOT) and the State of Michigan in determining the potential impacts of the following speed limit changes:

- Raising maximum freeway truck speed limits to 65 or 70 mph
- Raising maximum urban freeway speed limits from 55 to 70 mph
- Raising maximum rural freeway speed limits from 70 to 80 mph
- Raising maximum speed limits on non-limited access roadways from 55 to 65 mph

The aforementioned speed limit increases are expected to impact various performance measures, which include the following:

- Mean Speeds
- 85th Percentile Speeds
- Speed Variance/Standard Deviation
- Fatality Rates
- Road User Costs
- Pavement Condition
- Air Quality
- Economics for Trucking Industry

It is imperative that a comprehensive policy analysis is conducted that identifies the potential impacts of speed limit increases for various functional classes of roadways and for various vehicle classes. Ultimately, the objective of this research is to examine empirical evidence in order to estimate the impacts of speed limit changes on traffic safety, mobility, economics, and environmental aspects of Michigan's transportation system.

SUMMARY OF TASKS

The following tasks were performed in order to accomplish the aforementioned research objectives:

- Perform a comprehensive state-of-the-art review of research examining the relationships between traffic speed, safety, and crash risk.
- Survey state agencies to better understand the processes and procedures that have been utilized in enacting speed limit increases.
- Survey trucking companies to ascertain opinions on differential versus uniform speed limit policies.

- Collect and analyze national and Michigan-specific crash, injury, and fatality data to ascertain the effects of speed limit policies on traffic fatalities while controlling for potential confounding factors such as vehicle-miles of travel, weather, and temporal trends.
- Collect and analyze urban and rural freeway data in Michigan, Indiana, and Ohio in order to ascertain differences in driver speed selection between states with varying speed limit policies for trucks and buses.
- Perform an economic analysis of various speed limit policy alternatives and estimate the potential impacts of enacting such policies.
- Provide recommendations for decision-making as it relates to speed limit policies, including the development of strategies for selectively considering speed limit changes.

A full description of all work performed as a part of this research is provided in the chapters that follow.

CHAPTER 2:

LITERATURE AND HISTORICAL REVIEW OF SPEED LIMITS AND THE RELATIONSHIP BETWEEN SPEED AND SAFETY

The following review provides a historic overview of speed limits and a summary of studies that reviewed the effects of speed limits on actual speeds. The impacts of speed limits on traffic safety are an area that has generated much research, though a strong consensus has not emerged to the relationship between speed and safety. The purpose of this literature review is to critically assess prior research and summarize the findings.

GENERAL OVERVIEW

Maximum speed limits are posted to inform drivers of the highest speed that is considered safe and reasonable for ideal traffic, road, and weather conditions. Speed limits also establish a basis for the enforcement of legislation for unreasonably high travel speeds. Numerous research studies have sought to examine the relationship between vehicle speeds and traffic safety, as well as the effects of posted speed limits on the frequency and severity of crashes.

Much of the research on the effect of speed limits was motivated by the initial passage of the Emergency Highway Energy Conservation Act in 1974, which mandated the 55 mph National Maximum Speed Limit (NMSL) on interstate highways in the United States. The initial reason for the change was to reduce fuel consumption in response to the Mid-East Oil Embargo. However, the NMSL was extended, in part, due to a reduction in traffic fatalities that occurred during this same time period. One issue that arose with the introduction of the NMSL was that observed driving speeds did not necessarily reflect the new lower speed limits. This was particularly true on interstate highways where posted speed limits were significantly below the design speeds of these roadways.

The speed limit issue was revisited by subsequent research and legislation. The 1987 passage of the Surface Transportation and Uniform Relocation Assistance Act (STURAA) permitted states to increase speed limits from 55 to 60 or 65 mph on interstate highways in rural areas with populations of less than 50,000. Following the enactment of the STURAA, a series of evaluation studies showed increases in traffic crashes and/or fatalities in states where the speed limit had been increased [*3-10*]. However, additional studies found either marginal or no changes in traffic safety [*29-31*], while a few studies found safety improvements after speed limit increases [*33, 34*].

On November 28, 1995, the National Highway System Designation Act of 1995 gave states complete freedom to set interstate speed limits. As a result of this legislation, many states have raised interstate speed limits to 70 mph or more, providing ample opportunity to observe the same highways under different speed limits and determine user responses to these limits. The repeal of the NMSL in 1995 led to a series of additional studies, which produced some negative [*11-13*] and neutral [*14*] safety findings, indicating that the increased speed limits did not have a positive effect on injury or fatality rates.

The purpose of this literature review is to provide a detailed synopsis of research with emphasis on the following topics:

- The Relationship Between Speed, Risk, and Safety
- Safety Trends Following Speed Limit Policy Changes
- Effects of Speed Limits on Actual Speeds
- Differential vs. Uniform Speed Limits for Trucks and Buses
- Impacts of Speed Limits on Non-Motorized Users
- Recent and Proposed Changes to State Speed Limit Policies

THE RELATIONSHIP BETWEEN SPEED, RISK, AND SAFETY

Speed management has long been a concern of transportation agencies, dating back to research from the 1960's, which showed vehicles traveling excessively below or above the speed limit to be overrepresented in crashes on rural highways and interstates [*1, 2*]. The earliest, and perhaps most cited work in this area is that of Solomon [*1*] and Cirillo [*2*]. Solomon [*1*] compared the estimated speed (from police crash reports) of 10,000 crash-involved vehicles with field-measured speeds from 29,000 control vehicles. Using these data, relative crash rates for 10-mph speed categories were estimated. The results, illustrated in Figure 1, present the crash involvement rate (per 100 million vehicle-miles of travel) with respect to travel speed (Figure 1a) and with respect to variation from the average speed of traffic under similar conditions (Figure 1b). Collectively, these figures suggest that crash risk (i.e. possibility of being in a crash) is greatest at very low speeds and very high speeds. Vehicles traveling approximately 6 mph above the average speed exhibited the lowest crash rates.

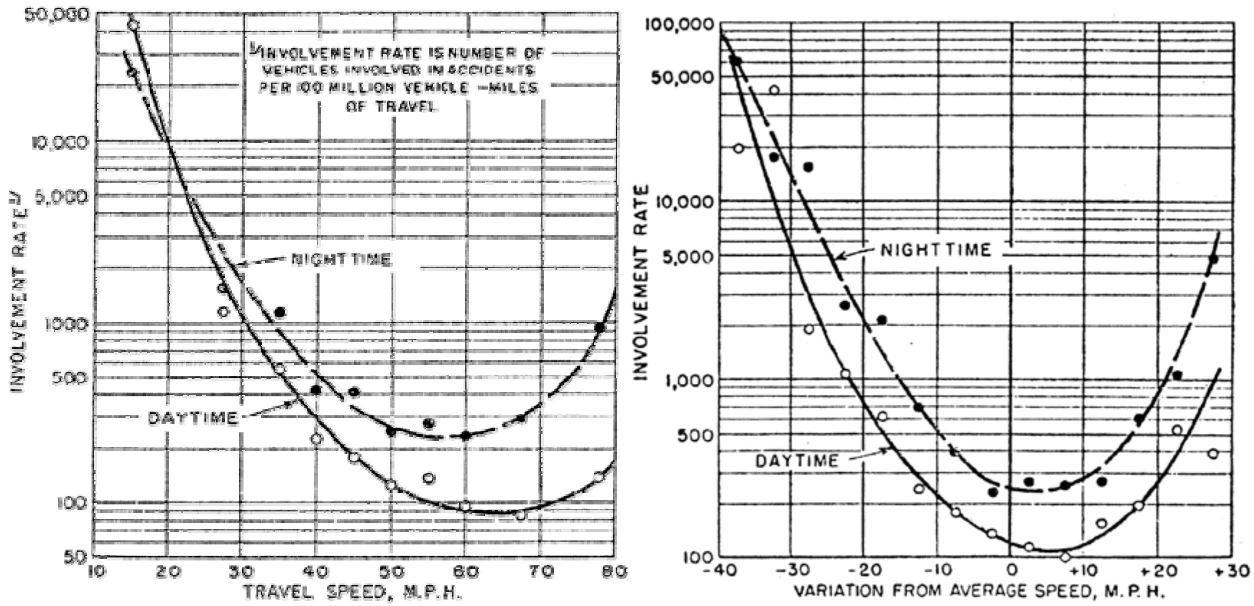


Figure 1. Crash Rates by Travel Speed and Variation from Average Speed [*1*]

In 1968, Cirillo [*2*] conducted a similar study on rural and urban interstates, which focused on two-vehicle, same-direction crashes. The results generally reflected this same trend, though the lowest crash rate was about 12 mph above the average speed.

Subsequent research used speed data from traffic detectors, in combination with pre-crash speeds based on crash reconstruction, and found similar trends [*37*]. However, 44 percent of these crashes involved low-speed maneuvers (e.g., turning into or out of traffic) and an analysis of the data excluding these maneuvers demonstrated crash risks were much less pronounced at low speeds in comparison to prior research. This reflects one of the limitations of the work by Solomon [*1*] and Cirillo [*2*], which is that many of the lower speed crashes result from slower moving vehicles entering or exiting the roadway. Subsequent work by West and Dunn [*38*] shows that removing turning vehicles substantially mitigates the apparent risk at lower speeds as shown in Figure 2.

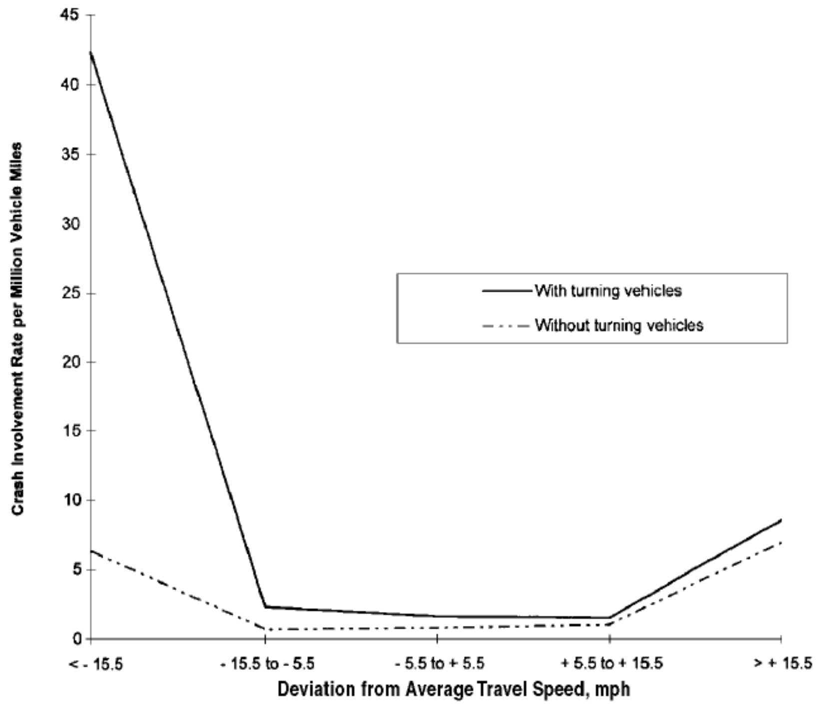


Figure 2. Crash Rates by Deviation from Average Speed [*38*]

Fildes et al. [*39*] conducted interviews of drivers who provided self-reported information regarding their crash involvement during the preceding five-year period. These drivers were selected based upon their observed travel speed on two urban roadways in Australia. Drivers were selected based upon how fast they were driving relative to the posted speed limits of 60 kph (37.3 mph) and 100 kph (62.1 mph). Figure 3 shows that drivers who were traveling at higher speeds tended to experience more crashes, particularly in the urban environment.

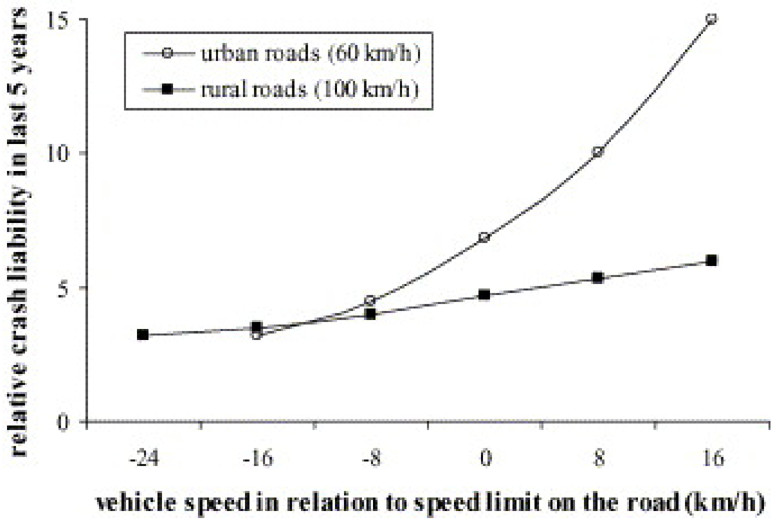


Figure 3. Crash Risk Relative to Speed Limit [*39*]

However, it must be noted that the travel speeds under which the drivers were selected for the interviews is not necessarily reflective of their travel speed prior to the crashes, which would have occurred at an earlier time and likely on a different roadway. Two subsequent studies from the United Kingdom [*40, 41*] utilized a similar self-reporting method and both found crashes to increase consistently with driver speed as shown in Figure 4.

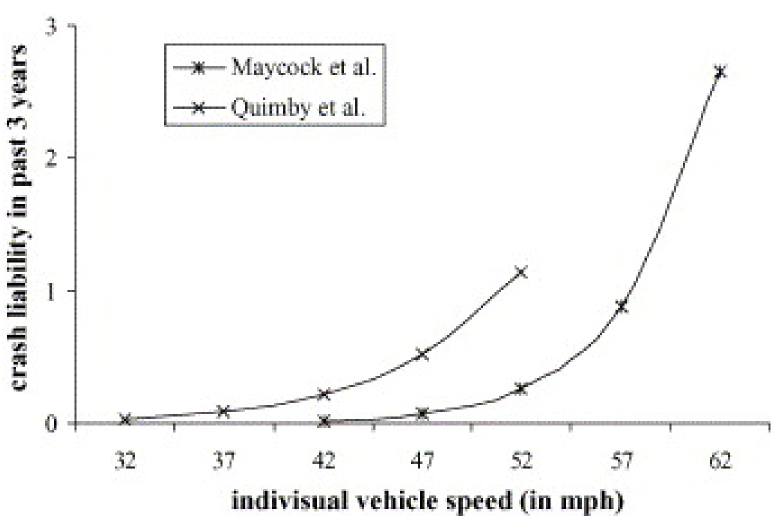


Figure 4. Crash Liability Relative to Vehicle Speed [*40, 41*]

Finch et al. [*42*] conducted a study in Switzerland, which showed fatal crashes to decrease by 12 percent when speed limits were lowered from 81 mph (130 kph) to 75 mph (120 kph). This research also showed crash rates to increase consistently with speed, as illustrated in Figure 5, when examining data from Denmark, Finland, Switzerland, and the United States.

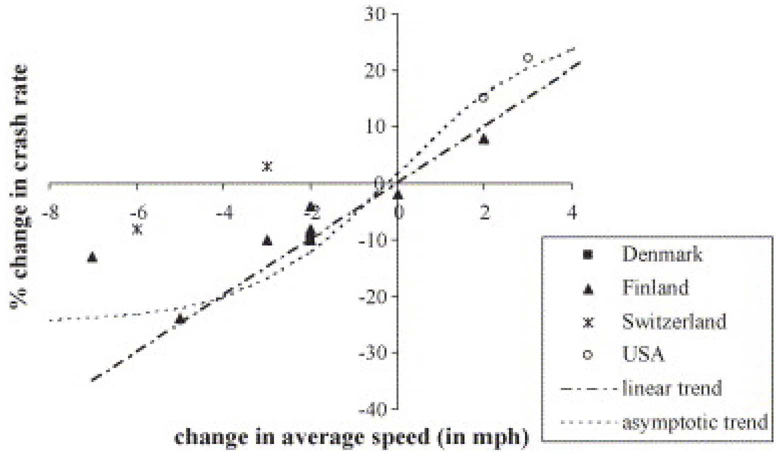


Figure 5. Change in Crash Rate with Respect to Average Speed [*42*]

Taylor et al. [*43*] examined the relationship between crash frequency and average traffic speed for several different roadway classes in the United Kingdom. The results from Figure 6 show that crashes increased consistently with speed for each of the road types. Further, these increases were most pronounced in the more urbanized areas, where higher levels of congestion were experienced.

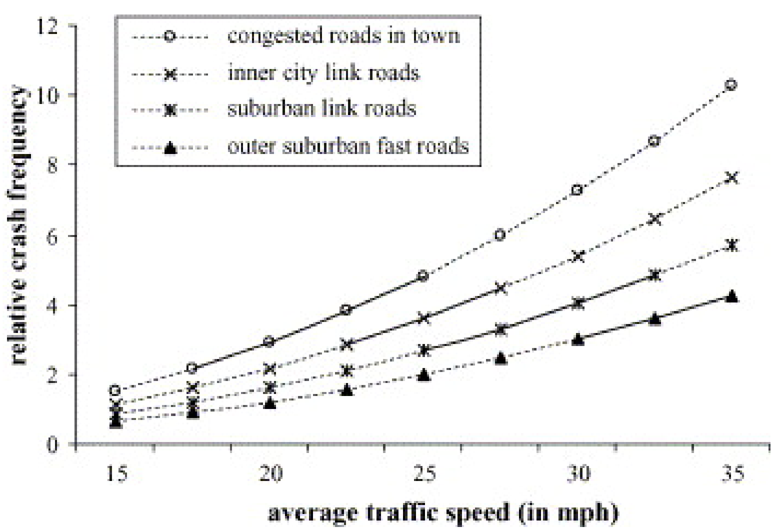


Figure 6. Relative Crash Frequency with Respect to Average Traffic Speed [*43*]

Research in the United States by Garber and Gadiraju [44] examined data more closely at the road segment level. This research focused on three types of roadways with 55 mph speed limits: interstates, arterials, and major collectors. Results showed that roads with larger speed variance (that is, larger speed differentials between drivers) exhibited higher crash rates than roads with lower variance. Ultimately, Garber and Gadiraju [44] found that the relationship between speed limit and design speed was a key determinant of safety trends. Both crash rates and speed variance were lowest when speed limits were 5 to 10 mph below the road's design speed.

Additional work has shown that increases in average speed and speed variance each result in increased fatality rates [15] [45-49]. The fact that fatalities increase with speed is unsurprising given the physics involved, which show the kinetic energy (i.e. energy of motion of an object, which is equal to the work the object would do if it were brought to a stop) [50] involved in a crash increases with speed (kinetic energy = 0.5 x mass x velocity^2) [51]. Nilsson [52] developed a "Power Model" whose purpose was to model the relationship between the number of people injured in a crash and speed as well the numbers of people fatally injured in a crash and speed. This model incorporates the concept of kinetic energy because increases in the amount of kinetic energy has an association with an increased risk of being in a crash, as well as a change in the outcomes of such crashes [52]. Analytical results suggest that a 5 percent increase in the mean speed will subsequently produce a 10 percent increase in the total amount of injury crashes, along with a 20 percent increase in the number of fatal crashes [53].

SPEED, RISK, AND SAFETY TRENDS FOLLOWING SPEED LIMIT CHANGES

Ultimately, the research literature clearly demonstrates that traffic crashes tend to increase with both average speed and speed variance. However, the preceding discussion has not explicitly addressed the specific impacts of speed limit policy changes.

Following the introduction of the National Maximum Speed Limit (NMSL) in 1974, which mandated a national speed limit of 55 mph on interstate highways, Burritt [16] found crash rates to decrease at all injury severity levels, which was attributed to reduced speeds and speed variance. Subsequent studies by Dart [17], Weckesser et al. [18], Tofany [19], and Deen and Godwin [20] found that lower speed limits resulted in safety benefits. Forester et al. [15]

analyzed crash data from 1952 to 1979 and estimated that traffic fatalities decreased by 7,466 per year as a result of the speed limit reduction. Conversely, Labrum [*32*] concluded that available data could not allow for the determination of speed limit impacts due to concurrent changes in other factors (e.g., fuel shortage, driver attitude, etc.), representing one of the few neutral findings of this period.

In 1987, the NMSL law was relaxed, allowing states to raise their speed limits to 65 mph on rural interstate highways. Much additional research was conducted following this, as many states increased the speed limits on their rural interstates. Hoskin [*21*], Gallaher et al. [*9*], and Upchurch [*10*] each found fatalities to increase in various states following these legislative changes. Baum et al. [*5*] estimated a 15 percent increase in fatalities in states that increased speed limits as part of a 38-state study. Subsequent research, which expanded this analysis to 48 states [*6*], estimated fatalities to increase by 29 percent and the risk of fatality in the event of a crash to increase by 19 percent in states where the rural interstate limits were increased to 65 mph. Conversely, 12 percent fewer fatalities occurred in those states that retained the 55 mph limit.

In contrast to the aforementioned research, Pant et al. [*29*] compared monthly crash rates on rural interstates in Ohio and found no difference following the 1987 change in rural speed limits. Similarly, Chang and Paniati [*31*] assessed monthly fatality data, but could not reach a conclusion as to the impact of the 65 mph limit due to limited post-increase data.

Subsequent work by Lynn and Jernigan [*22*] noted increases in fatal crashes, fatalities, and average and 85th percentile speeds on rural interstates in Virginia, though significant increases were not found on urban interstates. The 85^{th} percentile speed is the speed at which 85 percent of people drive at any given location under good weather conditions. It is generally considered to be the safe maximum speed limit for that area. Ossiander and Cummings [*23*] found a large increase in fatal crash rates on rural highways in Washington State while urban rates remained stable. In addition to these safety impacts, mean and 85^{th} percentile speeds also increased by 5.5 and 6.4 mph, respectively. Interestingly, speed increases did not occur immediately, but over time as drivers adapted to the new limits. Garber and Graham [*24*] estimated the 65 mph limit to result in a 15 percent increase in fatalities on rural interstates and a 5 percent increase on rural non-interstates. These results varied significantly between states, which likely reflects the effects of other factors such as seasonal patterns, highway design improvements, the quality of emergency medical care, traffic volumes, mandatory belt-use laws, etc. McKnight and Klein [*7*] found a 22 percent increase in fatal crashes on 65 mph rural interstates. Similar increases were also found in Iowa [*4*] following the speed limit increase.

In contrast to the broader research literature, Lave and Elias [*33, 35*] estimated that fatal crash rates fell by 3.4 to 5.1 percent following the 1987 speed limit increase. They suggest that the decrease in fatalities may have resulted from a shift in police resources from speed enforcement on the interstates to other activities and other highways, in addition to changes in driver route choice toward safer interstates. Similarly, Houston [*36*] found an increase in rural interstate fatalities, but reductions in fatalities on rural non-interstates, all other roads, and the road system overall. It should be noted however, that subsequent research by Greenstone [*3*] was unable to validate these claims or reproduce the same results, finding fatality rates to increase by 30 percent on rural interstates and fall by 17 percent on urban non-interstates nationwide from 1982 to 1990.

Wagenaar et al. [*8*] reported increases of 19 percent in fatalities, 40 percent in serious injuries, and 25 percent in moderate injuries on 65 mph rural highways in Michigan. The authors suggest that spillover speeding (i.e., speeding on roadways near the site of the speed limit increase, and potentially due to the increase) may have contributed to a concurrent 38 percent increase in fatalities on 55 mph rural highways. Rock [*25*] found crashes, injuries, and fatalities to increase on 65 mph rural highways in Illinois. Increases were also observed for each of these measures on 55 mph rural highways, providing further support of this spillover hypothesis.

The preceding discussion illustrates that most estimates suggest that the 1987 relaxation of the NMSL generally showed fatality increases. The primary exceptions indicate three studies that could not draw definitive conclusions [*29-31*] and several studies [*33-36*] that suggested higher limits might have had positive impacts.

The safety impacts of speed limit policies were revisited after the repeal of the National Maximum Speed Limit (NMSL) in 1995. This repeal gave states full authority to determine all types of speed limits. In 1996, Taylor and Maleck [*26*] examined the impacts of increasing the speed limit on 500 miles of rural freeway in Michigan from 65 to 70 mph. Results showed that, after the speed limit was raised, the 50th and 85th percentile speeds increased by 2 mph in some locations and less than 1 mph at most locations. In a follow up study [*27*], total crashes were found to increase by 10.5 percent, severe crashes increased by 4.5 percent, and fatal crashes decreased by 9.3 percent. Friedman et al. [*28*] conducted a 10-year follow up study on fatal crashes in the United States (except for Massachusetts and Hawaii) subsequent to the repeal of the NMSL in 1995, concluding that the increase in speed limits accounted for approximately 12,545 fatalities. Several additional studies found increases in fatality rates, including Farmer et al. [*11*], Patterson et al. [*12*], and Haselton et al. [*13*]. Najjar et al. [*14*] conducted research in Kansas, resulting in one of the few studies that did not find significant changes in crash and fatality rates on rural and urban interstates.

Kockelman et al. [*54*] conducted one of the most recent comprehensive studies aimed at estimating the impacts of raising speed limits on high-speed roads through a disaggregate-level analysis of the relationships between speed limits, speed choice, crash frequency, and crash severity. The results showed that vehicle speeds increase with speed limit increases, with the average vehicle speed increasing by less than half of the amount of the speed limit increase. Based on the results of this cross-sectional study, it was estimated that a 10-mph increase from 55 to 65 mph would result in an increase of approximately 3 percent in total crashes and 28 percent in fatal crashes. Increases from 65 to 75 were projected to increase total and fatal crashes by 0.6 percent and 13 percent, respectively. In addition to speed limit impacts, other roadway features also affected crash rates, such as horizontal curves and vertical grades. Road segments with horizontal curves were found to have higher crash rates, when everything else was held constant, the same was true for vertical grades.

In contrast to the United States, where most studies have evaluated the speed and safety effects of raising speed limits on limited-access highways, international studies have primarily examined the effects of reductions in speed limits. However, despite this difference, the results of the studies have been quite similar. Research examining the effects of speed limit reductions in Finland [*55*], Denmark [*56*], Sweden [*57, 58*], the Netherlands [*59*], and Australia [*60*] all reported the lower speed limits to result in lower average speeds, with these reductions typically being less than the associated reduction in the speed limit. Lower speed limits were also associated with reduced crash incidence and, in some cases, reduced crash severity. Aarts et al. [*61*] conducted a meta-analysis, which focused on speed as it relates to crash frequency and severity, with an emphasis on more recent studies. Most of the studies dealt with average speed, either at the road section level, or with respect to individual vehicles. Both types of studies showed that the rate of crashes increases significantly with speed. Results also showed that crash rates increase more quickly with speeds on minor roads as compared to major roads. Other factors that were found to influence crash rates were lane width, access point density, and traffic volumes. Vehicles moving much faster than the surrounding traffic had a higher crash rate, through results regarding slower moving vehicles were mixed [*61*].

EFFECTS OF SPEED LIMITS ON ACTUAL SPEEDS

In addition to the safety impacts of speed limits, another area of substantive debate is how speed limits influence the actual speed selection behavior of drivers. According to the American Association of State Highway and Transportation Officials (AASHTO) [*62*], driving speeds are affected by the physical characteristics of the road, weather, other vehicles, and the speed limit. Among these, road design is a principal determinant of driving speeds. Geometric factors tend to have particularly pronounced impacts on crashes. Ultimately, many factors affect speed selection beyond just road geometry and posted limit as shown by prior research in this area [*63-76*]. Research has generally shown that speed limit changes result in changes in the observed mean and 85^{th} percentile speeds that are less pronounced than the actual speed limit changes. This has been true for cases where speed limits were decreased [*15, 17*] or increased [*10, 22, 23, 77, 78*].

In one of the most extensive studies in this area, Parker [*79*] conducted a large-scale study from 1985 to 1992 to determine the impact that raising or lowering posted speed limits on non-limited access highways had on driver behavior. At the time of this study, the maximum speed limit on such roadways was 55 mph. Over the duration of the study, states and local authorities raised and lowered posted speed limits on short segments of roadways, typically less than two miles in length. Data on driver behavior and crashes were collected from 22 states. These included 100 sites along non-limited access highways where the speed limits were either raised or lowered and 83 control sites where there were no changes made to speed limits. The range of speed limit changes consisted of lowering the speed limit by 5, 10, 15, or 20 mph, or increasing the speed limit by 5, 10, or 15 mph, with only one change made at each site. Interestingly, the difference in speed after these changes was less than 1.5 mph on average. The study results clearly demonstrated that drivers select their speeds on non-limited access highways primarily on the basis of roadway geometry and traffic characteristics rather than the posted speed limits [*79*].

A meta-analysis of research from European countries and the United States, conducted by Wilmot and Khanal [*80*], showed similar results. It was concluded that drivers ultimately choose their speeds based on perception of safety rather than posted speed limits. Similarly, Feng [*81*] prepared a synthesis of studies on speed and safety and emphasized the importance of speed limits that are appropriate for the type of road, weather, and traffic conditions.

Kockelman et al. [*54*] found that speed limit increases tend to increase average vehicle speeds. On average, speed increases were generally less than half of the amount of the actual speed limit increase. Average speed and speed variability were largely influenced by highway design and lane use characteristics more than posted speed limits. In fact, after controlling for these other characteristics, variations in observed speed choices were largely unaffected by speed limits.
The findings discussed above are largely reflective of driver opinions on speed limits as shown by recent surveys. Mannering [*82*] conducted a 2007 freeway user survey studying their normal driving speed on interstate highways that have posted speed limits of 55 mph, 65 mph, and 70 mph. On average, drivers reported driving 11 mph over the speed limit on roads posted 55 mph, 9 mph over the speed limit on roads posted 65 mph and 8 mph over the speed limit on roads posted 70 mph.

A national survey conducted by the United States Department of Transportation (USDOT) in 2003 [*83*] gathered information regarding driver attitudes and behaviors related to violating the speed limit and other unsafe driving behaviors. Results showed that most drivers believe they can drive 7 to 8 miles per hour above the posted speed limit before being pulled over. On average, drivers felt that the ideal speed limit for a highway would be approximately 67 mph. Approximately 40 percent of drivers stated they would drive over the speed limit on interstate highways even if the speed limits were increased by 10 mph. While 51 percent of drivers admitted to driving 10 mph over the posted speed limit, 68 percent felt that other drivers violating the speed limit were a danger to their own personal safety. Drivers reported that the most influential factors dictating their speed selection were weather, their perception of what speeds were "safe", the posted speed limit, traffic volume levels, and the amount of personal driving experience they had on a particular road [*83*]. Collectively, the available empirical data and information from drivers suggest that the posted speed limit has a relatively small influence on speed selection in general.

SPEED LIMIT COMPLIANCE IN WORK ZONES

Working in close proximity to moving traffic is a potentially hazardous but necessary situation when conducting roadwork. To alleviate potential risk, speed limits in work zones are typically reduced to more safely accommodate construction workers, as well as motorists. Compliance with posted work zone speed limits has been found to be a common issue and various countermeasures have been evaluated aimed at reducing speeds through work zones.

In a study of four work zones in Missouri, Bham and Mojtaba determined that construction activity in work zones significantly decreased the average speeds of passenger cars and trucks, by 3.5 and 2.2 mph, respectively, as compared to times of inactivity. Speeds remained above the posted speed limits regardless of whether activity was ongoing. Reduced lane widths were revealed to be the most effective factors in reducing average speeds [*84*].

Debnath et al. reviewed four types of work zone speed control measures to determine the effect each had on speed limit compliance. Enforcement measures, such as speed cameras or police presence, were found to be the most effective methods of controlling work zone speeds while informational measures including static and variable message signage were determined to yield small to moderate effects. Several major causes of noncompliance to work zone speed limits were noted as the drivers' failure to notice signs and the public's inadequate understanding of roadwork risks and hazards [*85*].

Research conducted by Wasson et al. also found the presence of enforcement to be an effective means of speed reduction. Results showed the mean speed decreased by approximately 5 mph during periods of exceptionally high enforcement compared to no enforcement. Despite this reduction, 75 percent of passing vehicles were observed exceeding the speed limit, even at patrolled segments, and of those vehicles in violation, 25 percent were exceeding the limit by more than 5 mph [*86*]. Additional work by Finley indicated that the presence of enforcement dictates how sizeable the speed reduction is, in conjunction with the normal operating speeds of the roadway and the current situation of the construction zone [*87*].

Brewer et al. examined the effectiveness of three devices, including speed display trailers, changeable message signs, and orange-border speed limit signs. The results indicated that speed display trailers, which detect and display a vehicle's speed, were most effective in improving compliance as compared to static speed limits signs [*88*]. McMurtry et al. also reviewed the effectiveness of differing signage. The results showed that average speed reduction when using static speed limit signs compared to variable speed limit signs was not statistically different at a 95 percent confidence level, but speed variation in general did decrease [*89*].

A study conducted in rural Missouri on three Interstate 70 short-term work zones wanted to determine the effects of three speed limit signage possibilities; one with no posted speed limit reduction, a 10 mph posted speed limit reduction, and a 20 mph speed limit reduction. They found that the 85th percentile speeds were found to be 81, 62, and 48 mph, respectively. These differences were statistically significant, indicating that the posted speed limit reduction was effective in lowering speeds in the context of short-term work zones [*90*].

It was also discovered that compliance dropped with a greater decrease from the usual speed limit to the posted work zone speed limit. In Missouri, a work zone speed limit of 50 mph saw even less compliance than when set at 60 mph [*84*], and a study conducted in Australia supported these findings [*91*]. Overall, several studies concluded that although certain measures can be taken to try and slightly reduce speeds, motorists will regulate their speed as they feel necessary [*87, 88*].

SPEED LIMIT COMPLIANCE IN SCHOOL ZONES

Several studies have examined the effects of reduced speed zones, such as school zones. One study, conducted by McCoy and Heimann in Nebraska, assessed compliance with the posted speed limit in school zones. They found that speeds in school zones were more heavily influenced by the road characteristics and the posted speed limit on the road on which the school zone was located than by the lower posted speed limit within the school zone [*92*]. Another study, which was conducted in Washington State, found that a higher approach speed near a school zone led to higher speeds within the school zone, depending on the type of signage used. If a "flashing light" sign was being used, then there was a greater compliance with the posted speed limit for the school zone [*93*]. A study conducted in Atlanta conducted by Young and Dixon found that overall, the use of school zone signage had little to no effect on driver behavior [*94*]. An Australian study conducted by Ellison et al. in 2011 found that speed limit violations were among the highest in school zones among all type of road locations. They recommended targeting the road environment rather than using other types of campaigns to change speeding behavior [*95*].

DIFFERENTIAL VERSUS UNIFORM LIMITS FOR TRUCKS AND BUSES

Trucks and buses have long been a safety concern given their large size, which results in restricted maneuverability, longer stopping distances, and higher impact forces in a collision. Given these concerns, many states had initially implemented a differential speed limit (DSL), where trucks and buses have a posted limit lower than passenger cars. While lower speed limits for larger vehicles helps to mitigate concerns with respect to high impact forces in truck-involved (the term truck-involved generally refers to trucks and buses) collisions, these differential limits potentially increase the variability in travel speeds and may increase the potential for truck-involved crashes. In light of this fact, numerous states have subsequently transitioned to a uniform speed limit (USL), which establishes one maximum speed limit for all vehicles. There are currently 8 states with DSLs in place as shown in Figure 7, including the state of Michigan.

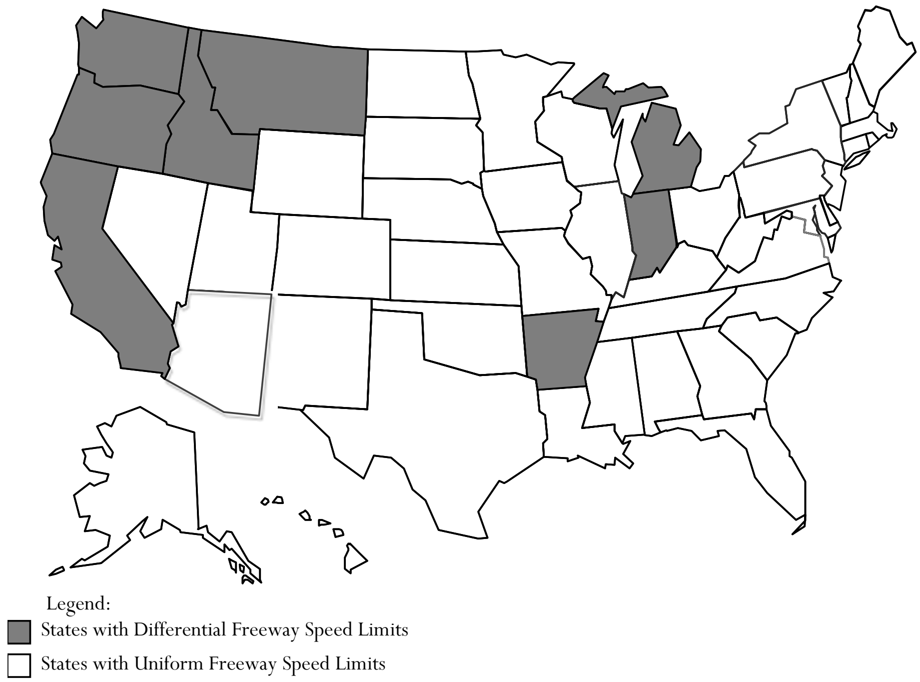


Figure 7. States with Differential and Non-Differential Freeway Speed Limits

Research results are relatively mixed with respect to both the operational and safety differences between USLs and DSLs. Freedman and Williams [*96*] analyzed data from eleven northeastern states to ascertain the effects of DSLs on mean and 85th percentile speeds. Six of the states maintained a uniform 55 mph limit, three states had uniform 65 mph limit, and two states implemented a 65-mph/55-mph differential limit. Passenger car speeds were not significantly different between the states. Truck speeds were close between the USL and DSL states, as well. Compliance rates with the posted speed limits were also similar between the states. Similar results were obtained by both Johnson and Murray [*97*] and Harkey and Mera [*98*]. Conversely, Garber and Gadiraju [*44*] found that there were differences in the mean speeds of trucks in states with DSLs and those with USLs. In addition, speed variances were found to be significantly greater in the DSL states.

Historically, there has been extensive research as to the safety impacts of differential speed limits. A study from the National Highway Users Conference in December 1963 indicated that the majority of states posted lower speed limits for trucks than for cars, especially on high-speed facilities [*99*]. Most of the truck limits were 5 to 10 mph lower than car limits; however, in some States such as Michigan and Virginia the differential was 15 mph.

One of the earliest studies of differential truck-car speed limits was conducted in 1966-67 by Ferguson in the state of Virginia [*100*]. Speed and crash data were collected at select locations on interstates and other routes, and surveys were conducted of the general public and state traffic engineers throughout the country. Based on the limited data, it was concluded that the 15 mph speed differential was unreasonably low and should be raised to be in line with the 85th percentile speed of trucks. As a result of the study, truck speed limits in Virginia were increased from 50 to 55 mph. Several years later when the car speed limit was raised to 70 mph, the truck speed limit was raised to 60 mph.

Joscelyn et al. [*101*] conducted a 1970 study for the National Highway Safety Bureau, which involved a survey of jurisdictions to examine the rationale for separate maximum speed limits for trucks and other vehicles. Jurisdictions with the same limit for all vehicles noted that the same limit avoids impeding the flow of traffic. Jurisdictions with lower limits for trucks noted that their decision was based on the interest of safety.

In 1972, Hall and Dickinson [*102*] examined speed and accident data on 55 sections of roadway in Maryland and found that the difference between car and truck speeds was typically less than 6 mph, which was less than the posted 10-mph differential. This study also found that the separate limits were not significantly related to truck accidents.

A 1978 review of traffic speed limit laws in the United States noted that the National Committee on Uniform Traffic Laws and Ordinances has generally been opposed to imposing different speed limits for different vehicle types [*103*]. The Committee's position was based on the belief that safety was best served when all traffic moves at the same speed. They observed states that establish lower limits base their decision on the belief that larger vehicles need to operate more slowly to maintain control, have comparable stopping distances with cars, and to diminish the damage caused by the extra weight when these vehicles are involved in a collision.

Following enactment of the STURAA, 12 of the 40 states that raised the maximum speed limit retained lower limits for trucks than for cars. For example, Michigan retained the 55 mph limit for trucks. In an effort to examine the effects of the differential speed limits, the National Highway Traffic Safety Administration [*104*] conducted a study in 1988 that examined rural interstate fatalities. This evaluation found few fatalities involving car and tractor-trailer crashes on rural interstates. Due to the limited sample of fatal crashes, the effect of the differential limits could not be determined.

A 1990 study by Baum et al. [*105*] assessed speed data on rural interstates with uniform and different limits for cars and trucks. Average truck speeds were found to be 1.4 mph higher in states with uniform 65 mph limits than in states with a 55 mph speed limit for trucks. The primary statistics used were the 95th percentile truck speed and the percentage of trucks exceeding 70 mph.

In 2005, Garber et al. [*106*] compared crash, traffic volumes, vehicles speeds, and other data between the State of Virginia, which had transitioned from a DSL to a USL, and three groups of comparison states: (1) states transitioning from USL to DSL; (2) states maintaining USL; and (3) states maintaining DSL. The results showed differences between passenger vehicle and truck speeds, but no consistent safety differences.

A 2008 study by Mannering [*107*] examined the effects of a 5 mph speed limit increase on crash severity after rural interstate speed limits in Indiana were raised from 65 to 70 mph. The speed limit for trucks and buses was also raised from 60 to 65 mph as Indiana remained a DSL state. Using data from 2004 (the year before speed limits were raised) and 2006 (the year after speed limits were raised), statistical models of the severity of different crash types were estimated. The results showed that the speed limit increase did not have a significant effect on the severity of accidents on interstate highways.

One study, conducted in Malaysia in 2011 by Saifizul et al., argued for the idea of incorporating the gross vehicle weight (GVW) when setting the differential speed limit instead of doing this by just the vehicle type or classification. The reasoning behind this was that their empirical analysis indicated that there was a statistically significant relationship between the free flow speed of a heavy vehicle and GVW, in that the mean free flow speed will decrease as GVW increases. It should also be noted that as the speed of heavy vehicles increase, so does the braking distance. Saifizul et al. noted that taking the GVW into consideration when setting the differential limit may be more effective than setting it by vehicle classification only, and that when heavy vehicles with high GVWs are driving at the 85th percentile speed, there is the potential risk for an increased number of accidents [*108*].

The most recent evaluation of differential speed limits was completed in 2012 by Dixon et al. [*109*] in Idaho, where a differential speed limit was introduced that reduced the truck limit from 75 to 65 mph. This research showed that truck mean speeds were reduced to 65.6 mph and that the speed variance and violation rate (in terms of vehicles traveling 5+ mph over the posted limit) were also reduced. The authors estimate that the DSL reduced crashes by 8.56 percent, though this result was not significant at a 95-percent confidence level.

While there has been extensive research comparing DSLs and USLs, a strong consensus has not emerged. A summary of the speed differences and crash impacts of differential speed limits for trucks on freeways was previously provided in *TRB Special Report 254* [*51*]. After examining available studies, including research in Europe, the authors concluded, "a strong case cannot be made on empirical ground in support of or opposition to differential speed limits."

VEHICLE SPEED IMPACTS ON PEDESTRIANS AND BICYCLISTS

Another area of concern when discussing speed limits and vehicular speeds is pedestrian safety. There have been a number of studies that have examined the impacts of vehicle speeds and speed limits on pedestrian injury severity. Pasanen [*110*] found a direct relationship between the risk of pedestrian fatality and impact speeds. At impact speeds of 20 mph, the probability of pedestrian fatality was 5 percent. At 50 mph, nearly 100 percent of crash-involved pedestrians were fatally injured. Andersen [*111*] reported similar results, as did Leaf and Preusser [*112*], the results of which are shown in Figure 8.

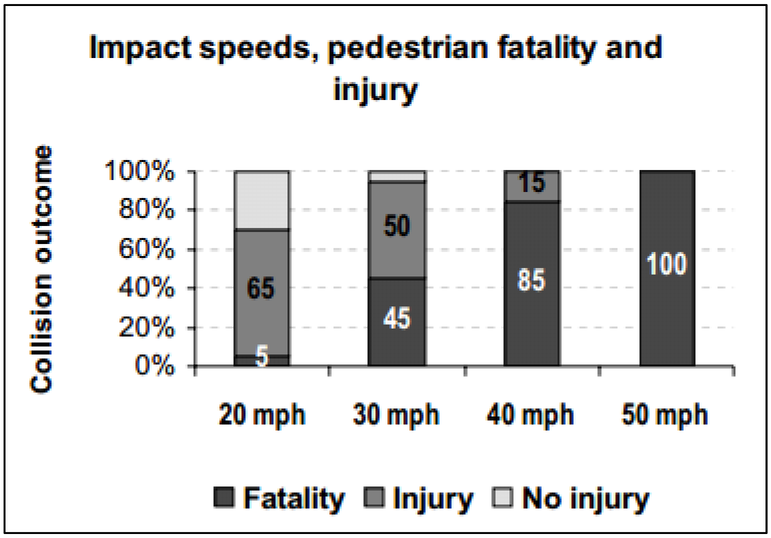


Figure 8. Effect of Impact Speed on Pedestrian Fatality and Injury [*112*]

Pasanen [*113*] conducted a study in Finland, which estimated the hypothetical effects of lower vehicular speeds on pedestrian fatality rates based on data from actual crashes. The speeds of the approaching vehicles ranged from 11 mph to 39 mph, with the results suggesting that if the approach speed was reduced to a maximum of 25 mph, the average death rate would have been reduced by over 60 percent. A similar study in Australia estimated that the chances of survival would range from 13 percent, if all drivers had traveled according to the speed limit, to 48 percent if all the drivers would have slowed down by 6 mph [*111*].

Research conducted by Jensen [*114*] in Denmark showed that after speed limits were introduced in 1974, vehicle travel speeds were reduced by 4 mph on average and pedestrian crashes were reduced by 25 percent. A similar trend occurred in 1985; when the urban speed limits were reduced from 37 mph to 31 mph, pedestrian fatality rates dropped by 31 percent, serious injuries by 4 percent, and slight injuries by 9 percent. Injury and fatality cases were plotted to determine the effect of speed on rate of survival. It was shown that no fatalities occurred for speeds less than 12 mph, 5 percent of fatalities occurred for speeds up to 31 mph, 20 percent of fatalities for speeds up to 50 mph, and 35 percent of fatalities for up to 68 mph speeds. The function of probability of fatality vs. speed was shown to be much less variable than those of serious injuries and slight injuries vs. speed. The author concluded that this was indicative of the fact that even for vehicles traveling at high speeds, the speed could be reduced to a level that would increase the chances of survival for most collisions. There appears to be a clear link between the traveling speed of a vehicle and the probability of injury or fatality for pedestrians, that is, the higher the traveling speed, the higher the probability of an injury or fatality for a pedestrian involved in a motor vehicle crash.

One analysis using accident data from 1997 to 2002 in North Carolina determined which factors have the greatest effect on different severity outcomes for bicyclists involved in motor vehicle crashes. The outcomes included fatal, incapacitating, non-incapacitating and possible or no injury categories. There are several factors that influence the severity of an injury experienced by a bicyclist in a motor vehicle accident, but the factor that had the largest effect was when the speed of the vehicle prior to impact was more than 50 mph. This was found to increase the probability of a fatal crash by 16-fold. The "threshold effect", or the speed at which there is a great increase in the probability of a fatality in an accident for a bicyclist is 20 mph [*115*].

Another study, conducted in the United States, found that the two most important variables that affect non-motorist (i.e. pedestrians and bicyclists) injury severity are the age of the person and the speed limit on the roadway on which the accident occurred, as speed limits that are higher lead to higher injury severity levels [*116*]. The speed at which the driver is traveling appears to have a very strong effect on injury severity for both pedestrians and bicyclists.

RECENT AND PROPOSED CHANGES TO STATE SPEED LIMIT POLICIES

The preceding sections outline a wide range of safety issues of importance in determining speed limit policies. While the extant research literature has generally shown that speed limit increases produce mixed results in terms of traffic safety impacts, many states have recently changed or considered changing their speed limit policies. This section provides a brief summary of such information.

Ten states have recently increased speed limits along some of their roadways since 2011. The majority of these increases occurred along interstate highways. In general, these increases were done selectively based upon traffic engineering, speed, and safety studies conducted by the state departments of transportation. This is an important distinction as not all segments of a particular roadway class are likely to be acceptable candidates for speed limit increases. In particular, segments with extensive horizontal or vertical curvature, sight distance limitations, or other features that may not comply with current design standards (e.g., design exceptions) may not be suitable for speed limit increases. Similarly, locations at which the 85th percentile speed is currently in compliance with the existing speed limit or locations where there is a history of crashes may not be suitable candidates. Specific details of the recent policy changes follow and a summary is provided in Table 1.

- In Ohio, state legislators raised the speed limit on the Ohio Turnpike from 65 to 70 mph. Other urban and rural interstates remained posted at 65 mph [*117*].
- As a result of a 2010 bill, a 200-mile stretch of Louisiana's I-49 speed limit was increased from 70 mph to 75 mph. The increase was authorized by the state Department of Transportation and Development after engineering and traffic investigations [*118*].
- Kansas increased its rural freeway speed limits by 5 mph (to 75 mph) following 2011 legislation. A committee comprised of staff from the Kansas DOT was given authority of selecting the divided, controlled access highways to receive the higher speed limit [*119*]. HB2192 allowed the Secretary of Transportation to set new speed limit on any separated multilane highway effective as of July 1, 2011. Several criteria were used in selecting the locations for increased speed limits from the 1,060 miles of eligible highways, including: whether it was rural or urban area, if it had at-grade intersections, natural barriers, commuter traffic, geometrics, surrounding state speed limits, district experience, traffic volumes, legal issues or concerns, and crashes. A multi-agency task force was assembled to determine the highways appropriate for a speed limit increase.
- As a result of a 2012 bill passed by the state legislature, Texas became the first state in the U.S. to enact a speed limit of 85 mph. While the Texas DOT concluded that speeds this high could not be safely implemented on current highways, a new 41-mile toll road was designed to handle the higher speeds and weights. Before opening, horizontal and vertical geometry, and sight lines were extensively analyzed [*120*].
- In Ohio, state legislators raised speed limits in non-urban areas by 5 mph. This included sections of five non-urban freeways, each of which are now posted at 70 mph [*117*].
- In Utah, speed limits on select rural freeways have raised from 75 mph to 80 mph. Beginning in 2008, UDOT started conducting studies on portions of I-15 that were

temporarily set to 80 mph. Results showed that crashes slightly decreased. Speed studies of highways posted at 75 mph, were also studied. UDOT concluded that most motorists preferred to drive between 82 and 83 mph regardless of the posted speed limit. As of September of 2013, 289 miles of highway in Utah were set to a speed limit of 80 mph [*121*].

- In September of 2013, the North Carolina DOT raised the speed limit of three major highways from 65 mph to 70 mph (I-540 between U.S. 70 and I-40; All of N.C. Highway 540, including the Triangle Expressway; and N.C. Highway 147 between N.C. Highway 540 and I-40). These increases came as a result of traffic studies that included a review of the current traveling speed, speed limits, crash data, and road characteristics such as lane and shoulder widths [*122*].

Table 1. Recent Changes to Speed Limit Policies by State

State	Type of Roadway	Prior Speed	New Speed	Effective Date
Ohio	Ohio Turnpike	65	70	April 2011
Louisiana	Select Rural Freeways	70	75	July 2011
Kansas	Rural Freeways	70	75	July 2011
Indiana	Tollway	55	70	February 2012
Arkansas	Select Rural Highway	55	60; 65	June 2012
Texas	Rural Freeways; Tollway	75; 80	80; 85	October 2012
Kentucky	Select US Highway	55	65	October 2012
Ohio	Select Rural Freeways	65	70	July 2013
North Carolina	Select Rural Freeways	65	70	September 2013
Utah	Select Rural Freeways	75	80	September 2013
Alaska	State Highway	55	65	November 2013
Georgia	Select Interstates	55	65	November 2013
Illinois	Tollway; Select Freeways	55; 65	70	January 2014
New Hampshire	Select Interstates	65	70	January 2014
South Carolina	Select State Highways	55	60	January 2014
Pennsylvania	Rural Freeways	65	70	January 2014
Maine	Select Interstates	55; 65	60; 70	May 2014
Wyoming	Select Interstates	75	80	July 2014

- In Illinois, the speed limit for ninety percent of interstate miles was raised from 65 mph to 70 mph at the beginning of 2014. These roadways are made up of mostly rural highways, with the exception of five short sections of the Illinois Tollway, which were increased 15 mph to 70 mph. The Illinois DOT conducted traffic engineering studies and examined 85th percentile speeds in support of these recommendations [*123*].
- In 2013, the speed limit was increased along a 30-mile stretch of I-93 in New Hampshire from 65 to 70 mph [*124*].
- South Carolina increased the speed limit for a section of SC-170, from 55 to 60 mph. The DOT examined this section of the route, which has no traffic lights and few exits, and determined it was safe to increase the speed limit [*125*].
- Pennsylvania increased rural freeway limits on select roadways in January 2014. The Pennsylvania DOT will conduct a study of any candidate segments [*126*].

A follow-up survey was conducted of the DOTs from those states listed in Table 1 in order to obtain feedback on any preliminary findings associated with the recent speed limit increases. A brief summary follows:

- Collectively, these states considered a range of factors in determining whether speed limit increases were appropriate at specific locations. This includes consideration of the existing 85th percentile speed, as well as whether there is a history of traffic crashes or fatalities on the associated segment. As one example, in Louisiana, the speed limit increases were conducted in accordance with the Louisiana DOT's *Engineering Directive and Standard Manual VIII Establishment of Speed Zones*.
- Preliminary data from these states show that both mean and 85th percentile speeds generally increased by 2 to 4 mph following the speed limit increase. This finding is consistent with empirical research in this area.
- Given how recently these increases were implemented, none of these states had been able to determine whether or not the speed limit changes had any measureable effect on traffic crashes.
- The only documented cost elements provided by any of the responding states was for the provision of new speed limit signage, which could include either sign replacement or the use of a new speed limit plaque that was overlaid on the existing sign.

In addition to the preceding initiatives, each of which has been approved by state legislatures, five states have recently implemented, or are in the process of implementing, speed limit increases. These proposed changes, summarized in Table 2, are as follows:

- Florida lawmakers proposed a bill that would allow the Florida DOT to selectively study and, if permitted, raise speed limits. Driver feedback and safety data would be used to prompt a speed study for candidate sections. The bill was focused on mostly rural stretches of highway, such as I-10 and I-4. These four-lane highways would see a 5-mph increase in the speed limit from 70 mph to 75 mph. Other four-lane highways with speed limits currently set at 60 mph or 65 mph could see similar 5-mph increases [*127*].
- Lawmakers in North Carolina are considering similar legislation to raise the maximum speed limit for some interstates and highways from 70 mph to 75 mph. If the bill is passed, NCDOT will then complete traffic studies and examine crash histories for specific roadways to determine if the increase is reasonable and safe [*128*].
- In New York State, interstate highways including the Thruway could see a 10 mph boost, if permitted by the state transportation commissioner, from 65 mph to 75 mph [*129*].
- In Missouri, lawmakers are considering allowing the speed limits along rural freeways, to be increased from 70 mph up to 75 mph [*130*].
- In Kentucky, non-limited access highways may also see an increase as lawmakers are considering increasing the speed limits from 55 to 65 mph for state highways, such as KY-80 [*131*].

Table 2. Proposed Changes to Speed Limit Policies by State (as of January 2014)

State	Type of Roadway	Current Speed	Proposed Speed
Florida	Select Rural Freeways	70	75
	Four-Lane Highways	60	65
		65	70
New York	Interstates	65	75
Missouri	Rural Freeways	70	75
North Carolina	Select Rural Freeways	70	75
	3 Major Highways	65	70
Kentucky	State Highways	55	65

FEEDBACK FROM THE TRUCKING INDUSTRY

In addition to soliciting feedback from state DOTs, an additional survey was distributed to trucking companies and large shipping/freight companies throughout the state of Michigan. The objective of this survey was to obtain feedback on the current speed limit policy, particularly with respect to the existing differential speed limit. Complete responses were received from a total of 12 trucking companies. Table 3 provides a summary of these survey responses. These results show most of the trucking companies utilized speed-limiting devices, which restrict maximum operating speeds. The use of these devices introduces an inherent upper limit to truck operating speeds. Consequently, even if truck limits were increased to 65 or 70 mph, it is likely that many trucks would operate at average speeds below these limits. Among the respondents, the most common limits at which speeds were governed were 65 mph and 68 mph.

Table 3. Trucking Industry Survey Results (N = 12)

1. Are any of the trucks in your fleet speed limited or governed?
   Yes = 9 (75%); No = 3 (25%)

2. If yes, at what speed are your trucks governed?
   62 mph = 1 (11%); 65 mph = 4 (44%); 68 mph = 4 (44%)

3. Do you prefer a uniform speed limit (USL) or a differential speed limit (DSL)?
   USL = 8 (67%); DSL = 4 (33%)

4. What do you believe is the most appropriate speed for trucks on rural freeways?
   60 mph = 3 (25%); 65 mph = 6 (50%); 70 mph = 3 (25%)

The respondents were also asked whether they preferred a uniform speed for trucks and buses or the existing differential limit (or some variation thereof). Two-thirds of respondents favored a universal limit. Among these, there was a 2:1 preference for a 65 mph limit as opposed to a 70 mph limit. Additional comments were provided by most of the trucking companies and several consistent themes were cited among these comments. In general, the companies indicated that their primary concerns with the differential limit were due to perceived safety concerns (due to variations in the speeds of passenger vehicles and the slower moving trucks), as well as inconsistency with respect to neighboring states that had uniform speed limits in place. Michigan and Indiana are the only Midwestern states that currently have DSLs. The preference for a 65-mph USL vs. a 70-mph USL appeared to relate largely to fuel economy and other vehicle operating costs. Several respondents cited the intermediate 65-mph limit provided for an optimal balance of safety and economy.

LITERATURE SUMMARY

The preceding discussion illustrates a rich body of research literature that has assessed the effects of speed and speed limit policies on traffic safety. This review also included surveys of state departments of transportation (DOTs) and trucking companies in order to gain diverse insights as to important issues associated with speed limit increases. The salient findings from this review are summarized as follows:

- The risk of traffic crashes increases as the variance in travel speeds (i.e., the variability among vehicles at a particular road location) increases. This risk is most pronounced at speeds that are significantly above the mean speed of traffic.
- The risk of traffic crashes and fatalities, in particular, is greater at higher travel speeds. The research literature has consistently shown the frequency and rate of traffic crashes, injuries, and fatalities to increase at higher speed limits.
- The literature is largely mixed with regard to the effects of differential speed limits. While no consensus has developed with respect to prospective safety impacts, the majority of states have gone toward uniform speed limits. Uniform limits have been shown to reduce the variance in travel speeds, which in turn is expected to reduce the risk of traffic crashes and resultant injuries/fatalities. Responses from the trucking industry survey suggest that trucking companies are receptive to increasing the maximum truck/bus limit, though the use of speed limiting devices and economic considerations suggest there is a practical upper limit.
- During the past four to five years, various states have enacted selective speed limit increases. These increases have generally occurred on the limited access (i.e., interstate/freeway) highway network. In contrast to prior efforts, which were generally of a larger scale, recent increases have been applied after careful study of existing traffic crash and travel speed data.

CHAPTER 3:

ANALYSIS OF NATIONAL AND STATE-LEVEL TRAFFIC CRASH DATA

One of the principal objectives of this study was to examine the impacts of speed limit policies on traffic safety. To this end, a series of statistical analyses were conducted at two levels of aggregation:

1. A national-level assessment of fatal crash trends on interstate highways across all 50 states – A longitudinal analysis was conducted to examine trends in traffic fatalities among states with various speed limit policies while controlling for other factors that may be expected to influence fatalities at the aggregate level. Ultimately, the data collected for these states allowed for a determination of how traffic fatalities have changed over time and how these trends may relate to the speed limit policies that were in place.
2. A state-level assessment of traffic crash trends on freeways in Michigan – traffic crash, injury, and fatality rates were examined for freeways throughout Michigan. The emphases of this analysis were to discern differences in safety performance between three freeway classes: urban freeways posted at 55 mph for all vehicles; urban freeways posted at 70 mph for passenger vehicles and 60 mph for trucks/buses; and rural freeways posted at 70 mph/60 mph for passenger vehicles and trucks/buses.

ANALYSIS OF NATIONAL INTERSTATE FATALITY DATA

An aggregate-level (i.e., national) analysis was conducted to analyze trends across all 50 states. This analysis allows for an assessment of statewide trends in traffic fatalities while considering changes in additional factors such as vehicle-miles of travel, population characteristics, and safety-related legislation, policies, and programs. The following aggregate-level data were obtained for all 50 states and the District of Columbia:

- Fatality Data – The Fatality Analysis Reporting System (FARS) database provides information for all traffic crashes that result in a fatal injury within 30 days of the crash. For the purposes of this project, information for all interstate fatal crashes occurring in each state dating back to 1999 were collected [*132*]. These crashes were aggregated by interstate class (urban versus rural) and whether a truck or bus was involved in the crash.

- Traffic Volume, Freeway Mileage, Vehicle Registration, and Driver Licensure Data – The FHWA requires states to report Highway Performance Monitoring System (HPMS) data on an annual basis. Data for total statewide vehicle-miles of travel were obtained for each state from the FHWA annual series, *Highway Statistics* [*133*]. These data include estimates of travel for all vehicle types, as well as estimates of the number of registered vehicles and licensed drivers in each state. Table 4 shows the annual vehicle-miles in millions for rural and urban interstates by state, and Table 5 shows the percentage of annual miles traveled by vehicle type for rural and urban interstates for each state. The most recent volume data available were for the year 2011. Consequently, the analysis period was from 1999 to 2011. As volume estimates by vehicle class are only available at the state level for 2009 and 2010, these values were averaged for each state across the analysis period.
- Speed Limit Policy Data – The policy for setting interstate speed limits for each state, including whether differential speed limits are used, were obtained from the Insurance Institute for Highway Safety (IIHS) and from state DOT or legislative records. Figures 9 and 10 show the maximum speed limits on rural interstates for passenger vehicles and trucks/buses, respectively. Figures 11 and 12 show the maximum speed limits on urban interstates for passenger vehicles and trucks/buses, respectively. It should be noted that data for states with speed limits above 75 mph are very limited. Only Idaho, Texas, Utah, and Wyoming have limits of 80 mph or above. In these states, the higher limits are in effect at only select locations. Consequently, it not possible to distinguish specific trends at these to speeds. For the purpose of the analysis, these states are coded in a 75-mph and above category.
- Occupant Protection Data – The type of seat belt use law (primary, secondary, or none) and type of motorcycle helmet use law (universal, partial, or none) for each state was determined for each year of the study period, and the most recent laws by state are shown in Figures 13 and 14 for seatbelt laws and helmet laws, respectively. Additionally, the National Highway Traffic Safety Administration (NHTSA) requires states to provide annual statewide estimates of safety belt use, which generally become available each fall. This information was obtained for the same time period, and the most recent snapshot of seatbelt use by state (2013 Data) is shown in Table 6.

- Population Data – Data for the driving age population of each state (ages 16 and older) were obtained from the United States Census Bureau [*134*].
- Climate Data – Statewide average yearly temperature and total precipitation data were obtained from the National Oceanic and Atmospheric Administration (NOAA) [*135*]. Statewide averages were unavailable for Alaska and Hawaii.
- Gasoline Price Data – Average annual gasoline prices were calculated for each state based on data provided by the Energy Information Administration (EIA). These data were converted from dollars per MMBtu to dollars per gallon using the procedure recommended by the EIA.

Collectively, these data were aggregated for select states based upon historical interstate speed limit policies. States were aggregated based upon the following policy factors:

- Maximum rural interstate speed limit (60-65 mph, 70 mph, 75-80 mph)
- Maximum urban interstate speed limit (50-60 mph, 65 mph, 70-75 mph)
- Uniform versus differential speed limit (9-11 states w/rural DSLs, 4 states w/urban DSLs during the study period)

Table 4. Annual Vehicle-Miles (Millions) for Rural and Urban Interstates by State (Source: FHWA Highway Statistics Series 2010 - Table VM-2)

State	Rural Interstate	Urban Interstate	Total	State	Rural Interstate	Urban Interstate	Total
Alabama	5,745	7,552	13,297	Montana	2,393	355	2,748
Alaska	859	663	1,522	Nebraska	2,624	1,376	4,000
Arizona	7,133	6,065	13,198	Nevada	1,870	3,481	5,351
Arkansas	4,328	4,093	8,421	New Hampshire	1,297	1,597	2,894
California	17,565	68,207	85,772	New Jersey	1,583	13,513	15,096
Colorado	4,149	7,489	11,638	New Mexico	4,406	2,643	7,049
Connecticut	711	9,633	10,344	New York	6,135	20,317	26,452
Delaware	-	1,191	1,191	North Carolina	5,996	14,907	20,903
Dist. of Columbia	-	477	477	North Dakota	1,527	422	1,949
Florida	9,459	25,371	34,830	Ohio	9,137	22,652	31,789
Georgia	10,007	19,088	29,095	Oklahoma	5,143	4,885	10,028
Hawaii	109	1,746	1,855	Oregon	4,243	4,511	8,754
Idaho	2,204	1,271	3,475	Pennsylvania	10,372	13,154	23,526
Illinois	9,066	23,053	32,119	Rhode Island	407	1,717	2,124
Indiana	7,143	9,363	16,506	South Carolina	7,596	6,144	13,740
Iowa	4,858	2,592	7,450	South Dakota	2,032	627	2,659
Kansas	3,192	3,641	6,833	Tennessee	8,656	11,641	20,297
Kentucky	6,875	6,178	13,053	Texas	15,480	39,732	55,212
Louisiana	5,404	7,569	12,973	Utah	3,166	6,105	9,271
Maine	2,249	838	3,087	Vermont	1,265	379	1,644
Maryland	3,555	13,485	17,040	Virginia	9,342	14,913	24,255
Massachusetts	1,373	15,092	16,465	Washington	4,606	10,884	15,490
Michigan	5,792	15,435	21,227	West Virginia	2,787	2,753	5,540
Minnesota	4,108	8,260	12,368	Wisconsin	5,194	5,267	10,461
Mississippi	3,835	3,382	7,217	Wyoming	2,382	481	2,863
Missouri	6,329	11,642	17,971	**Grand Total**	**245,687**	**477,832**	**723,519**

Table 5. Percentage of Annual Miles Traveled by Vehicle Type for Rural and Urban Interstates (Source: FHWA Highway Statistics Series 2010 - Table VM-4)

State	Rural Interstates				Urban Interstates			
	Passenger Vehicles	Buses	Single-Unit Trucks	Tractor Trailer Trucks	Passenger Vehicles	Buses	Single-Unit Trucks	Tractor Trailer Trucks
Alabama	75.2	0.7	5.6	18.5	88.4	0.4	3.3	8.0
Alaska	87.5	0.2	8.6	3.7	93.1	0.2	5.8	1.1
Arizona	74.2	0.7	3.0	22.1	88.6	0.8	3.8	6.9
Arkansas	62.6	1.1	2.7	33.6	78.9	0.6	2.0	18.6
California	74.4	0.2	5.0	20.5	93.5	0.1	2.4	4.1
Colorado	87.7	0.3	1.8	10.4	92.9	0.2	2.0	4.9
Connecticut	87.9	0.3	3.6	8.2	90.9	0.2	3.0	5.9
Delaware	-	-	-	-	87.3	1.2	5.3	6.3
Dist. of Columbia	-	-	-	-	94.7	0.6	4.0	0.7
Florida	82.1	0.6	3.8	13.6	91.7	0.5	2.9	4.9
Georgia	78.0	0.7	2.8	18.4	91.6	0.6	2.6	5.3
Hawaii	95.7	0.3	2.1	1.9	95.2	0.5	3.6	0.8
Idaho	70.4	0.3	25.7	3.6	55.5	0.4	5.2	38.9
Illinois	70.9	1.0	3.2	24.9	87.4	0.7	2.2	9.7
Indiana	65.0	1.1	3.5	30.4	73.7	0.9	2.9	22.5
Iowa	73.0	0.7	2.6	23.8	85.2	0.6	2.5	11.7
Kansas	75.1	0.2	2.6	22.1	91.1	0.1	2.5	6.4
Kentucky	75.6	0.8	2.6	21.0	88.4	0.6	1.9	9.1
Louisiana	76.7	0.4	6.0	16.9	80.3	0.4	5.8	13.5
Maine	84.5	0.3	3.3	11.9	88.1	0.5	3.0	8.4
Maryland	83.1	0.9	3.7	12.2	92.4	0.7	3.0	3.9
Massachusetts	90.0	5.8	1.7	2.5	93.4	1.1	2.0	3.5
Michigan	86.5	0.2	2.5	10.8	90.2	0.2	2.3	7.4
Minnesota	88.3	0.5	2.9	8.2	93.1	0.3	2.2	4.0
Mississippi	74.8	0.8	4.4	20.0	86.2	0.6	3.7	9.6
Missouri	65.9	0.7	3.9	29.5	83.6	0.5	3.6	12.3

Table 5. Percentage of Annual Miles Traveled by Vehicle Type for Rural and Urban Interstates (Cont'd) (Source: FHWA Highway Statistics Series 2010 - Table VM-4)

State	Rural Interstates				Urban Interstates			
	Passenger Vehicles	Buses	Single-Unit Trucks	Tractor Trailer Trucks	Passenger Vehicles	Buses	Single-Unit Trucks	Tractor Trailer Trucks
Montana	77.2	0.7	3.3	18.8	88.0	0.3	4.6	7.1
Nebraska	65.4	0.2	2.0	32.5	93.1	0.1	1.9	4.9
Nevada	75.6	0.6	2.7	21.1	92.3	0.5	2.0	5.3
New Hampshire	91.8	0.3	3.2	4.7	93.9	0.2	3.1	2.8
New Jersey	88.4	0.4	9.0	2.3	86.3	0.4	3.5	9.9
New Mexico	58.4	2.6	6.9	32.1	75.7	1.1	3.7	19.5
New York	84.4	0.5	2.1	13.0	90.7	0.8	2.8	5.7
North Carolina	78.8	0.6	3.2	17.4	86.4	0.6	3.1	9.9
North Dakota	78.8	1.4	6.0	13.8	86.3	1.1	4.7	7.9
Ohio	68.0	0.0	3.0	29.0	87.0	0.0	2.0	11.0
Oklahoma	67.0	0.5	5.2	27.5	87.6	0.4	5.2	6.9
Oregon	70.8	0.2	3.7	25.3	87.5	0.3	3.5	8.8
Pennsylvania	66.5	0.9	12.5	20.2	86.5	0.7	7.0	5.8
Rhode Island	86.7	0.6	3.1	9.6	95.3	0.6	2.8	1.3
South Carolina	82.4	0.7	2.4	14.5	91.4	0.4	2.3	5.9
South Dakota	78.2	0.3	18.4	3.1	86.7	0.1	9.8	3.4
Tennessee	71.7	0.3	5.3	22.7	80.9	0.2	2.8	16.1
Texas	69.9	0.3	4.6	25.2	89.5	0.2	3.3	7.0
Utah	58.6	1.3	8.8	31.4	81.2	0.3	8.9	9.7
Vermont	84.4	1.4	4.9	9.3	90.9	0.9	3.4	4.8
Virginia	80.8	0.7	1.5	17.0	92.1	0.6	1.3	6.1
Washington	83.0	0.3	5.5	11.3	90.6	0.2	4.3	4.9
West Virginia	78.7	0.9	3.9	16.5	84.1	0.8	3.5	11.6
Wisconsin	75.3	0.9	8.4	15.4	89.2	0.2	5.8	4.8
Wyoming	64.5	0.5	1.8	33.2	69.2	0.5	2.0	28.3

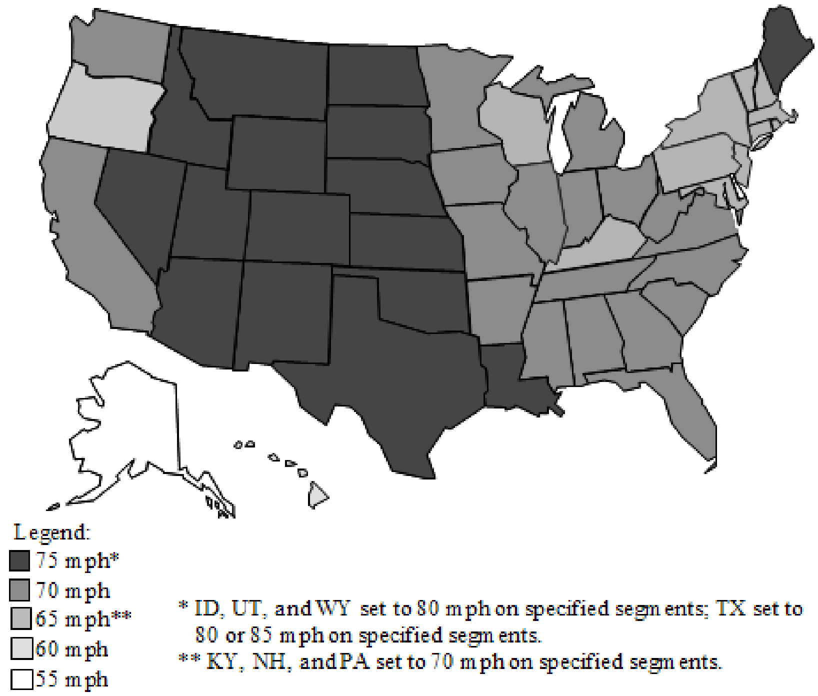


Figure 9. Maximum Speed Limits on Rural Interstates for Passenger Vehicles

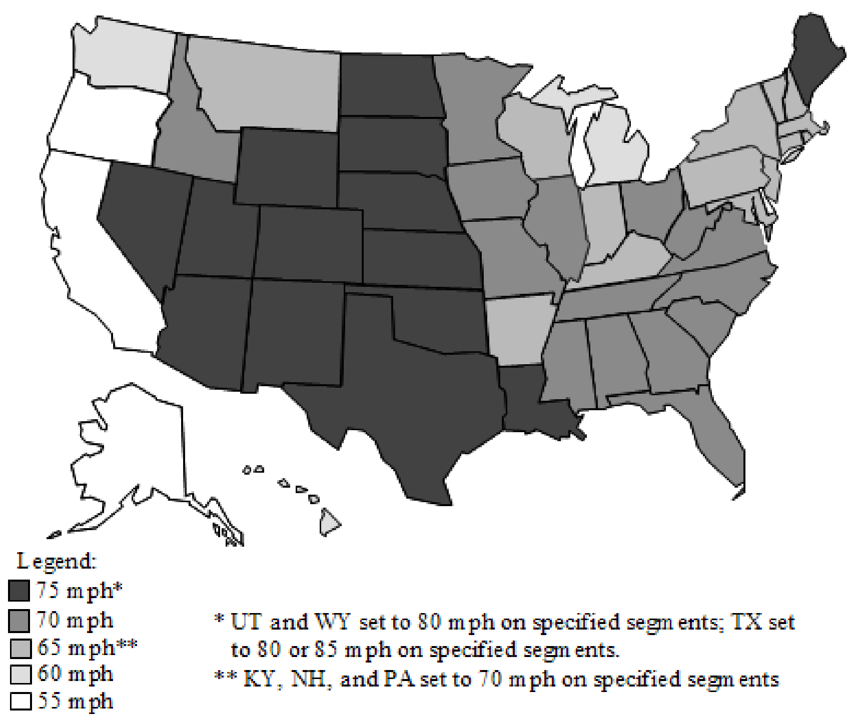


Figure 10. Maximum Speed Limits on Rural Interstates for Trucks

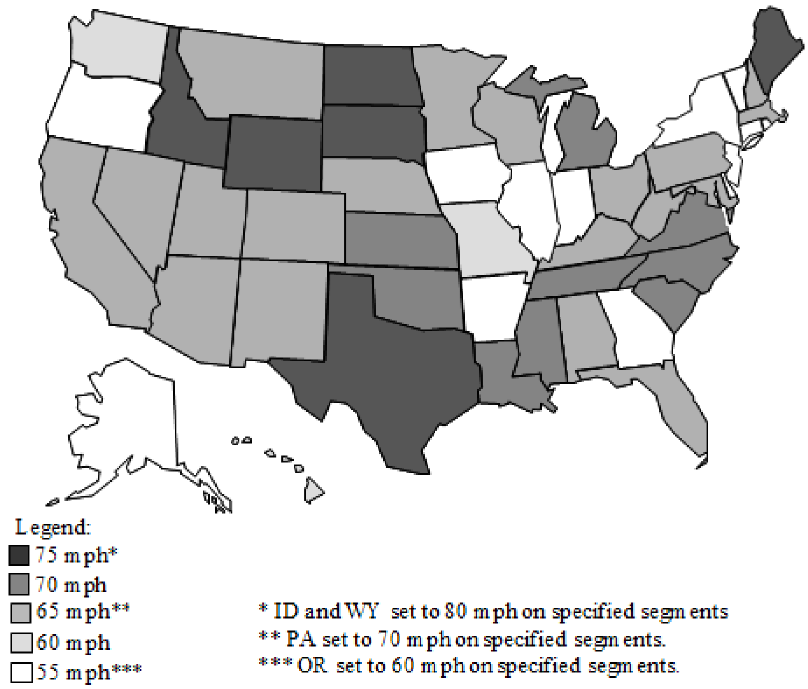


Figure 11. Maximum Speed Limits on Urban Interstates for Passenger Vehicles

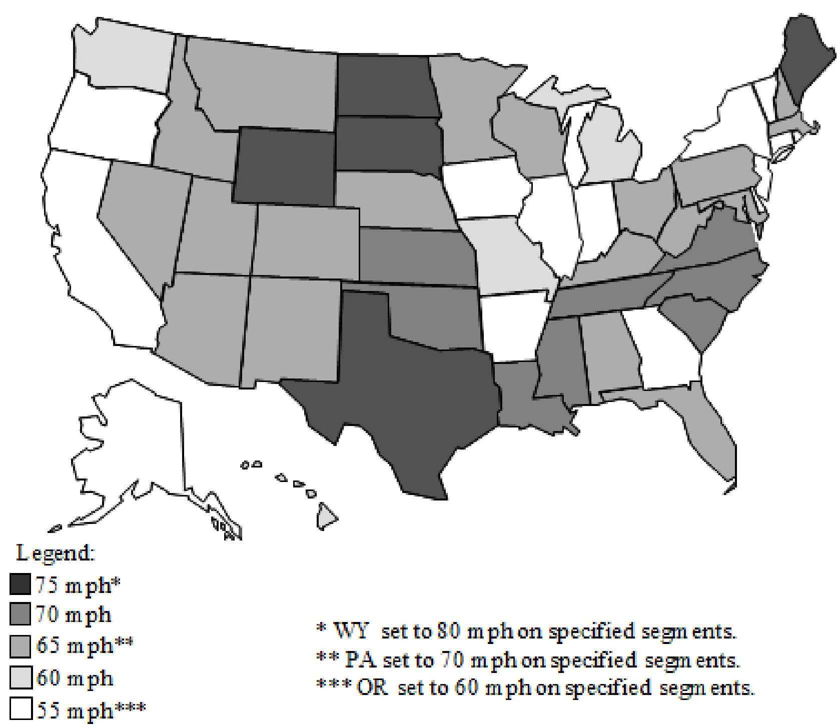


Figure 12. Maximum Speed Limits on Urban Interstates for Trucks

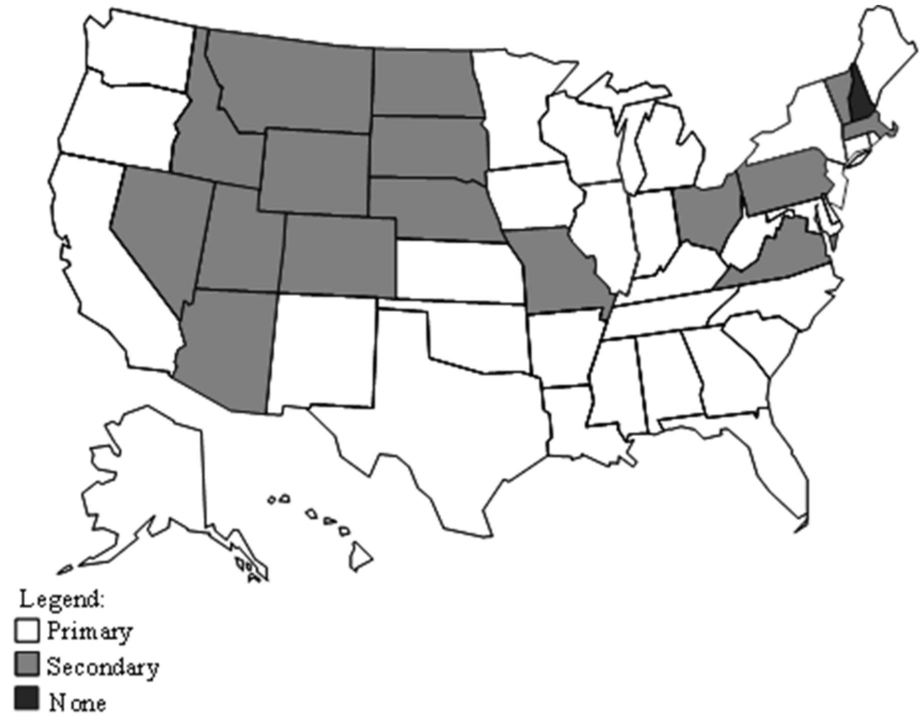


Figure 13. Seatbelt Use Laws by State

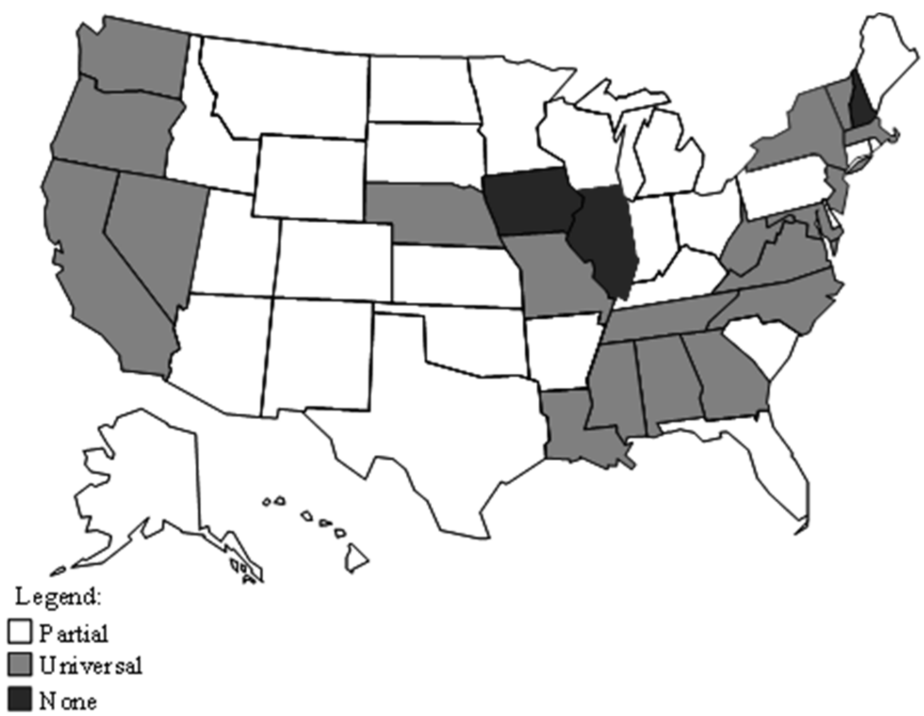


Figure 14. Helmet Use Laws by State

Table 6. Seatbelt Use Rates by State (2013 Data)
(Source: NHTSA Seatbelt Use in 2013 – Use Rates in the States and Territories)

State	2013 Seat Belt Use Rate (%)	State	2013 Seat Belt Use Rate (%)
Alabama	97.3	Montana	74.0
Alaska	86.1	Nebraska	79.1
Arizona	84.7	Nevada	94.8
Arkansas	76.7	New Hampshire	73.0
California	97.4	New Jersey	91.0
Colorado	82.1	New Mexico	92.0
Connecticut	86.6	New York	91.1
Delaware	92.2	North Carolina	88.6
Dist. of Columbia	87.5	North Dakota	77.7
Florida	87.2	Ohio	84.5
Georgia	95.5	Oklahoma	83.6
Hawaii	94.0	Oregon	98.2
Idaho	81.6	Pennsylvania	84.0
Illinois	93.7	Rhode Island	85.6
Indiana	91.6	South Carolina	91.7
Iowa	91.9	South Dakota	68.7
Kansas	80.7	Tennessee	84.8
Kentucky	85.0	Texas	90.3
Louisiana	82.5	Utah	82.4
Maine	83.0	Vermont	84.9
Maryland	90.7	Virginia	79.7
Massachusetts	74.8	Washington	94.5
Michigan	93.0	West Virginia	82.2
Minnesota	94.8	Wisconsin	82.4
Mississippi	74.4	Wyoming	81.9
Missouri	80.1	Nationwide	87.0

Table 7 presents summary statistics (minimum, maximum, mean, standard deviation) for each of the previously described data sources that were assembled for use in the safety analysis.

Table 7. Summary Statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
Fatality Data				
Urban fatalities	43.602	62.663	0	390
Rural fatalities	48.418	43.666	0	239
VMT Data				
Urban VMT (millions)	8759.098	11163.120	249	70950
LN (Urban VMT)	8.362172	1.327302	5.517453	11.16973
Percent Trucks (urban)	12.480	6.990	4.35	44.52
Rural VMT (millions)	5286.610	3865.146	88	20226
LN (Rural VMT)	8.241503	0.953756	4.477337	9.914724
Percent Trucks (rural)	22.939	8.786	4.75	40.65
Speed Limit Policies				
Rural Maximum Speed Limits				
N/A	0.041	0.197	0	1
60 mph	0.020	0.141	0	1
65 mph	0.345	0.476	0	1
70 mph	0.335	0.473	0	1
75 mph	0.245	0.430	0	1
80 mph	0.014	0.118	0	1
Urban Maximum Speed Limits				
50 mph	0.016	0.124	0	1
55 mph	0.294	0.456	0	1
60 mph	0.063	0.244	0	1
65 mph	0.409	0.492	0	1
70 mph	0.163	0.370	0	1
75 mph	0.056	0.230	0	1
Differential Speed Limits				
Urban	0.078431	0.269052	0	1
Rural	0.208145	0.406287	0	1
Speed Limit Increase During Study Period				
Urban	0.077	0.267	0	1
Rural	0.062	0.241	0	1
Weather Data				
Mean Annual Temperature (degrees F)	53.4745	8.632	38.300	85.5
Mean Annual Precipitation (in)	37.300	15.493	5.37	75.05
Occupant Protection Data				
Universal Motorcycle Helmet Law	0.412	0.492	0	1
Primary Seat Belt Use Law	0.667	0.512	0	2
Annual Seat Belt Use Rate	79.239	10.440	46.7	98
Census Data				
Total Population	5,788,751.59	6,468,033.29	479,602	37,691,912
Mean Household Income	46223.77	7899.134	29297	68876

During the analysis period, several states made changes to their interstate speed limit policies. These changes were accounted for during the analysis and a list of the changes can be found in the bulleted list below:

- Arizona – 10-mph increase in urban limit
- Hawaii – 10-mph increase in urban limit
- Illinois – transition from differential to uniform limit
- Indiana – 5-mph increase in rural limit
- Iowa – 5-mph increase in rural limit
- Michigan – 5-mph increase in rural and urban limits
- Ohio – transition from differential to uniform limit; 5-mph increase in rural limit
- South Carolina – 5-mph increase in rural and urban limits
- Texas – 5-mph increase in rural limit (cars); 5-mph increase in rural limit (all vehicles); 5-mph increase in urban limit (all vehicles)
- Utah – 5-mph increase in select rural limits
- Virginia – 5-mph increase in rural and urban limits

Statistical Methods

The data described previously provide diverse information regarding travel trends and safety policies for all 50 states and the District of Columbia. These data are used to examine the following questions of interest:

1. What are the impacts of differences in speed limit policies on the frequency of traffic fatalities?
2. Do differential and uniform speed limits result in substantive differences in the safety performance of rural interstates?
3. How do maximum rural and urban speed limits affect traffic fatalities at the aggregate level?

As the analysis data set is of a longitudinal nature, it is important to consider the temporal aspects of the data, as well as state-specific effects that are not captured by the nationally available data. These analytical methods include the following to address these considerations:

- Given that the number of annual interstate fatalities is best characterized as count data (i.e., non-negative integers), negative binomial regression models represent an appropriate modeling framework. These models can be used to examine how changes in various explanatory variables affect the number of fatalities occurring during a particular year in a specific state.
- Regression models were estimated that captured the general decreasing trend in traffic fatalities (over the period from 1999 to 2011) through the inclusion of a linear time trend. This model formulation provided better fit as compared to a series of indicator variables for the 13 time periods.
- Random effects models were estimated, which can capture state-specific effects (e.g., certain states will tend to exhibit more crashes than other, similar states). This controls for the fact that certain states may exhibit unique differences in geographic conditions, safety policies, or other factors.

As noted above, in order to ascertain the effects of speed limit policies on fatal crashes, a series of random effects negative binomial regression models were estimated as a part of this study. The negative binomial model specification estimates the probability $P(n_{it})$ of n_{it} fatal crashes occurring in state *i* during year *t* as:

$$P(n_{it}) = \frac{\Gamma(\theta+n_{it})}{\Gamma(\theta)n_{it}!} u_{it}^{\theta}(1-u_{it})^{n_{it}} \tag{1}$$

where $u_{it} = \frac{\theta}{(\theta+\lambda_{it})}$, $\theta = \frac{1}{\alpha}$, $\Gamma(\cdot)$ is a gamma function, and λ_{it} is given by:

$$\ln \lambda_{it} = \boldsymbol{X}_{it}\beta + \epsilon_{it} \tag{2}$$

where $\boldsymbol{X}_{it}$ is a vector of characteristics affecting the number of fatal crashes in state *i* during year *t*, $\boldsymbol{\beta}$ is a vector of estimable coefficients; and $\exp(\epsilon_{it})$ is a gamma-distributed error term with mean one and variance α.

This general specification does not allow for possible serial correlation arising from consistent unobserved factors that are unique to specific states over time. Consequently, it is more appropriate to consider a random effects modeling framework. A random effects negative binomial model can be estimated, which accounts for state- and time-specific effects, by assuming that the overdispersion parameter is randomly distributed across states:

$$\ln \lambda_{it} = \boldsymbol{X}_{it}\beta + u_i \tag{3}$$

where u_i is a random effect for the ith state such that exp(u_i) is gamma-distributed with mean one and variance α. To account for the variation of state effects over time, it is assumed that $\frac{\theta_i}{1+\theta_i}$ follows the beta distribution, *B(a, b)*, resulting in the joint density function:

$$P(n_{il}, \cdots n_{iT}) = \frac{\Gamma(a+b)\Gamma(a+\sum_T n_{it})\Gamma(b+\sum_T n_{it})}{\Gamma(a)\Gamma(b)\Gamma(a+b+\sum_T \lambda_{it}+\sum_T n_{it})} \prod_T \frac{\Gamma(\lambda_{it}+n_{it})}{(\lambda_{it})n_{it}!} \tag{4}$$

Estimation of the random effects model is done by standard maximum likelihood procedures. Separate analyses were conducted for rural and urban interstate highways.

Analysis Results – Rural Interstate Highways

Figures 15-18 provide scatterplots illustrating the general relationship between rural interstate fatalities and traffic volume (annual vehicle miles of travel) for the entire 13-year study period. Separate plots are provided for those states with maximum speed limits of 50-60 mph (Figure 15), 65 mph (Figure 16), and 70 mph or higher (Figure 17). The same general trends are observed between fatalities and traffic volume within each group of states. Figure 18 provides a summary of the mean fatality trends within each group. Fatalities tended to increase more rapidly among states with maximum speed limits of 65 mph or higher.

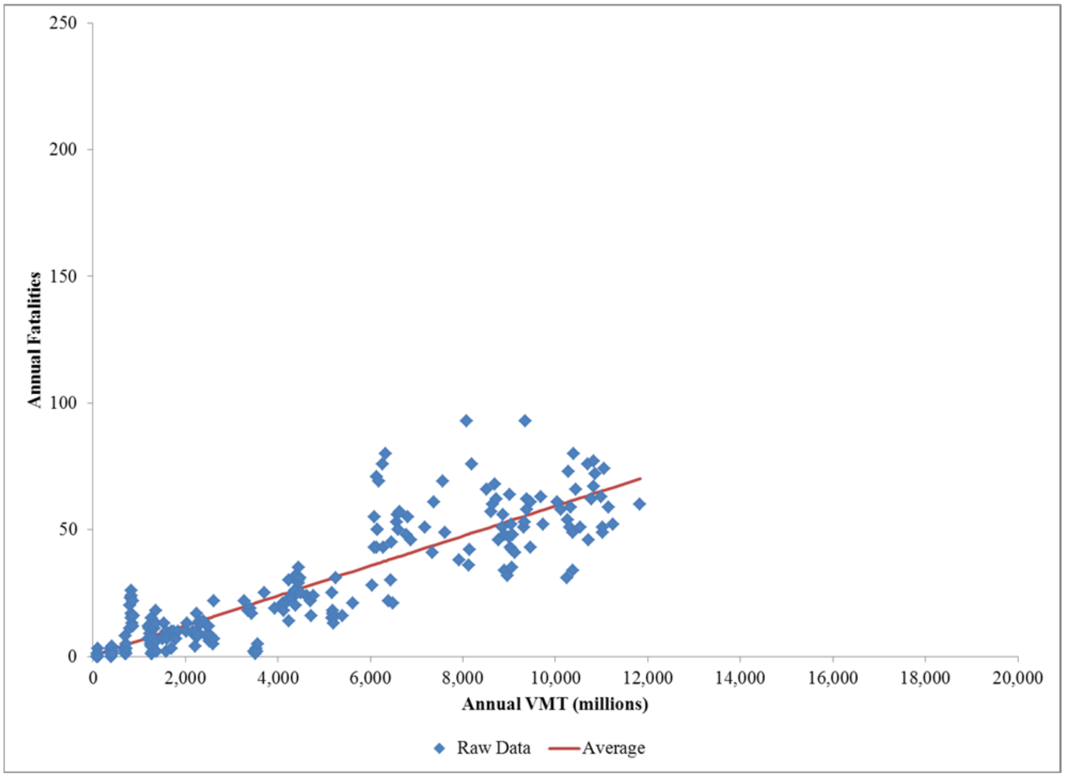


Figure 15. Annual Rural Interstate Fatalities in States with 50-60 mph Maximum Limit

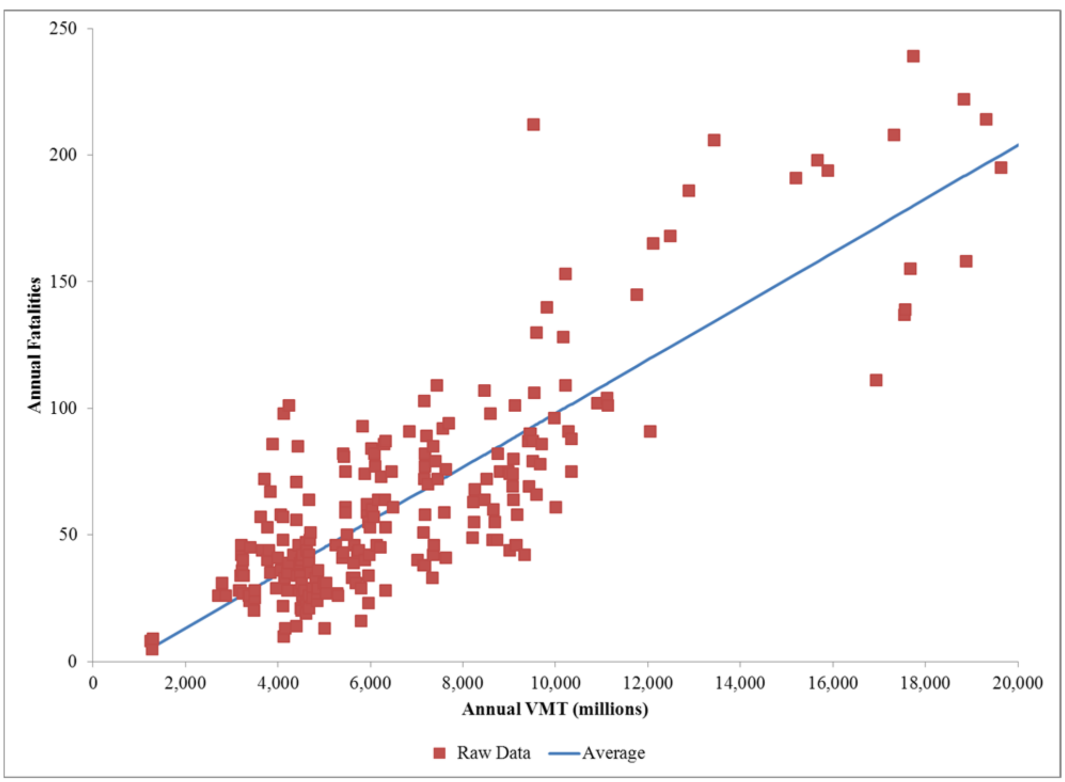


Figure 16. Annual Rural Interstate Fatalities in States with 65 mph Maximum Limit

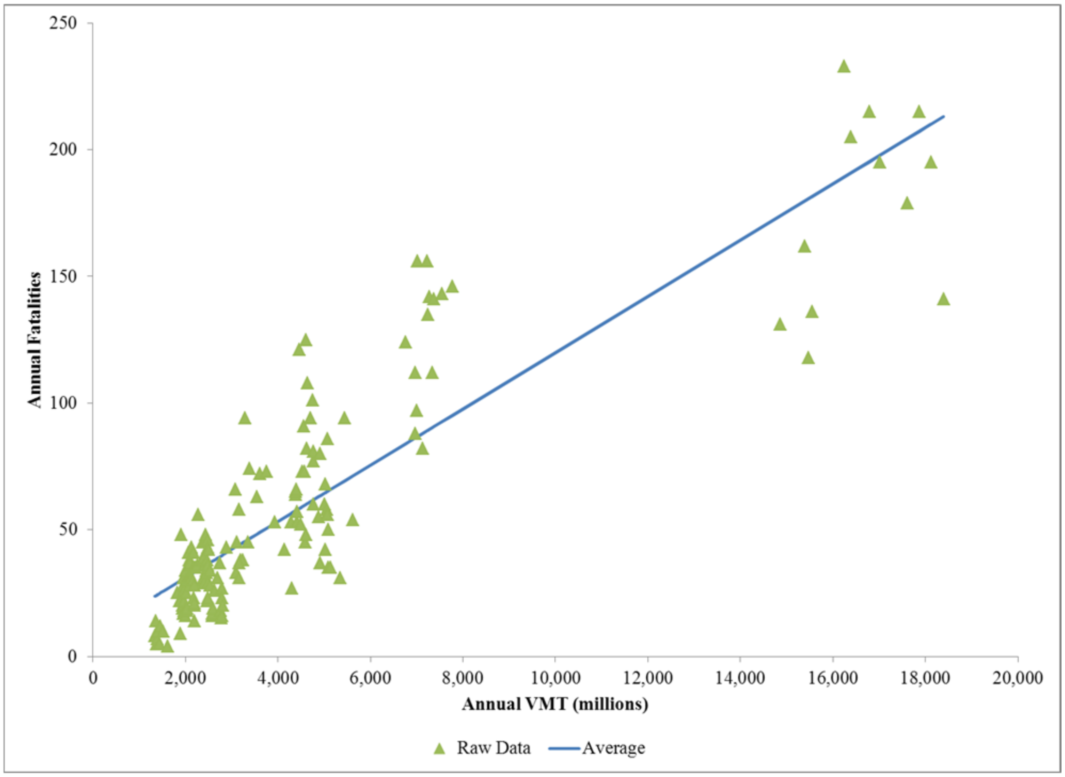


Figure 17. Annual Rural Interstate Fatalities in States with 70+ mph Maximum Limit

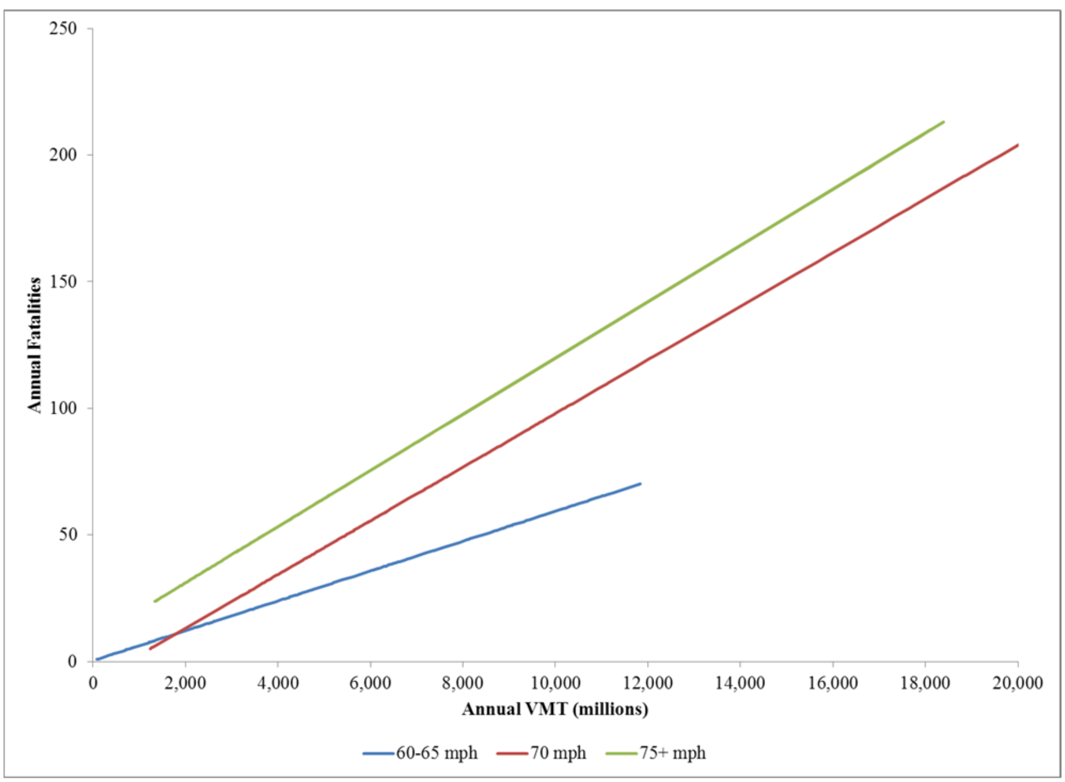


Figure 18. Average Annual Rural Interstate Fatalities by Maximum Limit

Figures 19 and 20 present additional graphical summaries of trends in fatality rates for rural interstate highways based upon the state-level speed limit policies that were in place from 1999 through 2011. Figure 19 illustrates the significant difference in fatality rates based upon the maximum posted limit. Over the duration of the analysis period, fatality rates were markedly higher in states with 70 mph rural interstate speed limits and, particularly, in those states with speeds limits of 75 or 80 mph. Over this 13-year period, states in each category experienced similar trends, with fatality rates remaining relatively stable through 2005, followed by a period of significant decreases, which is reflective of overall fatality trends in the United States during this same period. Figure 20 presents similar data, which compares the fatality rates between states with uniform and differential freeway speed limits for trucks and buses. States with differential limits generally exhibited slightly lower fatality rates, particularly from 2002 to 2008, though the most recent data do not indicate a clear difference between these groups.

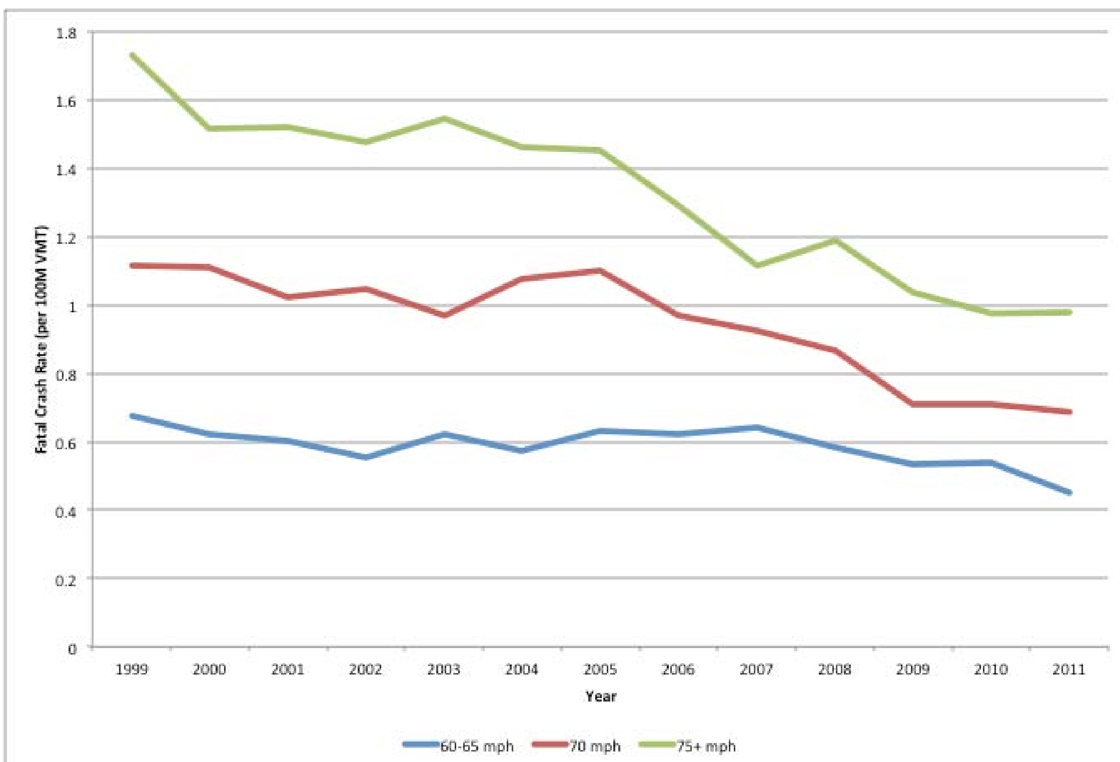


Figure 19. Annual Rural Interstate Fatality Rates by Maximum Speed Limit

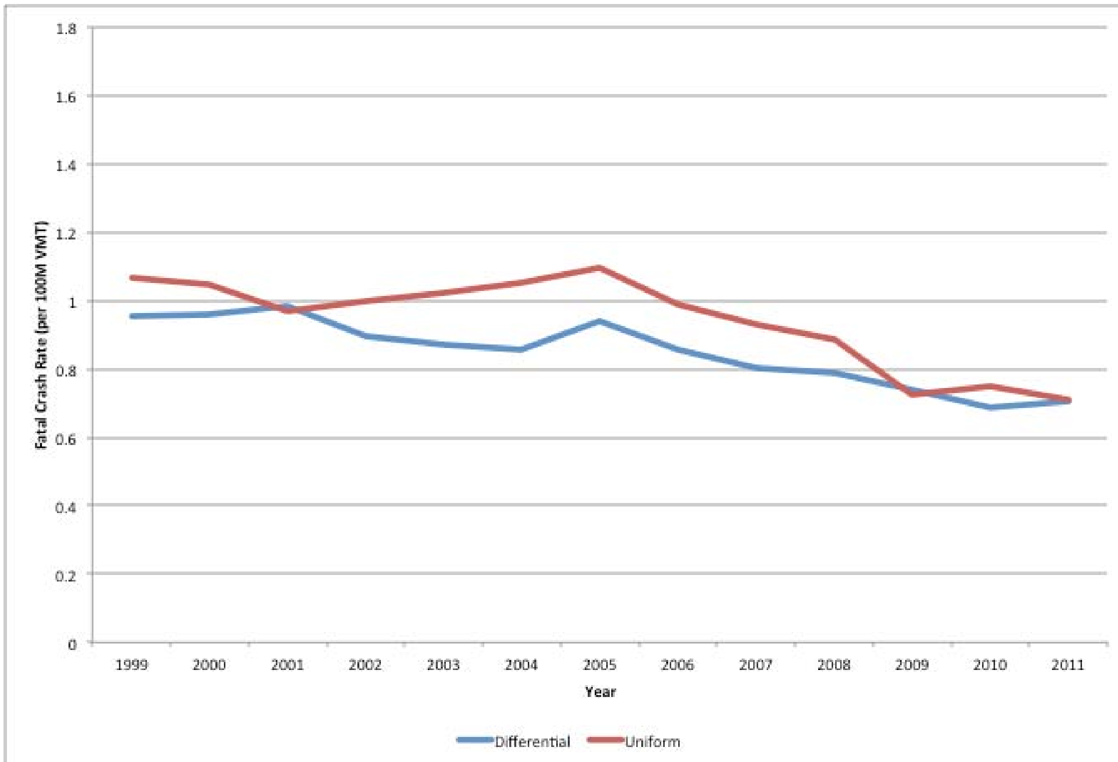


Figure 20. Annual Rural Interstate Fatality Rates by Truck-/Bus Speed Limit Policy

In order to gain a better understanding of the relationship between traffic fatalities and speed limit policy, the results of a random effects negative binomial regression model are presented in Table 8. This model relates the annual number of rural interstate fatalities in each state to the speed limit policies that were in place at that time while controlling for statewide vehicle-miles of travel (VMT) and other effects (percent trucks, mean temperature, and year). The results from Table 8 include the following:

- Goodness-of-fit statistics – Log-likelihood (LL) values are provided for the general negative binomial model formulation, as well as for the random effects negative binomial model. Higher LL values indicate better model fit and, in each case, the random effects model is shown to provide significantly improved fit (p-value < 0.01). This implies that there are state-specific effects that are not captured by the variables included in the model. These could include state policies related to safety countermeasures (e.g., cable median barrier), geographic differences (e.g., terrain), roadway characteristics (e.g., pavement condition, geometric design policies, etc.), or other data that were not available for all states. This is an important point because the failure to account for the resultant correlation in fatality trends within a state would potentially lead to biased parameter estimates and incorrect inferences. In addition to the LL statistics, McFadden's R-squared is also provided as a basis for comparing model fit.

- Predictor variables – Explanatory variables were retained if they were statistically significant at a 95-percent confidence level. The model results include parameter estimates, standard errors, t-statistics, and p-values for each such variable. When interpreting these results, a positive coefficient indicates that fatalities tended to increase as the related variable was increased. Conversely, variables with negative coefficients experienced fewer fatalities on average.

Table 8. Model Results for Annual Rural Interstate Fatalities

Log-likelihood values at convergence:				McFadden R^2
Negative binomial (NB) model -2362.213				0.804
Random effects NB model -2201.704				0.817
Variable	**Coefficient**	**Std. Error**	**T-stat**	**P-value**
Constant	-4.058	0.475	-8.55	<0.0001
LN (VMT)	0.766	0.044	17.21	<0.0001
Percent Trucks	0.018	0.006	3.13	0.0018
70-mph Maximum Speed (1 if yes; 0 otherwise)	0.270	0.063	4.27	<0.0001
75-80 mph Maximum Speed (1 if yes; 0 otherwise)	0.432	0.079	5.49	<0.0001
Mean Temperature (degrees F)	0.012	0.004	2.81	0.0050
Study Year (1999 as baseline)	-0.034	0.002	-16.90	<0.0001
a (beta distribution parameter)	17.257	4.310	4.00	0.0001
b (beta distribution parameter)	19.373	5.214	3.72	0.0002

In the case of the rural interstates, fatalities were found to consistently increase with the maximum posted passenger car speed limit. The increase in fatalities from 60-65 mph to 70 mph is more pronounced than the increase from 70 to 75 mph, particularly at higher traffic volumes.

In addition to analyzing trends in total traffic fatalities, additional analyses were conducted on truck/bus-involved fatal crashes to ascertain any relationship to speed limit policies. Results of a regression model for these types of crashes are shown in Table 9. The results show that truck/bus fatal crashes also increase with maximum speed limit at similar rates to total fatal crashes. States with a 70-mph maximum limit experienced an increase in truck/bus fatal crashes, which was not statistically significant at a 95-percent confidence level, though it was similar in magnitude to the increase in overall crashes. States with a maximum speed limit of 75 mph or above showed a marked increase, which was statistically significant. Ultimately, the results of this analysis suggest that speed limits play an important role on rural interstates.

Table 9. Model Results for Annual Rural Interstate Truck- and Bus-Involved Fatalities

Log-likelihood values at convergence:				McFadden R^2
Negative binomial (NB) model	-1636.440			0.605
Random effects NB model	-1592.559			0.616
Variable	**Coefficient**	**Std. Error**	**T-stat**	**P-value**
Constant	-7.544	0.597	-12.63	<0.0001
LN (VMT)	1.053	0.069	15.24	<0.0001
Percent Trucks	0.028	0.005	5.09	<0.0001
Differential Speed Limit (1 if yes; 0 otherwise)	-0.230	0.094	-2.44	0.0148
70-mph Maximum Speed (1 if yes; 0 otherwise)	0.158	0.104	1.52	0.1285
75-80 mph Maximum Speed (1 if yes; 0 otherwise)	0.394	0.102	3.87	0.0001
Mean Temperature (degrees F)	0.016	0.008	1.97	0.0488
Study Year (1999 as baseline)	-0.026	0.004	-7.13	<0.0001
a	64.018	21.094	3.03	0.0024
b	34.502	12.764	2.70	0.0069

Table 10 provides additional details regarding the circumstances associated with the rural interstate fatalities among states with similar speed limit policies. The percentages of fatalities by collision type, lighting condition, and work zone status are provided for states based upon maximum rural speed limit and truck/bus speed limit policies..

Table 10. Trends in the Percentage of Rural Interstate Fatalities by Speed Limit Policy

Manner of Collision	Percent of Fatalities by Maximum Speed Limit			Percent of Fatalities by Truck/Bus Speed Limit	
	60-65 mph	**70 mph**	**75+ mph**	**Differential**	**Uniform**
Single-Vehicle	69.4	72.7	78.2	74.1	73.5
Rear-End	16.1	14.7	11.2	13.7	14.0
Head-On/Sideswipe-Opposite Direction	9.6	7.5	7.0	7.4	7.3
Sideswipe-Same Direction	3.2	3.0	1.6	2.5	2.7
Other	1.7	2.1	2.0	2.2	2.6
TOTAL	100.0	100.0	100.0	100.0	100.0

Light Condition	Percent of Fatalities by Maximum Speed Limit			Percent of Fatalities by Truck/Bus Speed Limit	
	60-65 mph	**70 mph**	**75+ mph**	**Differential**	**Uniform**
Daylight	53.9	53.6	56.3	53.7	54.8
Dark	41.5	42.1	38.7	41.3	40.8
Dawn/Dusk	4.4	3.7	4.8	4.1	4.2
Other	0.2	0.5	0.2	0.7	0.2
TOTAL	100.0	100.0	100.0	100.0	100.0

Work Zone	Percent of Fatalities by Maximum Speed Limit			Percent of Fatalities by Truck/Bus Speed Limit	
	60-65 mph	**70 mph**	**75+ mph**	**Differential**	**Uniform**
No	96.2	95.8	96.6	95.3	96.5
Yes	3.8	4.2	3.4	4.7	3.5
TOTAL	100.0	100.0	100.0	100.0	100.0

The fatality trends were generally consistent regardless of speed limit policies with a few exceptions. In states with higher speed limits, there was a significantly higher percentage of single-vehicle crashes (e.g., run-off-the-road). This finding may be reflective of drivers traveling excessively fast in comparison to the design speeds of these roadways. In contrast, states with lower speed limits showed a higher rate of rear-end collisions. This result may also be due to drivers who are traveling at excessive speeds, who then collide with traffic that is moving more slowly in accordance with the lower posted limits. A slightly higher percentage of fatalities occurred under daylight conditions in states with the highest (70+ mph) speed limits. No clear trends emerged with respect to work zone related crashes and maximum speed limit policy. There were also no significant trends that emerged between states with uniform and differential limits.

Analysis Results – Urban Interstate Highways

In contrast to rural interstates, maximum speed limits were not found to have a significant impact on urban interstate fatalities, at least at the aggregate level. Figure 21 shows average urban interstate fatality trends over the same 13-year period (1999 through 2011), aggregated by the maximum urban speed limit. Examining data for all 50 states (and the District of Columbia) appears to indicate that states with a 70 or 75 mph limit have a higher fatality rate than those states with limits of 65 mph or less. However, this result is driven largely by data for the state of Texas. Removal of Texas from the dataset shows a much less pronounced difference, particularly for the period from 2005 through 2011.

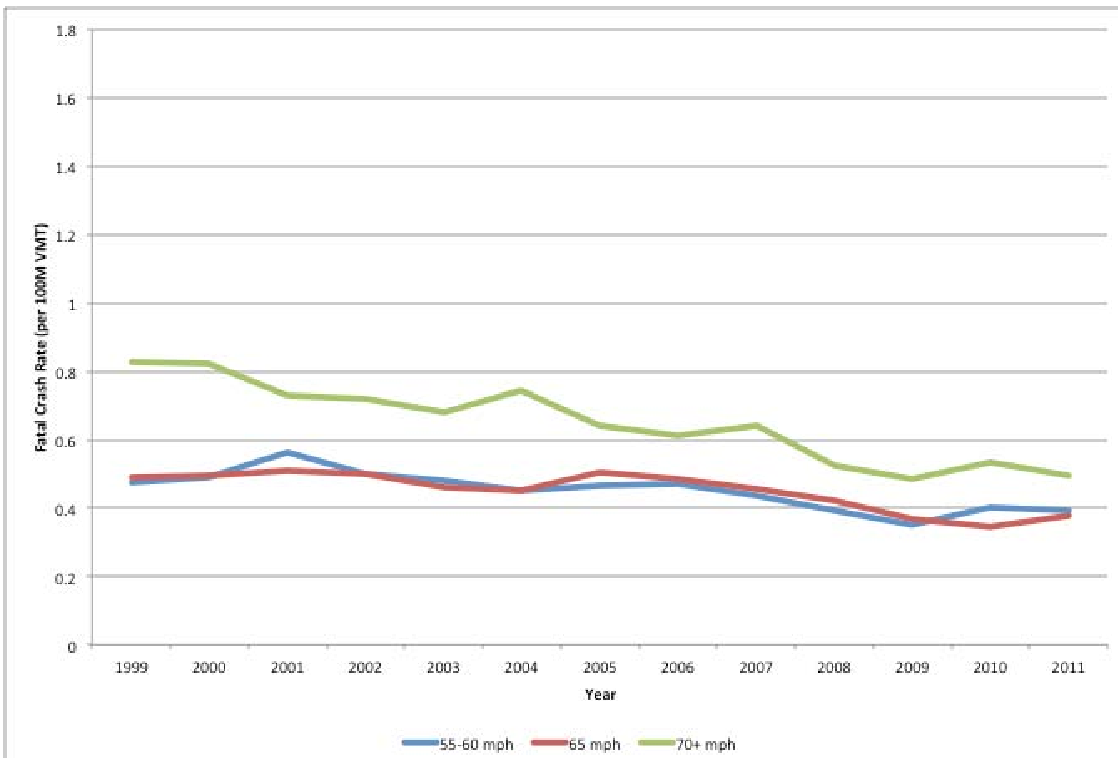


Figure 21a. Urban Fatality Rates including Texas

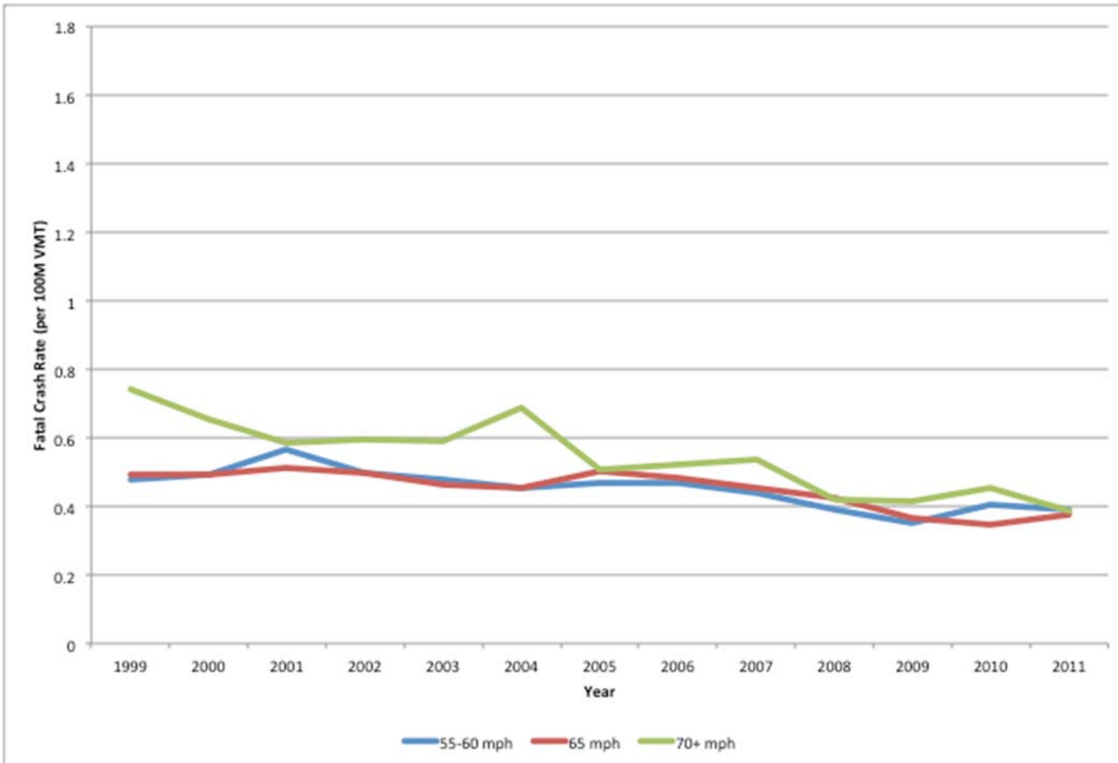


Figure 21b. Urban Fatality Rates excluding Texas

Figure 21. Annual Urban Interstate Fatality Rates by Maximum Speed Limit

Figure 22 provides a summary of fatality trends with respect to the truck/bus speed limit policies that were in place in each state. In contrast to the rural facilities, the aggregate data show states with differential limits to exhibit slightly higher fatality rates over the study period. However, as in the case of maximum speed limits, this difference is driven almost entirely by the state of Texas. Removing Texas from the sample results in fatality rates that are virtually indistinguishable between those states with uniform and differential limits.

Table 11 provides the results of the random effects negative binomial regression model for urban interstates. Consistent with the aggregate trends shown in Figures 21 and 22, maximum urban speed limits were not found to exhibit significant differences in fatality trends. There was also no significant difference in fatality rates between those states with uniform and differential limits for trucks and buses. This was true regardless of whether Texas was included in the sample.

Table 11. Model Results for Annual Urban Interstate Fatalities

Log-likelihood values at convergence:				McFadden R^2
Negative binomial (NB) model -2339.849				0.884
Random effects NB model -2167.750				0.893
Variable	**Coefficient**	**Std. Error**	**T-stat**	**P-value**
Constant	-6.078	0.332	-18.32	<0.0001
LN(VMT)	0.880	0.029	30.15	<0.0001
Percent Trucks	0.016	0.006	2.65	0.0080
Mean Temperature (degrees F)	0.030	0.004	7.38	<0.0001
Primary Belt Use Law (1 if yes; 0 otherwise)	-0.225	0.098	-2.30	0.0216
Study Year (1999 as baseline)	-0.028	0.002	-13.33	<0.0001
a	16.621	5.275	3.15	0.0016
b	20.543	6.262	3.28	0.0010

It is important to note that aggregation at the statewide level may potentially mask underlying trends in the data, particularly as it relates to maximum speed limits in an urban setting. Several states, including Michigan, may selectively post speed limits that are significantly below the urban maximum. For example, in the state of Michigan, approximately 8 percent of urban freeways (those freeways classified as urban interstate or urban other freeway under the old National Functional Classification system) are posted at 55 mph for all vehicles. This issue cannot be addressed with the national dataset given limitations as to the fidelity of the data.

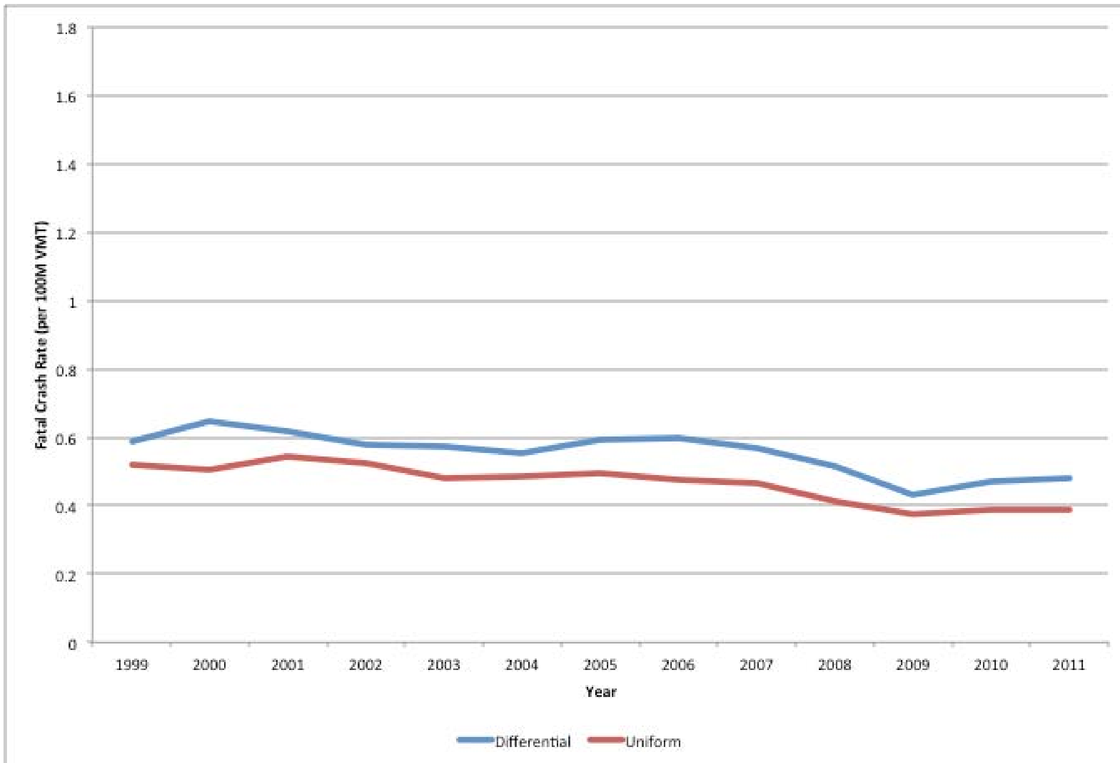


Figure 22a. Urban Fatality Rates including Texas

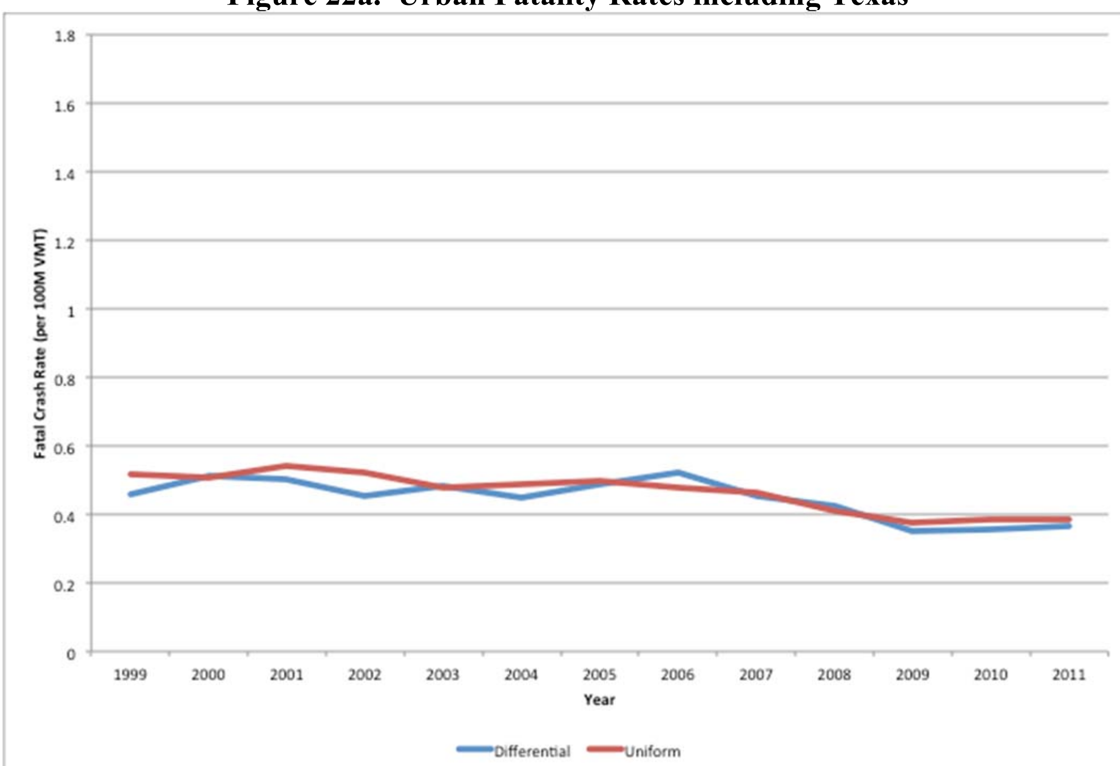


Figure 22b. Urban Fatality Rates excluding Texas

Figure 22. Annual Urban Interstate Fatality Rates by Truck-/Bus Speed Limit Policy

Similar to the rural interstate analysis, fatalities were found to increase with vehicle-miles of travel and mean temperature. There was also a general decline in fatalities during the study period (as indicated by the Study Year variable). States with primary belt use laws (allowing for vehicles to be pulled over solely for the non-use of a seat belt) were shown to experience fewer fatalities.

Table 12 provides a summary of the urban interstate fatality data by manner of collision, lighting condition, and presence/absence of a work zone. Marginal differences were observed with respect to collision type.

Table 12. Trends in the Percentage of Urban Interstate Fatalities by Speed Limit Policy

	Percent of Fatalities by Maximum Speed Limit			**Percent of Fatalities by Truck/Bus Speed Limit**	
Manner of Collision	**50-60 mph**	**65 mph**	**70+ mph**	**Differential**	**Uniform**
Single-Vehicle	68.2	69.0	69.9	71.5	69.1
Rear-End	17.9	18.1	17.0	18.0	18.0
Head-On/Sideswipe-Opposite Direction	7.6	5.9	6.6	4.9	7.2
Sideswipe-Same Direction	4.3	4.8	3.5	4.2	4.4
Other	2.0	2.2	3.1	2.3	2.4
TOTAL	100.0	100.0	100.0	100.0	100.0

	Percent of Fatalities by Maximum Speed Limit			**Percent of Fatalities by Truck/Bus Speed Limit**	
Light Condition	**50-60 mph**	**65 mph**	**70+ mph**	**Differential**	**Uniform**
Daylight	41.4	40.6	37.2	34.5	42.3
Dark	54.8	55.5	59.4	62.3	53.7
Dawn/Dusk	3.2	3.6	3.0	2.9	3.6
Other	0.6	0.3	0.4	0.3	0.4
TOTAL	100.0	100.0	100.0	100.0	100.0

	Percent of Fatalities by Maximum Speed Limit			**Percent of Fatalities by Truck/Bus Speed Limit**	
Work Zone	**50-60 mph**	**65 mph**	**70+ mph**	**Differential**	**Uniform**
No	93.7	95.6	93.1	94.9	94.9
Yes	5.5	4.4	6.1	5.1	5.1
TOTAL	99.2	100.0	99.2	100.0	100.0

While maximum speed limit did not show a significant impact, urban interstates were generally found to experience more rear-end collisions and fewer single-vehicle crashes as compared to rural interstates. States with higher urban speed limits showed a higher percentage of crashes under dark conditions, which may be an indication of reduced sight distance and visibility issues under such conditions. No consistent trends were observed with respect to work zone activity between the states.

The largest difference in Table 12 is between states with different truck/bus speed limit policies. States with differential limits were found to experience a significantly higher percentage of fatalities at night (62.3 percent vs. 53.7 percent). Most of this difference is due to the state of Texas, which had a nighttime differential limit in place over the duration of the study period.

Summary of Analyses for Rural and Urban Interstate Highways

Table 13 provides details of the elasticities, or average effects, of those variables that were found to be statistically significant in each of the interstate fatality models. The values shown in the table represent the impacts of each variable on the expected (average) number of traffic fatalities for both rural and urban interstates. As noted previously, states with higher maximum speed limits tended to experience significantly higher numbers of fatalities on rural interstates.

Table 13. Elasticities for Rural and Urban Interstate Fatality Models

Variable	Interstate Class		
	Rural Total	**Rural Truck/Bus**	**Urban Total**
Vehicle-Miles of Travel (millions)	0.8%	1.1%	0.9%
Percent Trucks	1.8%	2.8%	1.6%
70-mph Max Speed (relative to 65 mph)	31.0%	17.1%	-
75+ mph Max Speed (relative to 65 mph)	54.0%	48.3%	-
Differential Limit (relative to Uniform Limit)	-	-20.5%	-
Mean Temperature (degrees F)	1.2%	1.6%	3.0%
Primary Belt Use Law	-	-	-20.1%
Study Year (change per year with 1999 as baseline)	-3.3%	-2.6%	-2.6%

Given the results of these models, it is estimated that increasing the passenger car speed limits of rural freeways from 70 to 75 mph would result in a 17.6 percent increase in traffic fatalities. This increase is significantly less than the 31.0 percent increase in fatalities associated with an increase from 65 mph to 70 mph. This is consistent with expectations as the increases in mean and 85th percentile speeds tended to be smaller at higher limits. That is, vehicle speeds will increase by a larger amount when speed limits are raised from 65 to 70 mph than from 70 to 75 mph. By this same rational, it is estimated that increasing rural speed limits to 80 mph would result in an additional incremental increase in fatalities of approximately 10.0 percent. On average, states with differential speed limits for trucks and buses experienced 20.5 percent fewer truck/bus-involved fatal crashes on rural interstates. No significant differences were observed on urban interstates for any of the speed limit policy variables.

With respect to the other variables of interest, fatalities were consistently higher in states with higher average temperatures. This is likely capturing the effects of some nuances of driving behavior in such states. Prior research has shown fatality rates to be lower in winter months and under adverse weather conditions, which is likely to be attributable to lower travel speeds under such conditions. States with a primary seat belt use law, which allows for motorists to be pulled over and cited solely for non-belt use, exhibited significantly lower fatality rates on urban interstates. While the belt use law variable was not significant in the other three models, this is due in part to the correlation in belt use and year of the study because use rates have been increasing consistently over time.

Several alternate model formulations were evaluated, which included factors such as gasoline cost and mean household income. However, a model including only the temporal variable (i.e., year of analysis minus 1999) provided significantly improved fit and rendered these other variables (e.g., gas cost, belt use, etc.) statistically insignificant. It should also be noted that indicator variables were included to examine whether those states with speed limit changes during the study period exhibited any general fatality trends. However, the fatality rates in these states were not significantly different from those states that did not implement speed limit increases.

ANALYSIS OF MICHIGAN FREEWAY CRASH DATA

The results of the longitudinal analysis of interstate fatality data presented previously revealed some significant trends with respect to state speed limit policies. On rural roadways, fatalities were shown to consistently increase at higher speeds, particularly at 75 mph or above. However, on urban interstates, no significant differences were observed based upon maximum speed limits.

Ultimately, this result warranted further investigation. Several states utilize varying speed limits in urban areas, including Michigan, where an interstate under the urban classification is generally posted at either 70 mph (60 mph for trucks/buses) or 55 mph (all vehicles). As the national analysis of interstate fatalities by state did not allow for a more detailed level of analysis, some potentially significant effects may have been masked due to data aggregation. To address this concern, detailed data for freeway segments in Michigan were examined over the period from 2004 to 2012.

Data were collected for all freeway segments across the state, which were posted at maximum speeds of either 55 mph or 70 mph during this period. These segments were aggregated into three groups:

- Freeways with a uniform 55-mph speed limit
- Urban freeways with a 70-mph speed limit for passenger cars (60-mph for trucks/buses)
- Rural freeways with a 70-mph speed limit for passenger cars (60-mph for trucks/buses)

Summary statistics for these segments are provided in Tables 14 and 15. The urban/rural designation is based upon the old version of the National Functional Classification (NFC) system, which is based upon whether the population of the surrounding geographic area. Table 14 shows the mileage of freeways posted at 70 mph is relatively evenly split between urban (45%) and rural (55%) classifications. However, the urban segments experience roughly double the volume on an annual basis.

Table 14. Average Freeway Directional Mileage and Vehicle-Miles of Travel, 2004 to 2012

Freeway Type	Mileage (directional)	VMT (100M)
55 mph	201	32.381
70 mph (urban)	1,621	169.671
70 mph (rural)	1,967	81.363

Table 15 provides details of the average number of crashes (total, injury, and fatal) over the nine-year study period. However, the urban segments experience roughly twice the volume annually.

Table 15. Average Number of Total, Injury, and Fatal Freeway Crashes, 2004 to 2012

Freeway Type	Total Crashes	Injury Crashes	Fatal Crashes
55 mph	5,159	1,280	17
70 mph (urban)	18,579	3,711	60
70 mph (rural)	8,232	1,301	32

Table 16 provides details of the crash rates, which normalizes for the aforementioned differences in traffic volumes. These data show that crash risk is highest on the 55-mph urban freeways for all injury levels. The total, injury, and fatal crash rates are 49 percent, 97 percent, and 45 percent higher on the 55-mph freeways than the 70-mph facilities on average. Figures 23-25 show that these differences tended to be consistent over the entire study period.

Table 16. Average Crash, Injury, and Fatality Rates on Michigan Freeways, 2004 to 2012

Freeway Type	Total Crash Rate	Injury Crash Rate	Fatal Crash Rate
55 mph	159.31	39.54	0.53
70 mph (urban)	110.15	22.00	0.36
70 mph (rural)	101.18	15.99	0.39
70 mph (average)	107.23	20.04	0.37

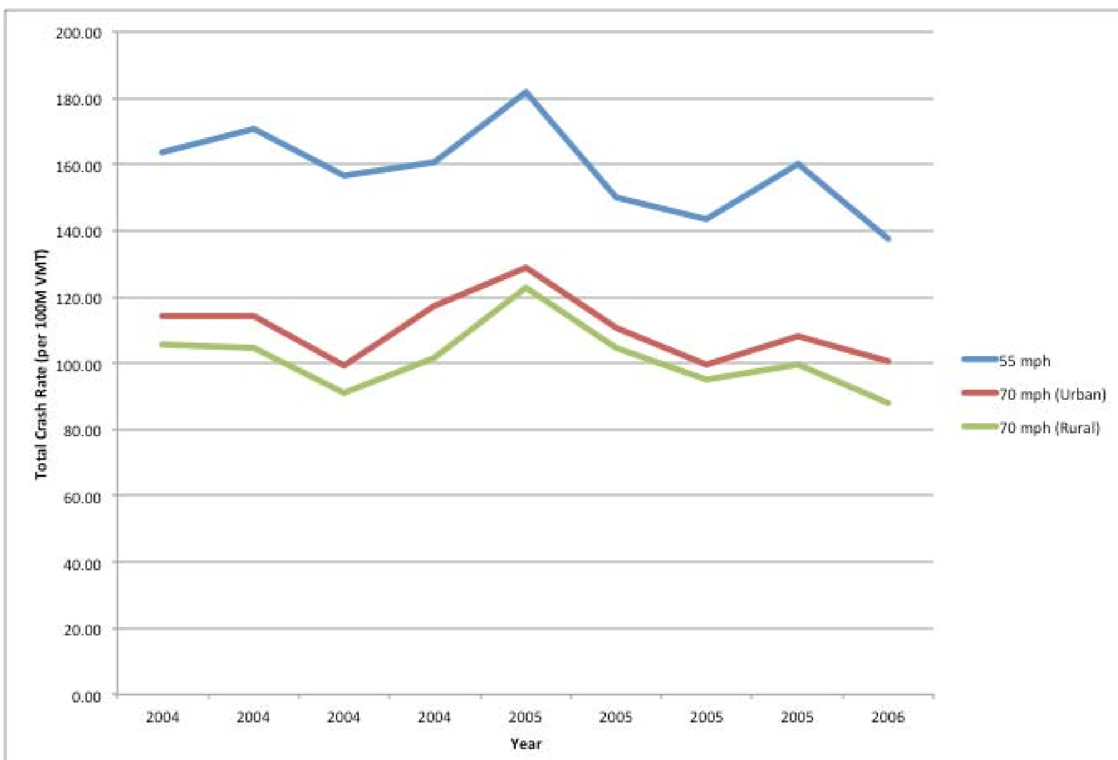


Figure 23. Michigan Annual Total Crash Rates by Freeway Type

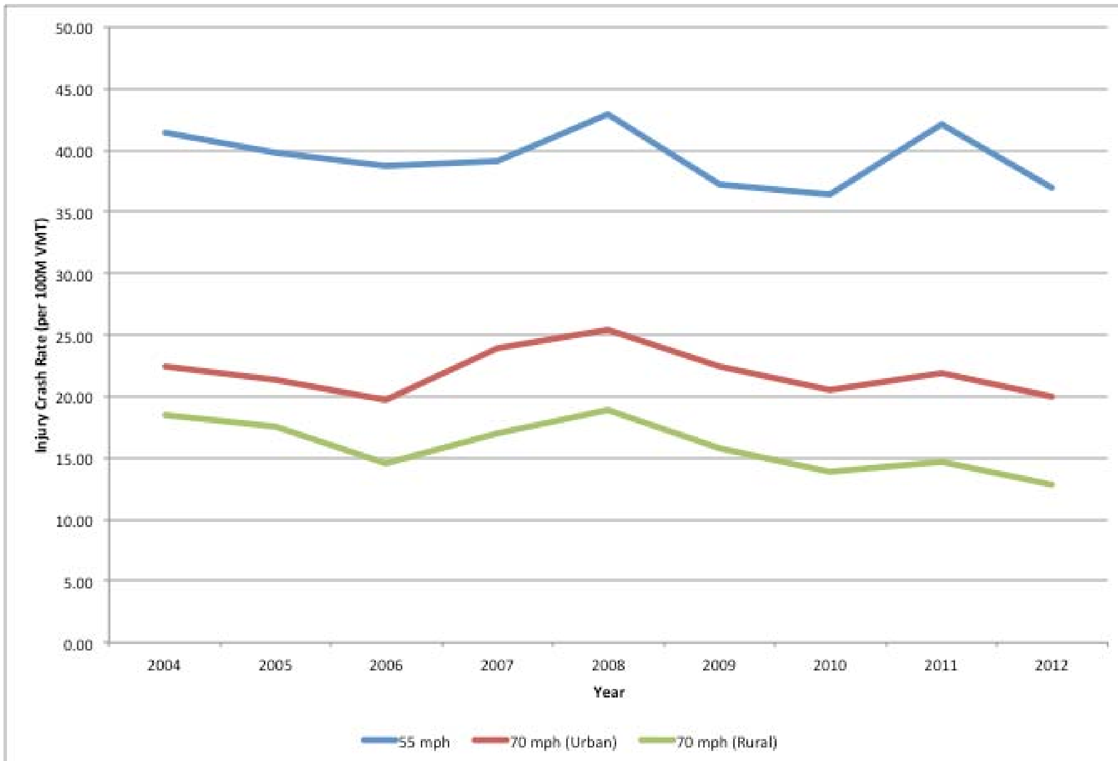


Figure 24. Michigan Annual Injury Crash Rates by Freeway Type

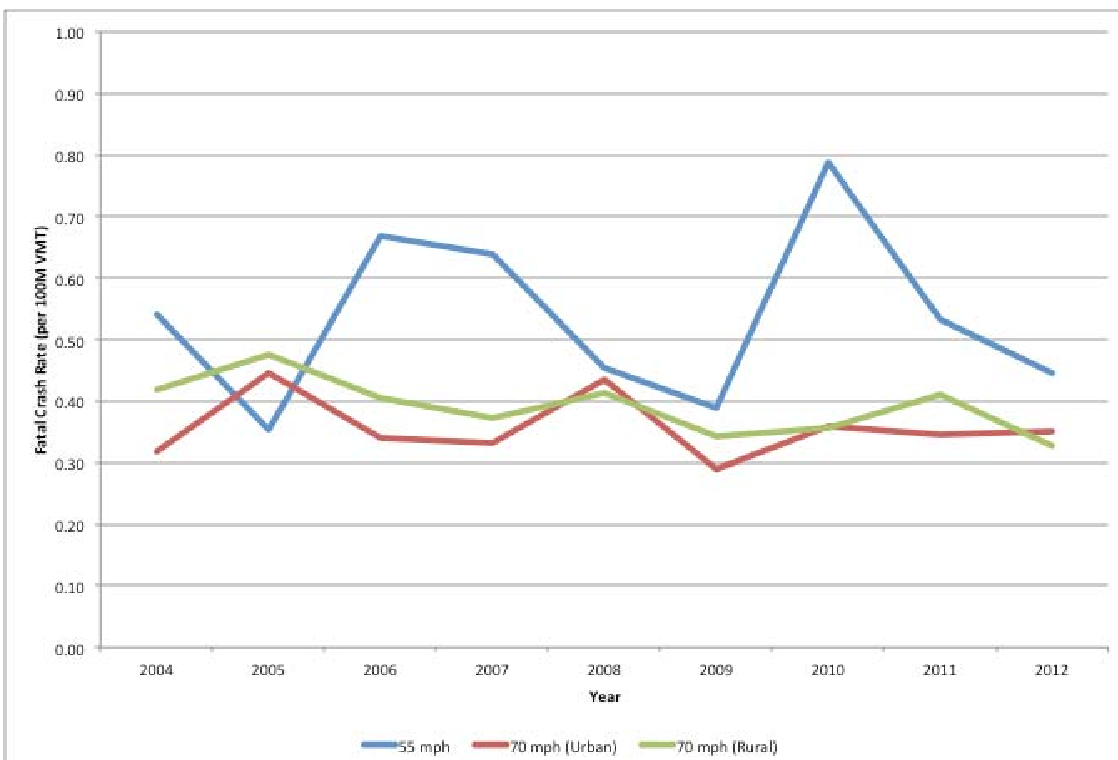


Figure 25. Michigan Annual Fatal Crash Rates by Freeway Type

There are several potential explanations for the higher rates on the 55-mph segments. These segments are generally more urban in nature and include more frequent entry/exit ramps, weaving behavior, and stop-and-go traffic. This likely explains why the urban 70-mph segments exhibit higher crash rates than comparable rural segments.

The urban segments that are posted at 55-mph also tend to be older in nature and have generally been designed for lower speeds, which is one of the principal determinants in establishing speed limits. Despite the fact that these segments have lower design speeds, field speed studies (described further in Chapter 4) show that mean speeds on the 55-mph segments are only 7 mph lower than the 70-mph urban segments and the 85th percentile speeds are only 3-4 mph lower, despite the 15-mph difference in posted limits. Furthermore, the 55-mph urban segments exhibited variations in travel speeds that were significantly higher than those urban segments that were posted at 70-mph.

These data suggest that increasing the speed limits of the 55-mph segments to 70-mph may potentially reduce the rate of total, injury, and fatal crashes. However, it is imperative to note that such increases would also require substantial infrastructure investments in order to bring these 55-mph segments up to the same design standard as the 70-mph segments. In order to investigate this issue further, additional analyses were conducted to assess safety performance at a select group of urban freeways where speed limits were increased during the period from 2004 to 2012.

The passage of Michigan House Bill 5240 (Public Act 85) in 2006 mandated a freeway speed limit of 70 mph for cars and 60 mph for trucks and buses unless it was determined that such speeds were greater than reasonable or safe for a particular section of freeway. The mandate included urban freeways, and consequently led to statewide speed limit increases on several sections of urban freeways that had previously been posted at 55 or 65 mph.

To determine the safety impacts of recent speed limit increases on urban freeways in Michigan, a case-control analysis of traffic crashes was performed. Of particular interest was the impact on total, injury, and fatal crashes associated with increasing the speed limit from 55 mph to either 65 or 70 mph. Increasing the maximum urban freeway speed limit also introduced a differential speed limit between cars and trucks/buses, the latter of which have been capped at 60 mph on freeways since 2006. Thus, it was also important to investigate the impacts of the urban freeway speed limit increase on truck/bus crashes.

It was first necessary to identify the sample of urban segments where speed limits were increased from 55 mph for all vehicles to 65 mph or 70 mph for passenger vehicles (and 60 mph for trucks/buses), as well as a sample of similar comparison segments where 70 mph/60 mph speed limits were already in place. These segments were identified as follows:

- Segments with an Increase: Urban freeway locations where the maximum speed limit was increased from 55 mph to either 65 or 70 mph between 2007 and 2010. Note that the truck/bus speed limit was capped at 60 mph on freeways after the change.
- Comparison Segments: Urban freeway locations immediately adjacent to the treatment segments with a maximum speed limit of 65 or 70 mph from 2004 to 2012. Note that the truck/bus speed limit was increased from 55 to 60 mph on freeways statewide in 2006.

Segments where speed limits were increased were identified through a review of the 2004 to 2012 MDOT sufficiency files. The year in which the speed limit change occurred for each such segment, along with the boundaries corresponding to each speed limit increase, was validated through a review of traffic crash reports and archived media reports. The boundaries of each control segment were determined by identifying the immediately adjacent segment(s) that most closely matched the general roadway alignment and surrounding land use, terminating prior to any freeway-to-freeway interchanges. Segments were excluded from the evaluation altogether if reconstruction or other major modification (i.e., lane addition) was performed at approximately the same time as the speed limit increase, as these modifications would likely affect crash frequencies. Ultimately, a total of eight suitable segments were identified where limits were increased, covering 22.72 centerline miles, which were paired with 40.84 centerline miles of adjacent control segments. Table 17 provides further details of the freeway segments utilized in the evaluation.

Table 17. Segment Information for Urban Freeway Crash Analysis

Roadway	Segment Boundaries	Length (miles)	Year of Speed Limit Increase	Speed Limit Before/After Increase
US-127, Lansing	I-496 to M-43	1.44	2007	55 / 70
	M-43 to Clinton County Line	1.93		70 / 70
I-496, Lansing	Lansing Rd. to Mt. Hope Rd.	4.80	2007	55 / 70
	Waverly to Lansing; I-96 to Mt. Hope	3.63		70 / 70
I-196, Grand	M-45 to US-131	1.56	2010	55 / 65
	44th St. to M-45	7.57		70 / 70
US-131, Grand	M-11 to I-196	4.66	2010	55 / 70
	M-6 to M-11	4.49		70 / 70
M-14, Ann Arbor	Business US-23 to US-23	1.71	2010	55 / 65
	I-94 to Business US-23	3.66		70 / 70
I-94, Jackson	US-127W to Elm Ave.	2.22	2008	55 / 70
	M-60 to US-127W; Elm to US-127E	3.92		70 / 70
M-20/US-10, Midland	M-20: Saginaw Rd. to US-10	2.55	2007	55 / 70
	US-10: Stark Rd. to M-20	8.75		70 / 70
I-75, Southwest	W. Outer Dr. to Springwells Ave.	3.78	2009	55 / 70
	US-24 Connector to W. Outer Dr.	6.89		70* / 70

*Speed limit was increased from 65 to 70 mph in 2005

Annual crash data were obtained from the Michigan crash database for each segment. As the speed limit increase occurred at different times for various segments, data from 2005 and 2006 were utilized for the before period for all segments, while 2011 and 2012 were utilized as the after period. The annual vehicle miles traveled (VMT) were computed for each segment annually using the annual average daily traffic (AADT) volume, in addition to the segment length provided in the sufficiency file. The site-by-site crash data summary statistics are provided in Table 18. The total crashes during the before and after periods are displayed in Figure 26 for both segment types. Aggregate crash rates were computed both before and after the period of speed limit increase for both the study segments (where limits were increased) and the control segments. These values are displayed in Table 19 along with the percent change in crash rate after the speed limit was increased.

Table 18. Urban Freeway Crashes Before and After Speed Limit Increase, by Site

Roadway	Section	Period	Total	Injury	Fatal	Truck/Bus	VMT
I-496/US-127, Lansing	Increase	Before	417	96	1	24	275,214,445
		After	532	109	2	19	260,577,050
	Control	Before	366	70	1	23	209,144,234
		After	307	63	1	10	188,232,839
I-196, Grand Rapids	Increase	Before	256	58	1	12	55,353,984
		After	258	61	1	15	78,985,854
	Control	Before	592	107	3	22	289,460,106
		After	443	92	3	12	287,264,281
US-131, Grand Rapids	Increase	Before	867	200	1	75	338,625,784
		After	947	212	0	36	349,873,917
	Control	Before	333	77	1	29	240,000,542
		After	282	63	0	22	271,020,385
M-14, Ann Arbor	Increase	Before	149	30	0	18	70,397,261
		After	185	38	0	16	69,831,947
	Control	Before	96	15	0	8	91,246,224
		After	106	21	0	7	89,425,481
I-94, Jackson	Increase	Before	113	23	0	32	106,043,779
		After	151	21	0	29	98,484,209
	Control	Before	184	32	0	29	154,346,382
		After	145	25	0	14	144,376,298
M-20/US-10, Midland	Increase	Before	37	4	0	3	27,365,466
		After	52	10	0	1	29,809,086
	Control	Before	103	12	0	4	123,058,647
		After	109	18	1	2	115,053,084
I-75, SW Detroit	Increase	Before	405	91	3	102	299,996,019
		After	420	112	0	80	261,397,451
	Control	Before	516	134	2	123	507,164,215
		After	493	119	3	96	402,481,184
TOTAL	Increase	Before	2244	502	6	266	1,172,996,738
		After	2545	563	3	196	1,148,959,514
	Control	Before	2190	447	7	238	1,614,420,350
		After	1885	401	8	163	1,497,853,552

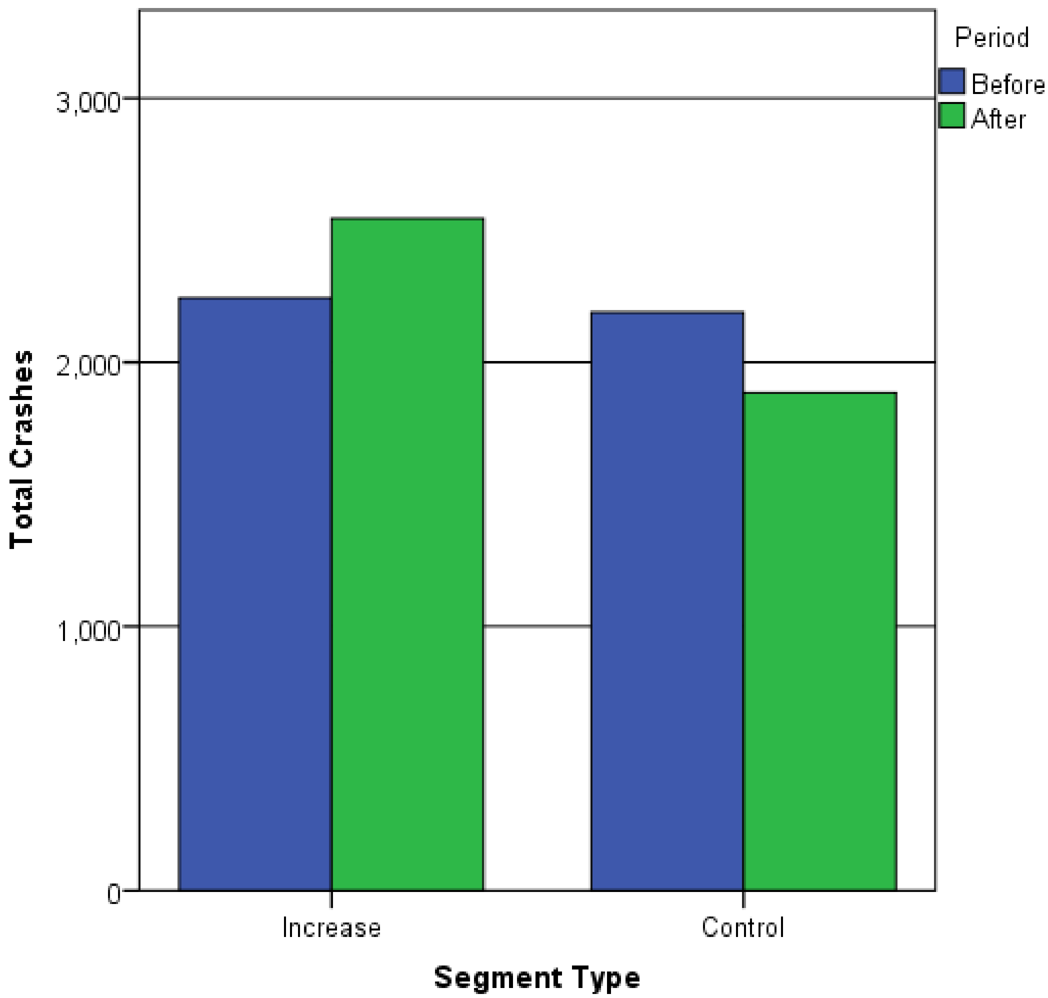


Figure 26. Total Crashes by Period and Segment Type

Table 19. Aggregate Urban Freeway Crash Rates Before and After Speed Limit Increase

Crash Type	Section	Rate Before	Rate After	Change	Percent Change
Total	Increase	191.30	221.50	30.20	15.8%
	Control	135.65	125.85	-9.81	-7.2%
Injury	Increase	42.80	49.00	6.20	14.5%
	Control	27.69	26.77	-0.92	-3.3%
Fatal	Increase	0.51	0.26	-0.25	-49.0%
	Control	0.43	0.53	0.10	23.2%
Truck/Bus	Increase	22.68	17.06	-5.62	-24.8%
	Control	14.74	10.88	-3.86	-26.2%

Note: Crash rates represent crashes per 100 million VMT.

Table 19 presents several important findings. First, the rates for total and injury crashes increased by 15.8 percent and 14.5 percent, respectively, following the speed limit increases at these seven study sites. However, total and injury crash rates decreased by 7.2 percent and 3.3 percent, respectively, at the control segments during the same period. Thus, the impact of the speed limit increases on total and injury crashes is even greater when accounting for the decrease in crashes at the control segments over the same period.

In contrast, fatal crash rates decreased by 49.0 percent at the treatment segments and increased by 23.2 percent at the comparison segments. However, these results must be viewed with caution due to very small samples of fatal crashes. Truck and bus crashes were found to decrease at both the treatment and comparison segments, by 24.8 percent and 26.2 percent, respectively, resulting in a negligible net change.

To confirm the statistical validity of the crash rates presented in Table 19, the annual crash data for both segment types were analyzed using negative binomial regression models. The results of the model for total crashes and injury crashes are displayed in Table 20. For the total crash models, the estimates for the "Period" variable confirm that crashes at the treatment segments increased after the speed limit was increased, while the comparison segments showed a decrease in total crashes during the same period. Compared to total crashes, the injury crash models showed slightly different results, as the estimates for "Period" show a marginal increase in injury crashes at the treatment segments after the speed limit was increased, while the comparison segments showed only a small decrease in injury crashes during the same period. Models were also generated for fatal crashes and truck/bus crashes. Although fatal crash occurrence decreased at the treatment segments and increased at the comparison segments, these changes were not found to be significant due to the small sample sizes. Similarly, comparison of the changes in truck/bus crashes between the treatment and comparison segments found no significant difference between the types of segments.

Table 20. Regression Model Results for Annual and Injury Crashes at Segments

	Segment	Variable	Parameter Estimate	Standard Error	P-value
TOTAL CRASHES	Increase	Intercept	-8.389	0.8328	<0.001
		Ln(AADT)	1.106	0.0798	<0.001
		Ln(Length)	0.830	0.0596	<0.001
		Period (0=Before, 1=After)	0.130	0.0744	0.080
	Control	Intercept	-7.158	0.7016	<0.001
		Ln(AADT)	0.959	0.0684	<0.001
		Ln(Length)	0.924	0.0667	<0.001
		Period (0=Before, 1=After)	-0.112	0.0609	0.067
INJURY CRASHES	Increase	Intercept	-10.817	1.2657	<0.001
		Ln(AADT)	1.194	0.1205	<0.001
		Ln(Length)	0.816	0.0861	<0.001
		Period (0=Before, 1=After)	0.105	0.0988	0.289
	Control	Intercept	-12.523	1.1491	<0.001
		Ln(AADT)	1.322	0.1107	<0.001
		Ln(Length)	1.034	0.1136	<0.001
		Period (0=Before, 1=After)	-0.030	0.0888	0.734

Ultimately, these results suggest that the higher crash, injury, and fatality rates on the 55-mph freeway segments is likely a reflection of the geometric characteristics and lower design standards of such segments. These findings reinforce the notion that additional investments would be required to realize the lower crash rates shown by the broader population of freeway segments posted at 70/60 mph. These investments would include reconstructing existing horizontal and vertical alignments to satisfy minimum curve radius and stopping sight distance requirements, in addition to purchasing additional right-of-way. Further discussion of the anticipated economic impacts is presented in Chapter 5, which examines the costs and benefits associated with increasing the existing speed limits for other facility types, as well.

CHAPTER 4:

ANALYSIS OF FIELD SPEED DATA

While the fatality analysis presented in the preceding chapter provides details of fatality trends at the national level, a related concern is how speed limit increases may affect travel speeds. The principal speed measures that have historically been associated with traffic safety are the mean speed, 85th percentile speed, and speed variance. Prior research has sought to relate these measures to speed limit policies while controlling for the effects of roadway geometry, traffic volumes, and other factors. One of the main objectives of this project was to examine the travel speeds of passenger cars, trucks, and buses in states with differing speed limits, as well as to determine the effects of differential vs. universal speed limits on travel speeds. Passenger vehicle and truck/bus spot-speed data were collected from Michigan, as well as the neighboring states of Ohio and Indiana. Collecting data from these three states proved advantageous for several reasons:

- Ohio and Indiana each share common freeways with Michigan, allowing for an examination of how truck/bus and overall speeds change while controlling for similar driving populations.
- Ohio has a uniform speed limit, which will allow for an assessment of whether speed variance is greater in comparison to differential states such as Michigan and Indiana.
- Indiana's differential speed limit is 5 mph lower for trucks/buses than passenger vehicles whereas Michigan's differential is 10 mph. Consequently, this study design will also allow for a determination of how mean speed and speed variance differ with respect to the magnitude of the differential.

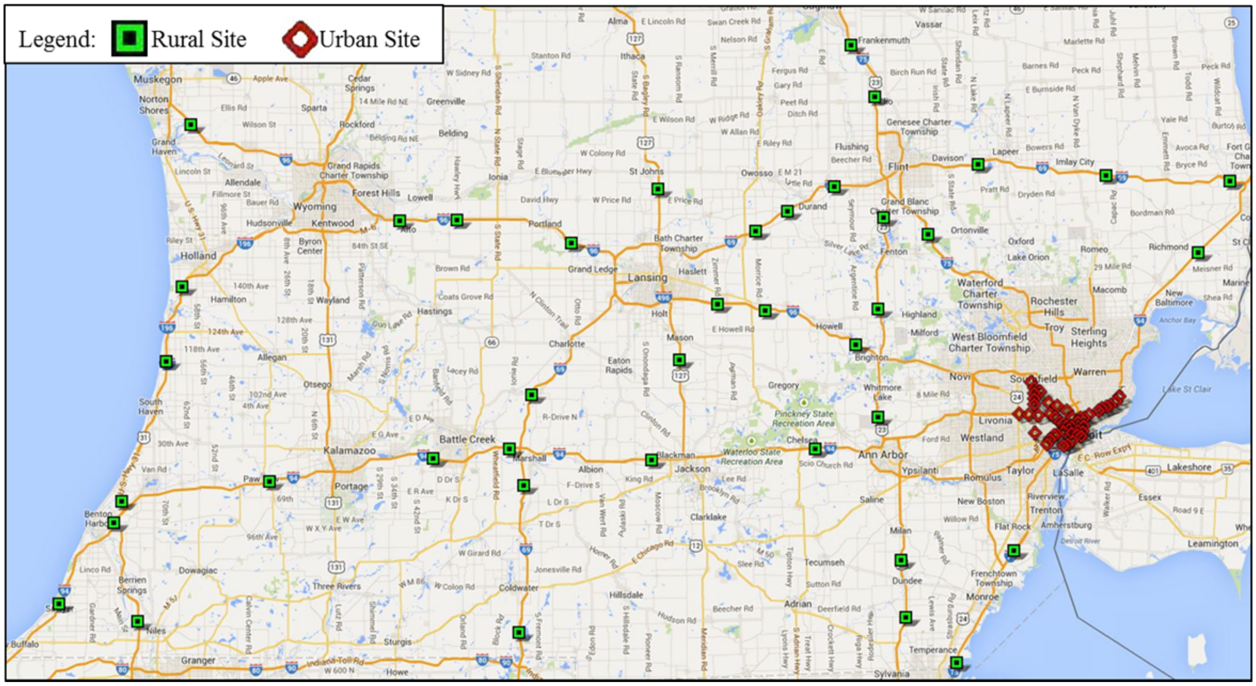
DATA COLLECTION

The full-scale data collection effort took place during the summer/fall of 2013 with rural speed data being collected from August through September of 2013, and urban speed data being collected from October through November of 2013. Data collectors would arrive at the pre-selected overpass of a given freeway and inspect the freeway for items that may affect speeds such as construction, roadway conditions, curves, or police presence. If the section of freeway was found to be inadequate, the site would be replaced with another site from a list of potential back-up sites. Speeds were recorded at appropriate sites from various overpasses on the freeway as vehicles traveled away from the overpass. This was done in an attempt to avoid affecting the speed of the vehicles, as their speed would likely be influenced if they saw data collectors with radar equipment. Video cameras were set up in order to record a 10-minute volume in each direction. Speeds were recorded onto paper either by the radar-gun operator or by an assistant. The device used for data was a “Pro Radar II” infrared lidar system, which was plugged in to an external battery pack for increased mobility.

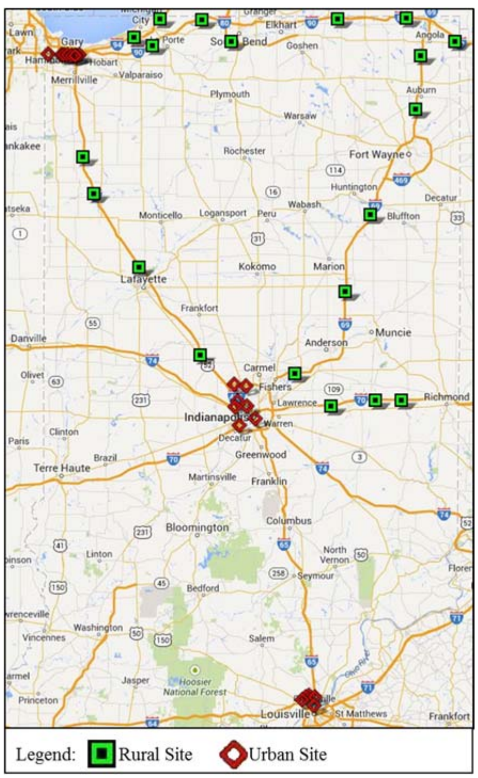
In order to ensure such representativeness, sites were selected from among candidate freeway segments on the basis of volume data. Sites were selected along flat, tangent segments to reduce the influence of geometric characteristics (e.g., horizontal and vertical alignment). Once the speed data were collected, they were aggregated and appropriate sample statistics (e.g., mean speed, 85^{th} percentile speed, and speed variance) were calculated.

Urban and rural speed data were each collected at 20 sites in Indiana, 20 sites in Ohio, and 40 sites in Michigan; totaling 80 sites of rural speeds and 80 sites of urban speeds. Maps showing the data collection site locations for Michigan, Indiana, and Ohio can be found in Figure 27. At each respective site, data were collected in both directions of freeway. The speeds of 100 passenger vehicles and 50 trucks and buses were collected per direction per site. This totals 8,000 passenger vehicles and 4,000 trucks and buses per freeway setting in Michigan and 4,000 passenger vehicles and 2,000 trucks and buses per freeway setting in Indiana and Ohio. If local lanes, as well as express lanes, were present on the freeway, 50 total vehicle speeds were also collected on the local portion of the freeway regardless of vehicle type. It should be noted that speed data were collected during free-flow conditions only.

Once the speed data were collected at all locations, they were aggregated and sample statistics were calculated for each site including mean speed, 85^{th} percentile speed, and speed standard deviation separately for passenger vehicles, trucks/buses, and all vehicles combined. Additionally, the percent of vehicles that were traveling at 5 mph and 10 mph over the speed limit at a specific site were calculated. The summary of the spot-speed data for Michigan, Indiana, and Ohio can be found in Appendix Tables 37, 38, and 39, respectively.



Michigan



Indiana **Ohio**

Figure 27. Speed Data Collection Sites

Figures 28 through 33 display graphically the changes in mean and 85th percentiles speeds for both passenger vehicles and trucks/buses at borders where there are changes in speed limits (both within Michigan jurisdictions and at state borders with Indiana or Ohio). A summary of the key inferences from these figures are as follows:

- Figures 28, 29, and 30 show segments of interstates I-75, I-94, and I-96, respectively, in Michigan which pass through the city of Detroit (a major urban area). These interstates have posted speed limits of 55 mph for all vehicles through the city of Detroit, but have higher variable speed limits outside of the city (70 mph for passenger vehicles and 60 mph for trucks/buses). For both I-75 and I-94, there are dramatic reductions in both mean and 85th percentile speeds for all vehicles as they enter Detroit (in fact, the mean speed for trucks/buses actually drops below 55 mph at one point in Detroit on I-94, which is most likely an artifact of the high interchange density in this area). The speeds on I-96 near Detroit exhibit the same general trends; however the speed reductions in Detroit are not as pronounced for I-96 as they are for I-75 and I-94, which may be due to differences in geometrics between the freeways.

- Figures 31 and 32 show segments of I-75 which extend over the Michigan-Ohio border, and Figure 33 shows a segment of I-69 which passes the Michigan-Indiana border. An interesting trend found in all three figures (as well as Figures 28 through 30) is that there is less variance between the mean speeds and 85th percentile speeds for both passenger vehicles and trucks when the maximum speed limit is 70 mph. This indicates that when speed limits are reduced to 55 mph through urban areas, there are a number of motorists that will continue travelling well above the 55 mph speed limit.

- One interesting finding when comparing Figures 28 and 31 is that all vehicles (especially trucks) tended to travel much faster through the urban 55 mph speed limit zone in Toledo, OH than the 55 mph zone in Detroit, MI. This may be due to differing geometries or different enforcement policies which may affect driver behavior.

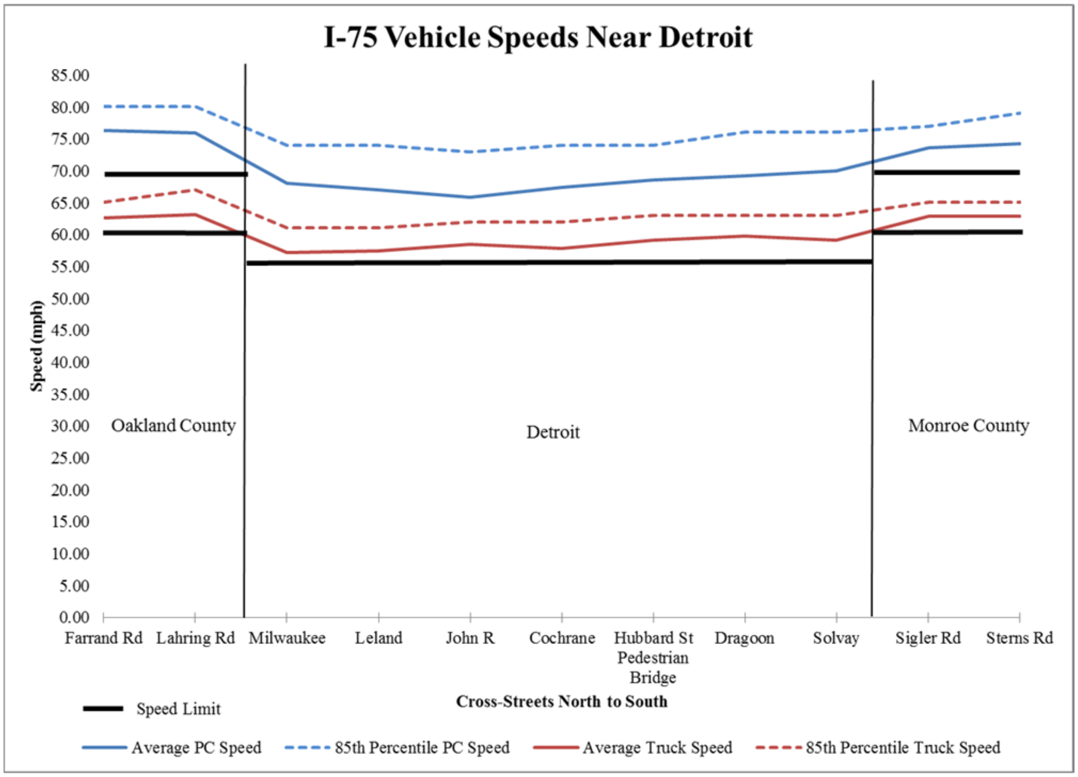


Figure 28. Speed Differentials Entering Detroit, Michigan along I-75

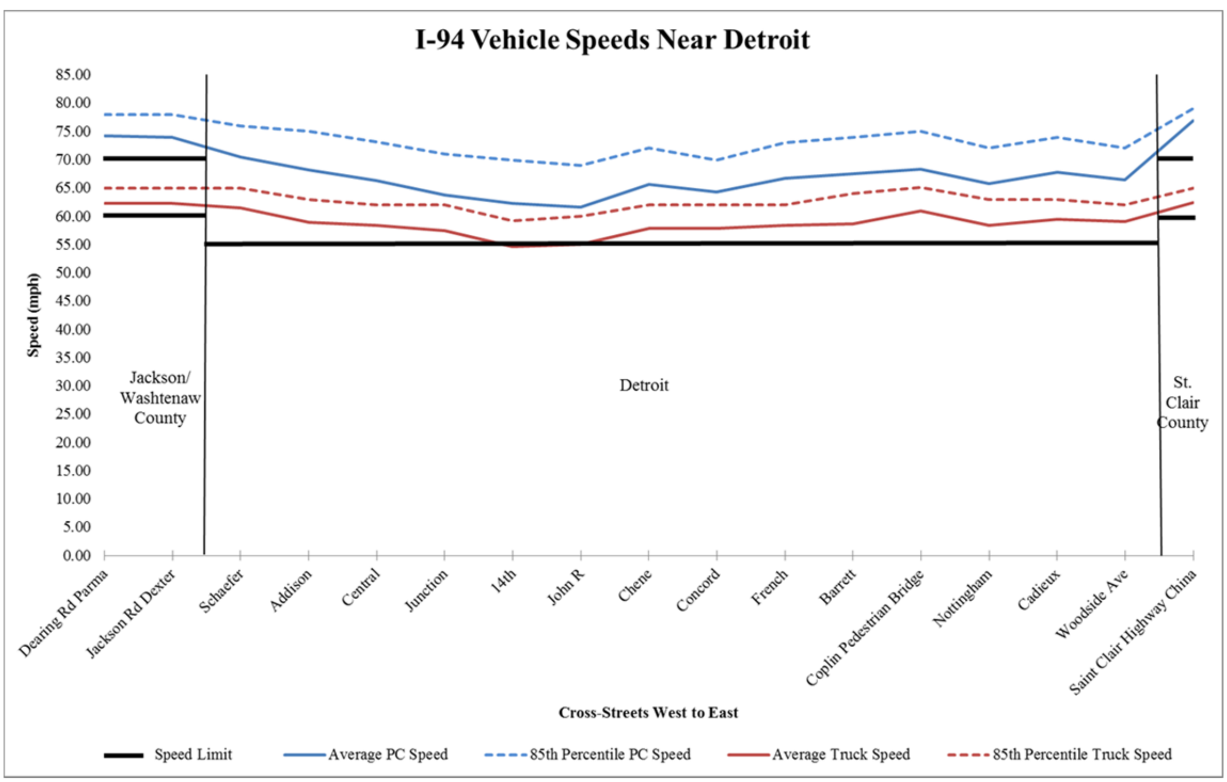


Figure 29. Speed Differentials Entering Detroit, Michigan along I-94

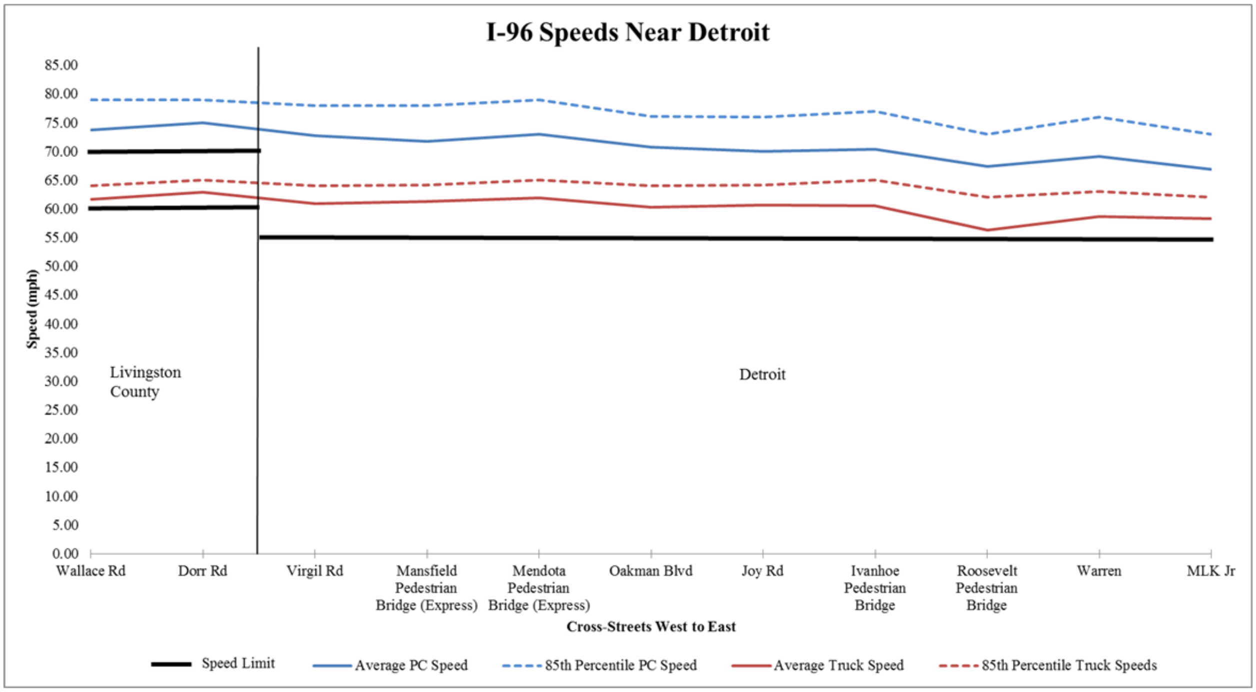


Figure 30. Speed Differentials Entering Detroit, Michigan along I-96

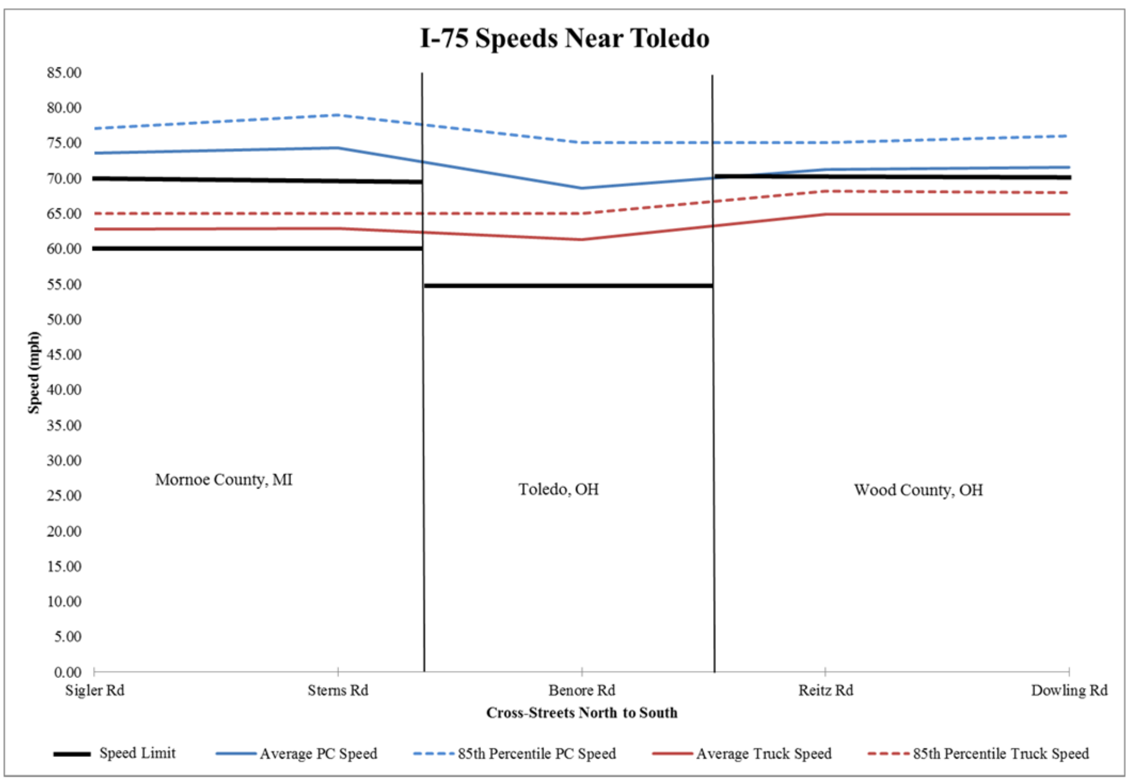


Figure 31. Speed Differentials Entering Toledo, Ohio along I-75

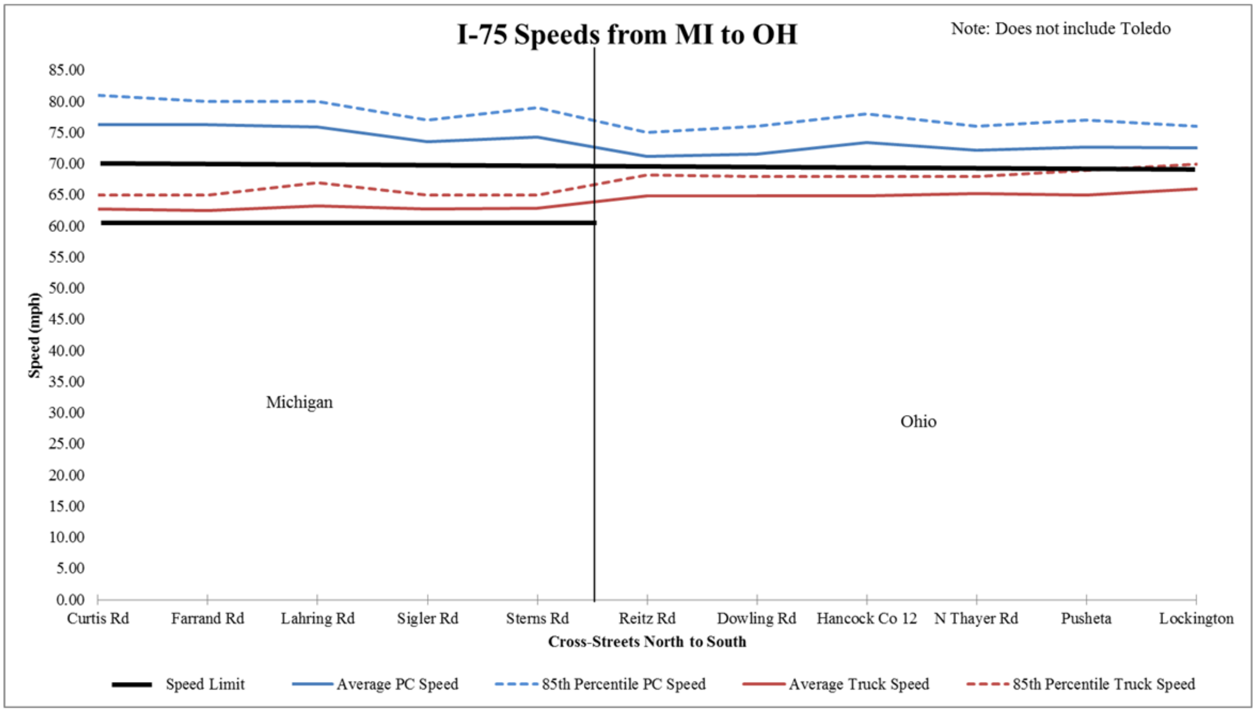


Figure 32. Speed Differentials between Michigan and Ohio

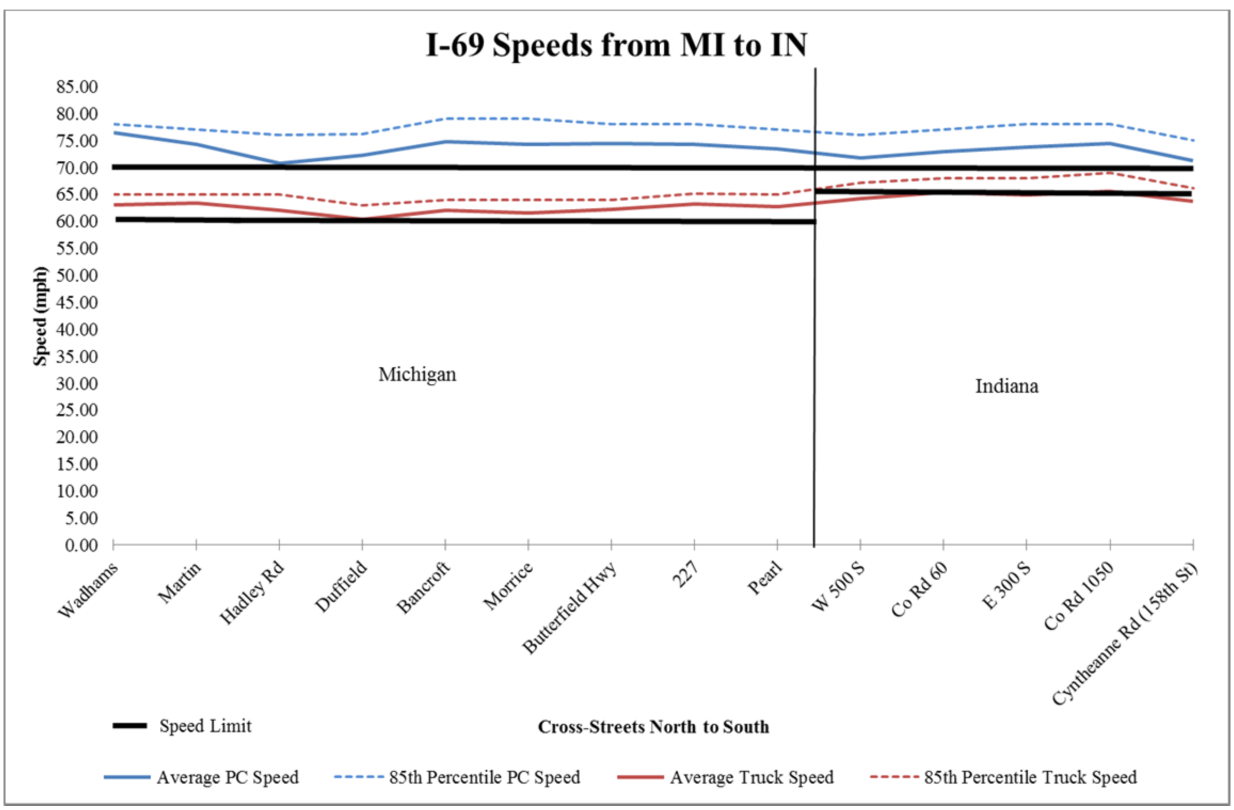


Figure 33. Speed Differentials between Michigan and Indiana

STATISTICAL METHODS

As noted previously, it is important to recognize that a speed limit change may affect not only mean and 85th percentile speeds, but also the standard deviation (and variance) of speeds. This, in turn, could result in substantive impacts on the overall safety of the highway. Consequently, the focus of the speed data analysis was to determine the effects of speed limit policies on each of the three performance measures noted above (mean speed, 85th percentile speed, and standard deviation of speeds).

The typical approach to analyze such speed data has been to estimate separate models for mean speed, 85th percentile speed, and speed variance. However, this approach is potentially problematic because these measures are endogenous (i.e., mean/85th percentile speeds are a function of speed variance and vice versa). Failure to account for this fact may result in biased or inconsistent estimates for standard linear regression models. To circumvent these issues, appropriate statistical analysis methods include the use of seemingly unrelated regression equations (SURE) or three-stage least squares (3SLS). Such methods allow for an identification of how speed limit policies and other variables simultaneously affect mean/85th percentile speeds and speed variance, as well as how these speed variables affect one another. There are several recent examples of these types of analyses in the research literature. A study by Boyle and Mannering [*136*] assessed the mean and standard deviation of speeds over one-kilometer sections of Interstate-90 in Washington State using 3SLS. The results showed that, for individual drivers, increases in the standard deviation of speed tended to decrease mean speeds and vice versa. In other work, Miller et al. [*137*] used SURE to examine the mean speed and standard deviation of speed at nighttime work zones in Indiana. Mean speeds and standard deviations were affected by a variety of roadway geometry and work zone characteristics.

For the purposes of this study, seemingly unrelated regression equations (SURE) were estimated using the field-collected spot-speed data from Michigan, Indiana, and Ohio. This analysis was focused on addressing the following questions of interest:

1. On freeways with the same maximum limit, how do speeds vary among states with uniform speed limits and differential speed limits?
2. How do truck/bus and passenger vehicle speeds differ from one another?

3. What is the relationship between mean speed and speed variance for passenger vehicles, as well as trucks and buses?

Seemingly unrelated regression equations (SURE) provide improved efficiency as compared to ordinary least squares (OLS) and are able to account for the indirect relationship between mean speed, 85th percentile speed, and speed variance. The SURE take the form of the following equations:

$$ms_i = \beta_{1i}\mathbf{X} + \varepsilon_{1i} \tag{5}$$

$$s85_i = \beta_{2i}\mathbf{X} + \varepsilon_{2i} \tag{6}$$

$$sd_i = \beta_{3i}\mathbf{X} + \varepsilon_{3i} \tag{7}$$

where: ms_i is the spot mean speed (in mi/h) at location *i*; $s85_i$ is measured 85th percentile at location *i* (in mi/h); sd_i is measured standard deviation of spot speeds at location *i* (in mi/h); **X** is a vector of roadway, traffic, and speed limit characteristics; β's are vectors of estimable parameters; and ε's are disturbance terms capturing unobserved characteristics.

Note that Equations 5, 6, and 7 do not directly interact with each other. However, because all three responses represented by these equations are from the same location, these equations share unobserved characteristics and, to obtain efficient parameter estimates, the contemporaneous correlation of disturbances ε_1, ε_2 and ε_3 must be considered and the common approach for doing this is referred to seemingly unrelated regression estimation (SURE) as discussed in Washington et al. [*138*]. As part of this analysis, separate models were developed for mean speeds, 85th percentile speeds, and speed standard deviations separately for passenger vehicles, trucks/buses, and all vehicles combined.

SPEED DATA ANALYSIS RESULTS

Several geometric- and traffic volume-related variables were considered during the analysis. Ultimately, the posted speed limits and percent of trucks in the traffic stream were found to be the significant determinants of the three speed measures that were analyzed. Binary indicator

(0/1) variables were created for each speed limit combination of passenger vehicle and truck/bus speed limits, which allowed for the examination of the potential effects of differential speed limits on travel speed characteristics. Table 21 provides summary statistics for the dependent variables and Table 22 provides summary statistics for the independent variables used during the modeling process.

Table 21. Summary Statistics of Dependent Variables for SURE Models

Vehicle Type Group	Speed Characteristic (mph)	Low (mph)	High (mph)	Mean (mph)	Std. Dev (mph)
Passenger Vehicles	Mean Speed	55.6	77.0	69.9	4.7
	85^{th}% Speed	60.0	81.0	75.0	4.2
	Std. Deviation	1.7	7.6	5.1	1.1
Trucks/Buses	Mean Speed	50.5	67.1	61.2	3.1
	85^{th}% Speed	54.0	70.0	64.7	2.8
	Std. Deviation	1.6	6.7	3.7	0.8
All Vehicles	Mean Speed	55.1	75.5	68.5	4.3
	85^{th}% Speed	60.0	79.0	73.2	3.4
	Std. Deviation	4.3	8.1	6.3	0.8

Table 22. Summary Statistics of Independent Variables for SURE Models

Speed Limit (P.V./T-B)* at Site	Number of Sites	Percent of Sites
55 mph/55 mph	64	40.0%
65 mph/65 mph	11	6.9%
70 mph/60 mph	49	30.6%
70 mph/65 mph	20	12.5%
70 mph/70 mph	13	8.1%
Other (low speed)	3	1.9%
Total	160	100.0%

*P.V. = Passenger Vehicle, T-B = Truck/Bus

Percent Trucks at Site	
Minimum	1.1%
Maximum	48.3%
Mean	15.8%
Standard Deviation	10.2%

During the modeling process, a 0.05 level of significance (95-percent confidence level) was used to identify factors that affected travel speed characteristics. Tables 23, 24, and 25 present the results of the SURE models for passenger vehicles, trucks/buses, and all vehicles, respectively. When examining the model results, the constant term indicates the baseline condition, which corresponds to freeways posted at speeds of less than 65 mph. The speed limit indicator variables (e.g., Speed Limit 65_65) express the difference in each speed measure as compared to the base condition.

Table 23. Seemingly Unrelated Regression Equations (SURE) Results for Passenger Vehicles

	Mean Speed Model (R-Squared = 0.630)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant (Speed Limit < 65 mph)	65.655	0.348	<0.001
Speed Limit 65_65	4.556	0.927	<0.001
Speed Limit 70_60	7.854	0.535	<0.001
Speed Limit 70_65	7.529	0.726	<0.001
Speed Limit 70_70	7.632	0.863	<0.001
	85th Percentile Speed Model (R-squared = 0.507)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant (Speed Limit < 65 mph)	71.579	0.359	<0.001
Speed Limit 65_65	3.071	0.956	0.001
Speed Limit 70_60	6.433	0.552	<0.001
Speed Limit 70_65	6.028	0.748	<0.001
Speed Limit 70_70	5.509	0.890	<0.001
	Standard Deviation Model (R-Squared = 0.475)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant (Speed Limit < 65 mph)	5.961	0.093	<0.001
Speed Limit 65_65	-1.497	0.248	<0.001
Speed Limit 70_60	-1.237	0.143	<0.001
Speed Limit 70_65	-1.465	0.194	<0.001
Speed Limit 70_70	-1.970	0.231	<0.001

Note: Speed limit variables represent: Passenger Vehicle Speed Limit_Truck Speed Limit

The results for the passenger vehicles models are largely expected; although it should be noted that percent of trucks in the traffic stream did not significantly affect any of the speed parameters. Both mean speed and 85th percentile speed for passenger vehicles increase with increasing speed limits, although they increase at a lower rate for 85th percentile speeds. It should be noted that the increases in both mean speed and 85th percentile speed were generally consistent between the three states. The speed standard deviation for passenger vehicles is generally higher than trucks or buses, though results indicated the smallest standard deviations for passenger vehicles occurred when speed limits were uniform (65/65 or 70/70).

Table 24. Seemingly Unrelated Regression Equations (SURE) Results for Trucks/Buses

	Mean Speed Model (R-Squared = 0.672)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant	58.086	0.225	<0.001
Speed Limit 65_65	4.932	0.533	<0.001
Speed Limit 70_60	3.631	0.333	<0.001
Speed Limit 70_65	5.322	0.457	<0.001
Speed Limit 70_70	6.609	0.499	<0.001
Percent Trucks	0.029	0.005	<0.001
	85th Percentile Speed Model (R-squared = 0.642)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant	62.517	0.201	<0.001
Speed Limit 65_65	5.259	0.530	<0.001
Speed Limit 70_60	2.348	0.310	<0.001
Speed Limit 70_65	4.478	0.420	<0.001
Speed Limit 70_70	6.534	0.495	<0.001
	Standard Deviation Model (R-Squared = 0.451)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant	4.594	0.095	<0.001
Speed Limit 70_60	-0.842	0.110	<0.001
Speed Limit 70_65	-0.584	0.162	<0.001
Percent Trucks	-0.033	0.005	<0.001

Note: Speed limit variables represent: Passenger Vehicle Speed Limit_Truck Speed Limit

The model results for trucks/buses indicate that both mean speed and 85th percentile speed are much lower than passenger vehicles, which is expected, and the general trends between the different speed limit groups are similar to the mean speeds and 85th percentile speeds for passenger vehicles. It should be noted, however, that mean speeds were found to increase slightly as the percent of trucks in the traffic stream increases, indicating that trucks tend to travel faster together. The standard deviations for trucks/buses were found to be smaller than passenger vehicles, and the speed limits were found to have smaller effects on standard deviation for trucks/buses. This indicates truck/bus drivers tend to travel either slower or faster together, regardless of speed limits.

The results for the models with all vehicles combined indicate that the general mean and 85th percentile speed trends for each speed limit group are generally consistent with those found with the passenger vehicle and truck/bus models. It should be noted that increasing percent of trucks in the traffic stream was found to decrease the mean speed for all vehicles; an expected result as trucks and buses tend to travel at slower speeds, and an increase in the percentage of these vehicles in the traffic stream would tend to slow all vehicles as a whole. The speed standard deviation for all vehicles was found to be higher than both passenger vehicles and trucks/buses.

Table 25. Seemingly Unrelated Regression Equations (SURE) Results for All Vehicles

	Mean Speed Model (R-Squared = 0.595)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant	64.908	0.339	<0.001
Speed Limit 65_65	4.728	0.873	<0.001
Speed Limit 70_60	7.140	0.501	<0.001
Speed Limit 70_65	7.067	0.595	<0.001
Speed Limit 70_70	7.175	0.818	<0.001
Percent Trucks	-0.022	0.010	0.021
	85th Percentile Speed Model (R-squared = 0.304)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant	70.972	0.330	<0.001
Speed Limit 65_65	2.119	0.918	0.021
Speed Limit 70_60	4.477	0.523	<0.001
Speed Limit 70_65	3.833	0.552	<0.001
Speed Limit 70_70	3.351	0.854	<0.001
	Standard Deviation Model (R-Squared = 0.280)		
Variable	**Estimate**	**Std. Error**	**P-value**
Constant	6.164	0.077	<0.001
Speed Limit 65_65	-0.476	0.230	0.038
Speed Limit 70_60	0.695	0.128	<0.001
Speed Limit 70_70	-0.791	0.214	<0.001

Note: Speed limit variables represent: Passenger Vehicle Speed Limit_Truck Speed Limit

This is expected because when faster passenger vehicles are traveling with slower trucks, a larger standard deviation will be measured. More interestingly, vehicles traveling at sites with the highest differential in speed limits (70/60) were found to have the highest standard deviations, while vehicles traveling at higher speed sites with uniform speed limits (65/65 and 70/70) were found to have the lowest standard deviations with respect to all vehicles. It should be noted that vehicles traveling at sites with uniform 55-mph speed limits and sites with 5-mph differential limits (i.e., 70/65) exhibited similar standard deviations. Standard deviations at these sites tended to be higher than at locations with uniform (65/65 or 70/70) speed limits.

Ultimately, the results of this analysis show that driver speed selection, as measured by mean and 85th percentile speeds, is generally consistent between states with similar posted speed limits. This is particularly true of those freeways that are posted at 70 mph. The variability in travel speeds, as measured by the site-specific standard deviation, is generally lowest at locations with uniform speed limits, with the minimum occurring at locations posted at 70 mph). Speeds were most variable at locations in Michigan with a 10-mph differential limit, as well as at urban locations in all three states where the speed limits were posted at a uniform 55 mph. As truck volumes increased, the overall variability in travel speeds tended to increase, though truck speeds became more uniform. Based upon these results, it appears that the minimum variability in travel speeds would occur at a uniform 70-mph limit. It is also interesting to note that passenger cars speeds were marginally lower at sites that were posted at a uniform 70 mph (as compared to locations with 5-mph or 10-mph differential limits). It is unclear whether these differences are due to inherent driver behavior in response to speed limit policies, or a function of the fact that these uniform limits were only present in the state of Ohio.

CHAPTER 5:

BENEFIT/COST ANALYSIS

One of the primary components of this research was to determine the economic impacts associated with raising the speed limit on MDOT highways. Simply put, the primary question of interest was, "Do the benefits of raising the speed limit outweigh the associated costs?" In order to answer this question, a comprehensive benefit/cost evaluation was conducted to provide an assessment of the economic impacts associated with raising speed limits on Michigan roadways.

The first step in the process was to identify potential economic factors that may be positively (i.e., benefit) or negatively (i.e., cost) impacted by a speed limit increase during a typical roadway life cycle, including both agency and non-agency costs and benefits. Only tangible costs and benefits directly resulting from an increase in speed limit were considered, including:

- Infrastructure
  - Speed limit signs
  - Roadway geometric components (e.g., horizontal and vertical alignment, sight distances, guardrail lengths, auxiliary lanes and tapers, etc.)
  - Additional non-freeway components (e.g., passing zones, speed reduction zones, traffic signal clearance interval timing, etc.)
- Fuel consumption
- Travel time
- Crashes

INFRASTRUCTURE IMPACTS

Speed Limit Signs

One of the most imminent agency-related costs associated with raising speed limits involves the modification of existing speed limit signs. The most recent statewide speed limit policy change in Michigan occurred in 2006 with the passage of House Bills 5104 and 5240, which raised truck/bus speed limits on 70 mph freeways from 55 to 60 mph, minimum freeway speed limits from 45 to 55 mph, and speed limits on certain freeways in urbanized areas from 55 to 65 or 70 mph. These policy changes necessitated modification to the speed limit signage on approximately 1,850 centerline miles of affected freeways. The speed limit sign modifications began shortly thereafter in 2006 and were performed by MDOT maintenance crews. According to MDOT personnel, speed limit signs were typically modified using a sheeting overlay of the speed limit, although in some cases it was necessary to replace the entire sign. These modifications typically did not require modification to either the size of the sign or the signposts. Traffic control during the sign modifications was also performed using MDOT forces and typically involved a short duration shoulder closure, although lane closures were occasionally required for replacements that occurred on or near ramps.

The total agency costs for the statewide freeway speed limit sign replacement associated with the 2006 policy change, including materials, labor, and traffic control, was approximately $1,000,000 (2006 dollars), or approximately $540 per mile. A recent internal reassessment of these sign modification costs by MDOT suggested that current (2014) costs to perform statewide speed limit sign replacement (no overlays) on MDOT roadways by agency forces would be approximately $1,350,000 ($730 per mile) on freeways and $400,000 ($63 per mile) on non-freeways, including costs for maintenance of traffic and mobilization. Overlaying the signs with new speed limit numbers rather than fully replacing the signs would reduce these costs by 75 to 80 percent. For purposes of the benefit/cost analysis, it was decided to conservatively assume full replacement of all speed limit signs. It was also necessary to convert these current statewide sign replacement cost to equivalent annualized values. Assuming a sign replacement life cycle of 15 years and a 3 percent discount rate, the annualized statewide speed limit sign modification costs were estimated at $113,100 and $33,500 for freeways and non-freeways, respectively.

The aforementioned statewide freeway speed limit sign replacement cost estimates may be considered as a baseline minimum infrastructure cost. For policy changes that only involve raising the truck/bus speed limit, it may be appropriate to consider the speed limit sign modification costs as the primary cost incurred by the agency, as it would not be necessary to subsequently increase the design speed of the affected roadways through substantial geometric modification upon reconstruction. However, policy changes that include raising the passenger vehicle speed limit on either freeways or non-freeways would typically include additional infrastructure costs, which are detailed in the subsections that follow.

Roadway Geometric Features

Increasing the passenger vehicle speed limit will require an engineering assessment of the adequacy of several speed-related geometric features, including (but not limited to): horizontal curvature (radius, superelevation), vertical alignment (grades, curvature), sight distances (stopping, decision, passing [two-lane roadways]), guardrail lengths, and lengths of auxiliary lanes and tapers. Raising the passenger vehicle speed limit on any high speed roadway would, as a minimum, initially necessitate installation of additional warning signs to treat deficient geometric conditions and/or relocation of existing advance warning signs. For example, horizontal curve locations where the newly increased speed limit exceeds the design speed may require additional signage, such as advance warning signs (including warning flashers where warranted), advisory speed plaques, and/or chevrons. Figure 34 displays a typical example of a freeway curve that may require additional warning signage after a speed limit increase.

Figure 34. Typical Freeway Curve that may Warrant Additional Curve Warning Signage after Speed Limit Increase

In many cases, utilizing warning signs to accommodate the substandard design cannot be considered a permanent fix for features that were designed for speeds lower than the posted speed. This is especially true for federal-aid roadways, which upon reconstruction, must accommodate the higher posted speed limits unless a design exception is approved by the FHWA. For example, horizontal curves with design speeds that are less than the posted speed limit may require realignment upon reconstruction if the superelevation cannot be increased. Horizontal curves with limited sight distance may also require realignment if the offending sight obstructions cannot be removed in order to achieve the required visibility. Similarly, vertical curves may also require modification if inadequate stopping sight distance exists. Other accommodations, such as guardrail runout length extensions, clear zone expansions, and extension of auxiliary lanes and/or tapers, may also be required in order to comply with the increased speed limit.

Geometric upgrades that expand the footprint of the existing roadway have right-of-way, environmental, social, mobility, and construction quantity components that often substantially exceed the cost of performing such upgrades within the existing roadway footprint. It is expected that exceedingly large cost increases will be required to achieve geometric element compliance with a higher posted speed limit, which will likely be prohibitive at many locations. Although attainment of design exceptions allows for other mitigation strategies to be utilized aside from full roadway realignment, MDOT cannot expect to frequently receive such exceptions. It is important to note that current MDOT policy does not require upgrading substandard geometric features during resurfacing projects unless a high crash pattern exists.

Under most circumstances, it is MDOT practice to design roadway geometric features using a design speed that is 5 mph greater than the current posted speed limit for roadways on the National Highway System [*139*]. This has resulted in a substantial portion of the existing MDOT freeway system being designed for 75 mph design speeds, with most non-freeways and freeways in dense urban areas typically designed for 60 mph, although many geometric elements are constructed to even lower design speeds. Thus, compliance with higher posted speed limits would present a very large budgetary burden on many road and bridge reconstruction projects, increasing project costs far beyond that which would be incurred based on the current posted speed limit.

A series of case studies have been prepared based on data provided by MDOT to demonstrate the potential impacts of speed limit increases on geometric components. These case studies feature rural and urban freeway sections and rural non-freeway sections. To illustrate the range of potential geometric modifications and associated costs related to increasing the speed limit, multiple examples are provided for each type of roadway facility, which include:

- Examples of Affected Geometric Characteristics on Rural Freeways
    1. Horizontal curve realignment (I-94, Mile Marker 22.5 in Berrien County)
    2. Horizontal and vertical curve realignment at an interchange (I-94, Exit 16 in Berrien County)
    3. Horizontal curve re-grading at bridge with substandard vertical clearance (I-94, Exit 85 in Kalamazoo County)
- Freeway Corridor Examples
    4. US-31 in Oceana County (Rural)
    5. US-131 in Montcalm County (Rural)
    6. I-94 in Berrien and Van Buren Counties (Rural)
    7. I-94 in St. Clair Shores (Dense Urban)
    8. I-196 in Grand Rapids (Dense Urban)
- Rural Non-Freeway Corridor Examples
    9. US-223, M-50, and M-52 in Lenawee County (Signing and marking costs only)
    10. M-37 in Newaygo County (Extensive geometric modifications)
    11. US-2 in Mackinac County (Minimal geometric modifications)

Case Study 1. Horizontal Curve Realignment on Rural Freeway

This case study example involves realignment of a horizontal curve on I-94 in Berrien County, between Exits 22 and 23 near Stevensville. The existing curve possesses a radius of 2,300 ft, which accommodates a 70 mph posted speed limit (75 mph design speed). The location has been designated as a high crash location and a design speed exception would be highly unlikely. The radius must be extended to 3,400 ft to accommodate an 80 mph posted speed limit (85 mph design speed). Extending the radius in this manner will involve a substantial horizontal realignment from the existing roadbed that will trigger additional project costs, including reconstruction of a bridge, acquisition of new right-of-way, and wetland mitigation. As a result, extending the curve radius to increase the design speed from 75 mph to 85 mph will conservatively result in the following estimated additional primary project costs:

- Bridge reconstruction: $3.0 million,
- Construction of 0.6 miles of new roadway/roadbed: $2.0 million,
- Right-of-way acquisition: $1 million, and
- Wetland mitigation: $0.5 million.

This horizontal curve realignment is expected to add $6.5 million to the overall project cost – an increase of 81 percent over the estimated $8 million cost to reconstruct the curve on the existing roadway alignment. This increase over the current costs would drop to $3.5 million if the realignment did not impact any bridges and to $3.0 million if wetlands are not impacted. A schematic depicting the probable upgrades required to accommodate an 80 mph posted speed limit at this location is shown in Figure 35.

Figure 35. Expected Horizontal Curve Realignment, I-94 Berrien County

Case Study 2. Horizontal and Vertical Curve Realignment at Rural Freeway Interchange

This example describes a combined vertical/horizontal curve on I-94 at Exit 16 in Berrien County, Michigan south of Bridgeman. The existing geometric features are designed for compliance with the 70 mph speed limit. Increasing the posted speed from 70 to 80 mph would require an 85 mph curve design speed upon reconstruction. Although at 5 percent, the superelevation falls below the 7 percent maximum allowable, the superelevation cannot be increased because the exit ramp diverges from outside edge of the curve at maximum superelevation. As a result, reconstruction of this interchange would include significant modification to both the horizontal and vertical alignments to achieve an 85 mph design speed. This would substantially increase costs related to earthwork, slope grading, wall reconstruction, barrier, real estate, ramp reconstruction, and wetland mitigation, as depicted in Figure 36.

Figure 36. Expected Interchange Geometric Modifications, I-94 Berrien County

Case Study 3. Horizontal Curve Modification at Bridge with Substandard Vertical Clearance on Rural Freeway

This example describes a horizontal curve passing under a bridge on I-94 at Exit 85 near Galesburg in Kalamazoo County. Design speed compliance with an 80 mph posted speed limit may be achieved at this horizontal curve by increasing the superelevation rather than realigning the curve. This increase would raise the outside (north) shoulder edge by 5 inches at the bridge, as shown in Figure 37. Due to the grade of the bridge, the outside shoulder edge is the point of minimum under clearance and such an increase in superelevation would require raising the elevation of the bridge to achieve the required underclearance during reconstruction. As depicted in Figure 38, this will result in an expanded bridge replacement footprint, requiring numerous additional costly modifications, beyond that which would be necessary to maintain compliance with the current 70 mph speed limit. In addition to the bridge structure, modifications would also be incurred on the crossroad approach and adjacent property, resulting in increased costs associated with embankments, retaining walls, adjacent parking lots/driveways, entry/exit ramps, and right-of-way purchases.

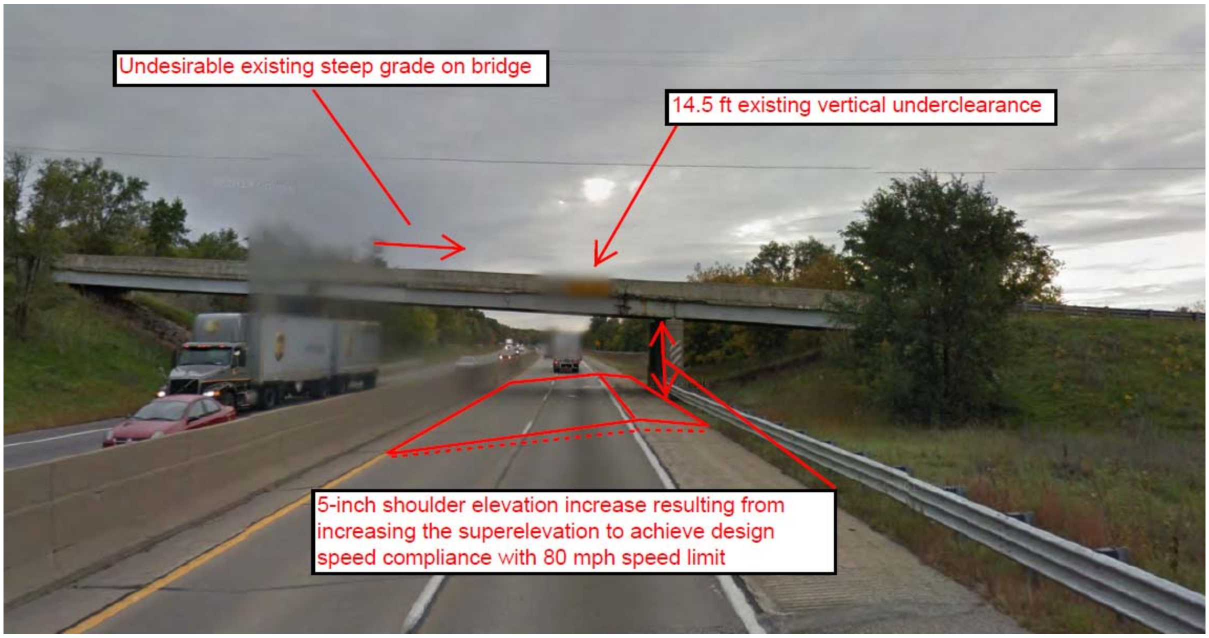


Figure 37. Impact on Bridge Vertical Clearance Associated with Superelevation Increase, I-94 Kalamazoo County

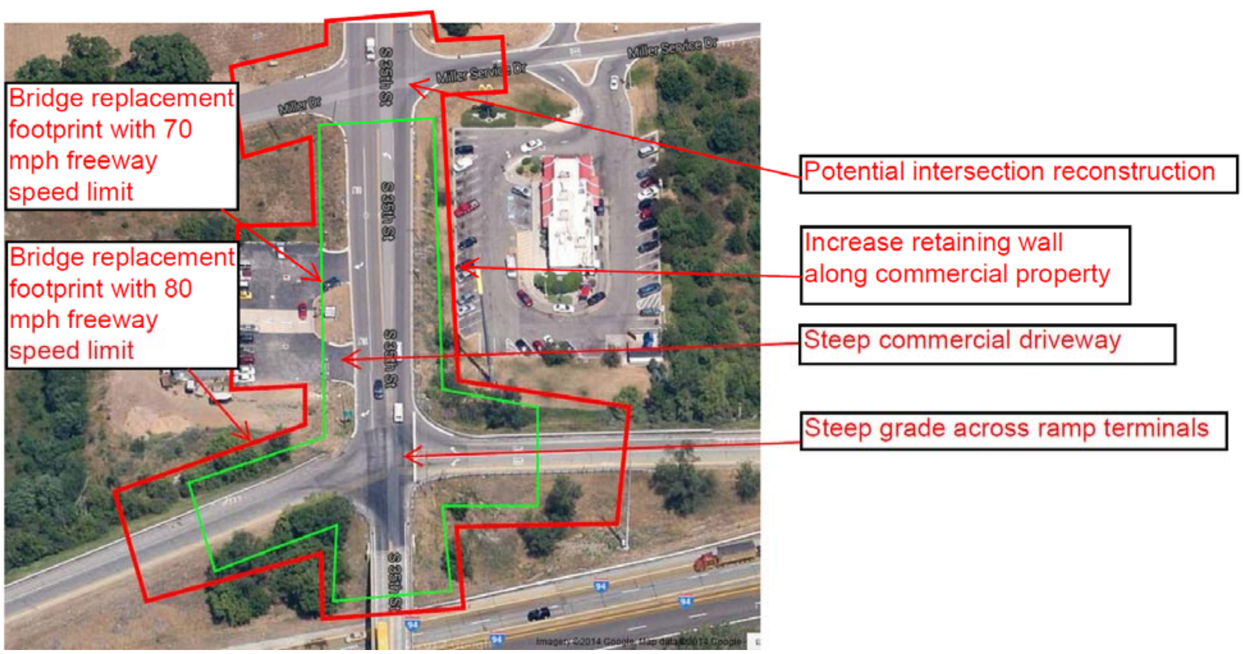


Figure 38. Expanded Bridge Replacement Footprint to Achieve Vertical Clearance

Case Study 4. US-31 in Oceana County (Rural Freeway Corridor)

A 25.9 mile four-lane section of US-31 in Oceana County was recently analyzed to determine the infrastructure costs associated with increasing the speed limit from 70 to 80 mph. An assessment of the horizontal and vertical curvature by MDOT staff found all horizontal curves to be compliant with an 85 mph design speed. However, five crest and two sag vertical curves were determined to be substandard. It was also determined that reconstruction of these curves would necessitate reconstruction of nine bridges. Furthermore, although all 13 deceleration lanes were compliant, all 13 acceleration lanes were non complaint. Additional extensions to guardrail and sign upgrades would also be necessary to comply with the increased design speed requirement. The following costs were estimated for the affected infrastructure components. Note that roadway reconstruction costs were based on an assumed unit cost of $2.5 million per lane mile.

- Crest vertical curve reconstruction: $2.4 million per curve ($12.1 million total)
- Sag vertical curve reconstruction: $0.6 million per curve ($1.2 million total)
- Bridge replacement: $3.4 million per bridge ($30.5 million total)
- Ramp acceleration lane extensions: $1.0 million per extended lane ($13.0 million total)
- Guardrail extensions: $19,305 per mile ($0.5 million total)
- Signing modifications: $30,000 per mile ($0.8 million total)

Thus, it is estimated that increasing the speed limit from 70 mph to 80 mph will result in additional reconstruction costs of $58.1 million over this 25.9 mile section of rural four lane freeway ($2.24 million per mile).

Case Study 5. US-131 in Montcalm County (Rural Freeway Corridor)

A 13.1 mile four-lane section of US-131 in Montcalm County was also analyzed to determine the infrastructure costs associated with increasing the speed limit from 70 to 80 mph. An assessment of the horizontal and vertical curvature by MDOT staff found all horizontal and vertical curves to be compliant with an 85 mph design speed. Furthermore, although all deceleration lanes were compliant, nine acceleration lanes were non complaint. Additional extensions to guardrail and sign upgrades would also be necessary to comply with the increased design speed requirement. The following costs were estimated for the affected infrastructure components. Note that roadway reconstruction costs were based on an assumed unit cost of $2.5 million per lane-mile.

- Ramp acceleration lane extensions: $1.2 million per extended lane ($10.5 million total)
- Guardrail extensions: $19,083 per mile ($0.25 million total)
- Signing modifications: $30,000 per mile ($0.40 million total)

Thus, it is estimated that increasing the speed limit from 70 mph to 80 mph will result in additional reconstruction costs of $11.2 million over this 13.1 mile section of rural four lane freeway ($0.85 million per mile). The lack of vertical curve regalement and subsequent bridge reconstruction work decreases the additional project costs by an estimated $1.39 million per mile compared to the US-31 case study.

Case Study 6. I-94 in Berrien and Van Buren Counties (Rural Freeway Corridor)

An assessment of the estimated geometric upgrade costs was performed for a 66.8 mile section of I-94 in Berrien and Van Buren Counties. Figure 39 presents an overview of locations along I-94 that have been identified by MDOT as likely requiring major geometric upgrades upon reconstruction if the speed limit was raised to 80 mph. The major geometric upgrades are separated into three categories including conservative cost estimates as follows:

- Horizontal curve realignment (N = 3 locations): includes earthwork, additional right-of-way, and wetland mitigation costs of $3.5 million per location ($10.5 million total).
- Crest vertical curve realignment (N = 5 locations): includes additional earthwork and related costs of $4.8 million per location ($24.0 million total).
- Horizontal curve modification requiring increased vertical clearance at a bridge (N = 8 locations): includes additional horizontal curve grading, bridge reconstruction, and earthwork costs of $6 million per location ($48 million total).
- Ramp acceleration lane extensions (N = 48 locations): $1.0 million per extended lane ($48.0 million total).
- Guardrail extensions: $19,305 per mile ($1.3 million total).
- Signing modifications: $30,000 per mile ($2.0 million total).

Thus, it is estimated that increasing the speed limit from 70 mph to 80 mph on will result in additional reconstruction costs of $133.8 million over this 66.8 mile section of I-94 in Berrien and Van Buren counties ($2.0 million per mile), which is consistent with the unit cost estimate for US-31 in Oceana County.

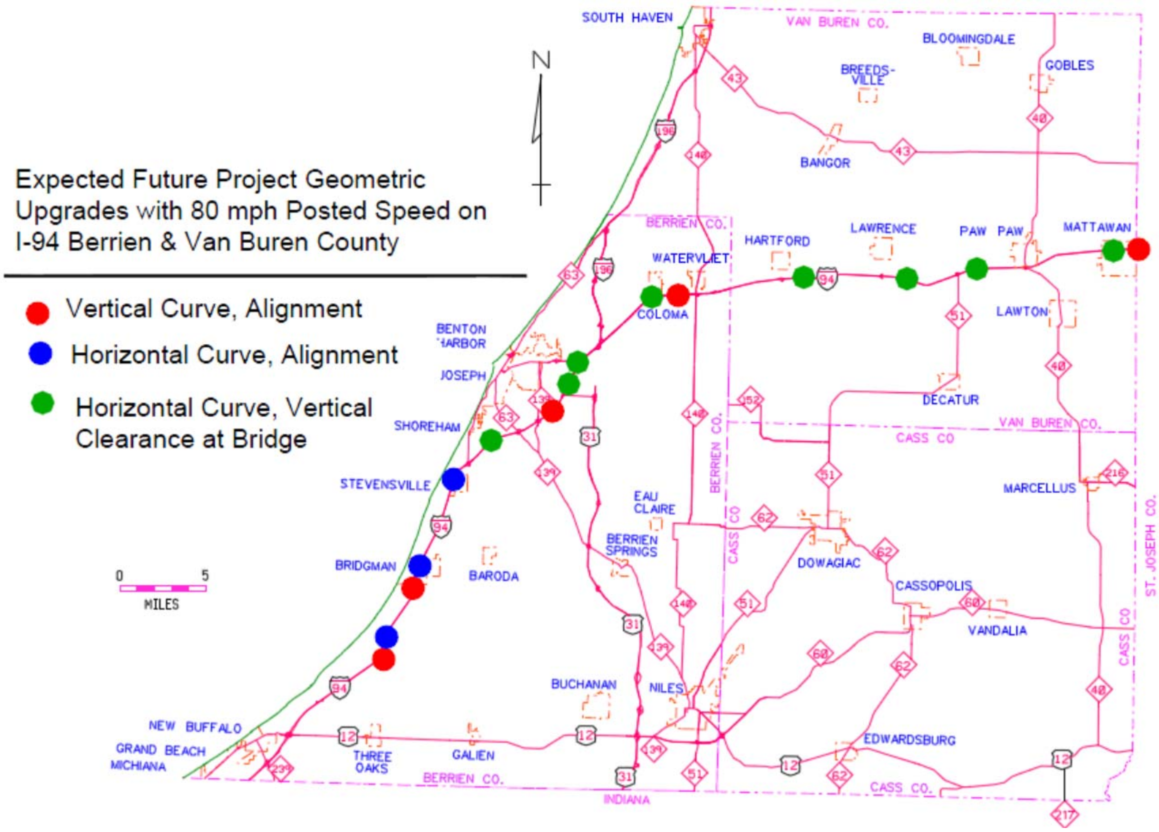


Figure 39. Expected Major Geometric Upgrades on I-94 in Berrien and Van Buren Counties after Speed Limit Increase from 70 to 80 mph

Case Study 7. I-94 in St. Clair Shores (Dense Urban Freeway Corridor)

A 1.58 mile six-lane section of I-94 from 8 Mile to Stephens Rd between Mile Marker 225 and 227 in the City of St. Clair Shores, Macomb County, was scoped by MDOT for reconstruction in 2011. The proposed scope of work included reconstructing the existing mainline and ramp pavements from the 8 Mile Road interchange to south of Stephens Road in addition to other reconstruction of other components. As this section of freeway passes through a dense urban area, the posted speed limit is 55 mph and many of the existing geometric features are designed for 60 mph, as required by the MDOT Design Manual. A total of 15 horizontal curves are included within the proposed project limits, including three on the mainline and 12 on the ramps. Only one of these curves does not meet the current necessary design speed of 60 mph and would require modification during the proposed reconstruction. Raising the posted speed limit to 70 mph would increase the design speed for the proposed reconstruction to 75 mph. Two of the three mainline horizontal curves and seven of the twelve ramp horizontal curves would not be in compliance with a 75 mph design speed and would consequently require modification during reconstruction. An example of a horizontal curve that would require realignment if the speed limit is increased prior to reconstruction is shown in Figure 40.

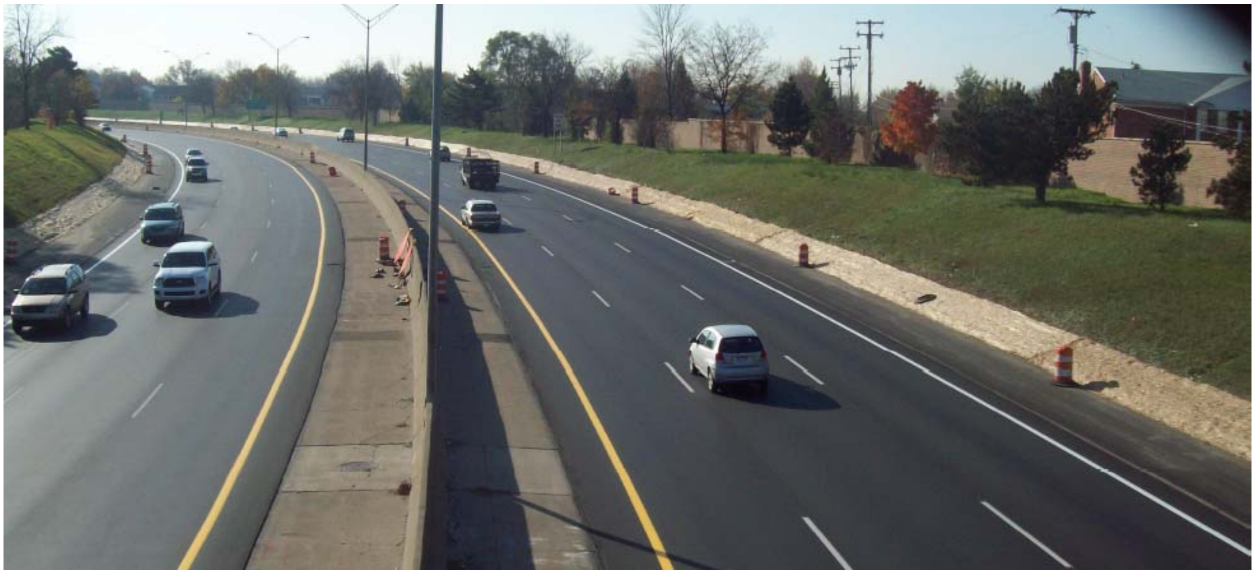


Figure 40. Horizontal Curve Requiring Realignment if Speed Limit is increased to 70 mph, I-94 Macomb County

Increasing the horizontal curve radii to achieve compliance with a 75 mph design speed will require realignment of the freeway, which will have a significant impact on the project costs. First, the necessary realignment will require additional right-of-way. As right-of-way costs are time sensitive and highly location-specific, such costs are very difficult to estimate. Secondly, the realignment will also include modification to the bridge and adjacent secondary roads to accommodate the increased curve radii. For this particular project, the necessary realignment would be extensive enough to impact two vehicle bridges and two pedestrian bridges, none of which would require modification based on the current 60 mph design speed. The design speed increase would also require extensive earth excavation and embankments to accommodate realignment of the curves. A rough estimate of additional earthwork is between 1.5 million and 2.0 million cubic yards for this project. The following costs (exclusive of right-of-way) were estimated for the infrastructure components for this project affected by increasing the speed limit from 55 to 70 mph:

- Vehicular bridge replacement: \$5.0 million per bridge (\$10.0 million total),
- Pedestrian bridge replacement: \$1.5 million per pedestrian bridge (\$3.0 million total),
- Realignment of secondary roads: \$2.5 million total, assuming approximately 500 feet of realignment in each direction, and
- Additional earthwork: \$4.7 to \$6.0 per cubic yard (\$7.0 to \$12.0 million total).

Thus, it is estimated that increasing the speed limit from 55 mph to 70 mph will result in additional project costs of \$22.5 million to \$27.5 million (\$14.2 to \$17.4 million per mile), representing an increase of 100 to 122 percent over the estimated reconstruction cost of \$22.4 million (\$14.2 million) per mile at the current 55 mph speed limit. Total project costs for this 1.58 mile section would likely range from \$44.9 to \$49.9 million (\$28.4 to \$31.6 million per mile). This likely underestimates the true cost for urban freeway realignment, as several required cost components, including right-of-way purchases necessary to accommodate the necessary horizontal realignment, additional design and construction engineering costs, and increased user costs, were not included.

Case Study 8. I-196 in Grand Rapids (Dense Urban Freeway Corridor)

To obtain a more accurate reconstruction estimate inclusive of right-of-way costs, a 2.7 mile segment of I-196 from M-45 to College Ave. through the City of Grand Rapids was also assessed. A speed limit feasibility study for this dense urban freeway segment performed by MDOT in 2002 was utilized to estimate the costs to increase the speed limit from 55 to 70 mph. The estimate included geometric realignment and associated right-of-way costs, auxiliary lane extensions, and reconstruction of affected bridges. After inflating the costs to 2014 dollars, it was estimated that additional reconstruction costs of approximately \$190 million (\$70.4 million per mile) were necessary to achieve a 75 mph design speed for this 2.7 mile section of corridor. Although this additional cost is several times greater than that expected for rural freeways, it is not unreasonable to expect such costs during reconstruction of urban freeways requiring extensive realignment and subsequent right-of-way costs in order to achieve compliance with the increased design speed.

To estimate urban freeway reconstruction costs for segments with less extensive geometric modifications and associated right-of-way costs, a subsequent cost assessment was performed for an adjacent 1.0 mile section of I-196 between the College Ave. and Fuller Ave. interchanges. All horizontal and vertical curves within this section are compliant with a 75 mph design speed and would not require realignment. However, all acceleration and deceleration lanes will require extension to achieve a 75 mph design speed. It was determined that these extensions would be most effectively handled through construction of an auxiliary lane to connect the acceleration and deceleration lanes in both directions between the College Ave and Fuller Ave interchanges, which would require reconstruction/lengthening of two bridges crossing over the freeway. The total cost to add the two auxiliary lanes and replace the two bridges within this one mile section was estimated at $7.6 million.

Additional Impacts on Non-Freeways

In addition to speed limit sign upgrades, increasing the posted speed limit on rural non-freeways will require additional infrastructure modifications. Initial modifications on non-freeways would include, as a minimum, modifications to passing/no passing zones, warning signs, and traffic signal clearance intervals. Increasing the speed limit from 55 to 65 mph will lengthen the necessary passing sight distance by 20 percent (from 1,000 ft to 1,200 ft) and require subsequent extension of no passing zones. In addition to adding/extending no passing zone pavement markings, this will necessitate either repositioning of the passing/no passing zone signs or placement of new signs where none previously existed. MDOT has estimated that the cost to modify the passing and no passing zone signing and associated pavement markings for the approximately 7,500 no passing zones on MDOT two-lane roadways statewide is approximately $3.5 million. This includes the costs of materials, removal, salvage and erection of the signs on new supports, in addition to costs for maintenance of traffic and mobilization. Assuming approximately 6,100 miles of MDOT maintained two-lane 55 mph highways, this equates to approximately $575 per mile. An example depicting potential passing zone traffic control device modifications is displayed in Figure 41.

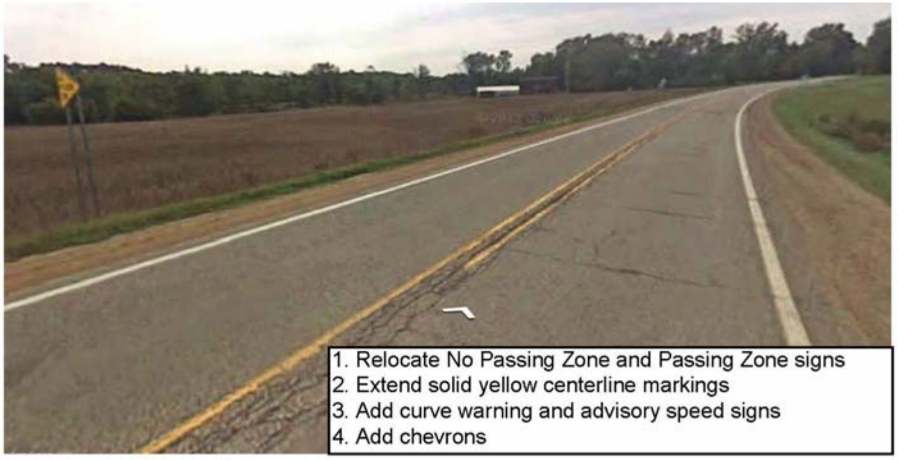


Figure 41. Typical Necessary Passing Zone Modifications after Speed Limit Increase

Increasing non-freeway speed limits will also require installation of new warning signs, such as at curves or limited sight distances areas, and relocation of existing advance warning signage. Immediate revision of yellow and red clearance intervals at traffic signals will also be required to accommodate the increased speed limit. Other traffic signal modifications, such as detector layout at actuated signals, may be applied during scheduled rehabilitation or reconstruction activities. It will also be necessary to expand the speed reduction zones on the approach to municipal speed zones and school speed zones, which in many cases will include modifying current signs and/or installing new signs. Stopping sight distances will also be impacted, particularly on roadways with excessive horizontal or vertical curvature. A broad range of infrastructure related costs are expected for non-freeways, which are demonstrated by the following three case studies prepared based on data provided by MDOT.

Case Study 9. US-223, M-50, and M-52, Lenawee County (Signing and Marking Upgrades Only)

MDOT recently estimated the costs for necessary modifications to the signing and pavement markings for approximately 56 miles of non-freeway on US-223, M-50, and M-52 in Lenawee County. The modifications included those associated with increasing the speed limit from 55 to 65 mph (as listed in the previous section, including speed limit signing) and included contracted costs for materials, labor, preliminary engineering, construction engineering, mobilization and maintaining traffic. The average cost was estimated at approximately $2100 per mile. As expected, the costs varied based on roadway alignment, ranging from $400 per mile on flat/straight sections to $4,000 per mile where extensive horizontal or vertical curvature exists.

Case Study 10. M-37 in Newaygo County (Extensive Geometric Modifications)

M-37 in Newaygo County is an example of a non-freeway that would require extensive geometric improvements during reconstruction to comply with a 65 mph speed limit (70 mph design speed). A 19.3 mile two-lane section of M-37 from M-20 north to the county line was analyzed using data provided by MDOT. This section was found to possess 11 horizontal curves and 46 vertical curves within 13.4 miles of this non-freeway section that do not meet a 70 mph design speed. The cost to reconstruct 13.4 miles of trunkline at $2 million per lane mile is estimated at approximately $53.6 million, or $2.8 million per mile over the entire 19.3 mile section included in this case study. This particular section of roadway is considered a worst case scenario with respect to geometric upgrades to accommodate a 70 mph design speed. Consequently, MDOT staff estimated that average regionwide unit costs per mile of trunkline would likely be approximately half of this cost, or $1.4 million per mile. An example of a horizontal curve on M-37 requiring modification to comply with a 70 mph design speed is displayed in Figure 42.

Figure 42. Example Horizontal Curve, M-37 Newaygo County

Case Study 11. US-2 in Mackinac County (Minimal Geometric Modifications)

The impacts to non-freeway roadways may be minimized at locations that are currently designed for higher speeds. US-2 in Mackinac County is an example of a roadway with vertical and horizontal alignment features based on design speeds that are higher than the typical MDOT undivided non-freeway. As a result, it is anticipated that geometric modification costs will be minimized since many of the existing primary geometric features already accommodate a 65 mph posted speed limit. The cost to perform necessary initial infrastructure upgrades to comply with a 65 mph posted speed limit over the proposed 26.33 mile segment was estimated by MDOT at $12,800 per mile. This estimate included upgrades to signing, pavement markings, guardrail installation/extension, clear zone widening, shoulder improvements, culvert end treatments, and flashing beacon upgrades. This unit cost may be considered the minimum cost scenario for geometric upgrades associated with a 65 mph speed limit on MDOT non-freeways. Figure 43 displays a typical section of US-2 in Mackinac County.

Figure 43. Typical Cross-Section, US-2 Mackinac County

Infrastructure Cost Summary

The preceding case studies have demonstrated a broad range of infrastructure costs related to potential speed limit increases in Michigan. Clearly, increasing the posted speed limits on high-speed roadways in Michigan will contribute to exceptionally large infrastructure costs, largely due to geometric modifications required to achieve compliance with the increased design speeds. This is especially true for freeways in dense urban areas, as the unit costs for infrastructure modifications are expected to be substantially greater than those expected for rural freeways.

Determination of the actual statewide cost to upgrade the required geometric features for compliance with an increased speed limit is a very difficult task requiring a detailed assessment of the impacts on the relevant infrastructure components on all affected roadways. To overcome this limitation, statewide costs associated with required geometric upgrades were estimated based on extrapolation of the comprehensive infrastructure unit costs summarized in the preceding case study examples. These unit costs broadly considered impacts to horizontal and vertical curvature, bridges, acceleration and deceleration lanes, guardrail, signage, earthwork, wetland mitigation, and right-of-way acquisition, among other impacts.

Infrastructure-related unit costs per centerline mile were developed for each of the three affected facility types. Separate estimates were generated for each type of facility assuming minimal versus extensive geometric modifications associated with the proposed speed limit increase. The average of the high and low unit cost values was used to generate MDOT systemwide costs based on the affected mileage within the 2012 statewide sufficiency file for each type of facility. This includes 1,847 centerline miles of freeway currently posted at 70 mph, 91 centerline miles of dense urban freeways currently posted at 55 or 65 mph, and 6,310 centerline miles of non-freeways currently posted at 55 mph. The annualized MDOT systemwide cost estimates are also provided in Table 26.

Table 26. Infrastructure Costs Associated with Increased Speed Limits

Facility Type	Proposed Speed Limit	Impacts to Horizontal and/or Vertical Alignment	Total Cost Per Centerline Mile	Annualized Cost Per Centerline Mile[a]	Annualized Systemwide Costs[b]
Freeway	80 mph	Minimal	$850,000	$48,800	$163,875,100
		Extensive	$2,240,000	$128,650	
Urban Freeway	70 mph	Minimal	$7,600,000	$436,450	$203,810,400
		Extensive	$70,400,000	$4,042,900	
Non-Freeway	65 mph	Minimal	$12,800	$735	$509,643,000
		Extensive	$2,800,000	$160,800	

[a]Assumes 3 percent discount rate; 25 year design life
[b]Assumes average of high and low unit costs applied to total MDOT mileage for the category. MDOT statewide centerline mileage: freeways currently 70 mph = 1847 miles; urban freeways currently 55 or 65 mph = 91 miles; non freeways currently 55 mph = 6,310 miles

FUEL CONSUMPTION IMPACTS

Increasing posted speed limits on high-speed roadways in Michigan will negatively impact fuel economy, contributing to increased fuel consumption and associated costs. In order to estimate the increased fuel consumption costs, it was first necessary to estimate the impact of speed on fuel consumption. Fuel consumption for vehicles traveling on uninterrupted high-speed roadways is function of several factors, including air resistance, which is largely impacted by speed and aerodynamics, and tire rolling resistance, which is largely impacted by weight. Nearly all vehicles are more fuel efficient at lower highway speeds, as air resistance begins to have a greater negative impact on fuel economy with increasing speeds. The literature suggests that heavy trucks achieve approximately 7 miles per gallon (mpg) at 55 mph and flat terrain, and fuel economy decreases by approximately 0.1 mpg for every 1 mph increase in travel speed above 55 mph [*140-142*]. For passenger vehicles traveling at 70 mph, the current average fuel economy is approximately 25 mph and fuel economy decreases by 0.4 mpg for every 1 mph increase in travel speed above 70 mph [*143*]. Costs associated with vehicle maintenance, repair, and depreciation are not included in this analysis because of a lack of evidence relating such costs to increasing travel speeds within the speed ranges assumed here.

In order to estimate the impact of a proposed speed limit increase on fuel economy, it was necessary to determine the increase in average travel speeds that would be expected to occur as a result of the speed limit increase. As it was not possible to directly measure before-and-after changes in mean speed associated with the possible speed limit policy changes in Michigan, such changes were estimated based on data collected in Michigan, Ohio, and Indiana. Table 27 presents truck mean speeds during free flow conditions associated with freeway truck speed limits of 55, 60, 65, and 70 mph and non-freeway speed limits of 55 and 65 mph as well as passenger vehicle mean speeds during free flow conditions associated with freeway speed limits of 55, 70, 75 and 80 mph and non-freeway speed limits of 55 and 65 mph.

Table 27. Fuel Economy based on Mean Speed, by Speed Limit and Vehicle Type

Facility Type	Truck Speed Limit (mph)	Estimated Truck Mean Speed (mph)	Estimated Truck Fuel Economy (mpg)
Freeway	55	58.38	6.66
	60	62.01	6.30
	65	63.70	6.13
	70	64.99	6.00
Non-Freeway	55	56.00	6.90
	65	59.00	6.60
Facility Type	**Passenger Veh. Speed Limit (mph)**	**Estimated Passenger Veh. Mean Speed (mph)**	**Estimated Passenger Veh. Fuel Economy (mpg)**
Freeway	55	65.66	26.74
	70	73.51	23.60
	75	75.81	22.68
	80	78.11	21.76
Non-Freeway	55	58.00	29.80
	65	61.00	28.60

The mean speed data were then utilized to estimate the fuel economy for trucks and passenger vehicles, which are also displayed in Table 27. Note that the prediction models were extrapolated to generate passenger vehicle mean speed estimates for speed limits of 75 mph and 80 mph. The 75 mph estimates showed good agreement with speed data provided by the Louisiana DOT before-and-after raising the speed limit on I-49 from 70 to 75 mph. Similarly, the estimated mean speeds associated with 65 mph speed limits on non-freeways were assumed to increase by 3 mph over the 55 mph mean speeds based on research by Kockelman [*54*].

The next step was to estimate the annual vehicle-miles traveled on the state-maintained roadway system in Michigan. These data were obtained from the MDOT Highway Performance Monitoring System for 2012 (most recent year available) and were separated by roadway functional classification, commercial vs. non-commercial vehicles, and rural vs. urban classifications [*144*]. It was necessary to estimate the proportion of VMT occurring during free flow conditions, as it was assumed that mean travel speeds observed during non-free flow conditions will be unaffected by a change in the posted speed limit.

In rural areas, free flow conditions are generally present during most times of the day and departures from free flow conditions are typically experienced only during poor weather, incidents, and road work. Traffic signals and stop signs may also cause departure from free flow conditions on non-freeways, although these devices are not common on high speed MDOT highways, particularly in rural areas. Thus, for rural areas, it was assumed that 95 percent of the VMT occurs during free flow conditions. Recurring peak period congestion in urban areas reduces the proportion of travel that occurs during free flow conditions. It was assumed that non-free flow conditions persist on urban highways during the peak morning and afternoon travel periods, affecting approximately 25 percent of the urban VMT. Thus, it was assumed that only 75 percent of the urban VMT occurs during free flow conditions. Total VMT and free flow VMT are reported in Table 28 for MDOT roadways, separated by facility type (freeway vs. non freeway), area type (urban vs. rural), speed limit, and vehicle type (commercial vs. non-commercial). As MDOT does not report VMT based on posted speed limit, proportional estimates for each facility type were made based on volume-weighted segment mileage from the 2012 MDOT sufficiency file.

Table 28. Vehicle-Miles Traveled on MDOT Highways

Vehicle Type	Area Type	2012 MDOT Freeway VMT[a] (thousands) All	2012 MDOT Freeway VMT[a] (thousands) Free Flow Conditions	2012 MDOT Non-Freeway VMT[b] (thousands) All	2012 MDOT Non-Freeway VMT[b] (thousands) Free Flow Conditions
Commercial	Rural	1,101,670	1,046,586	494,873	470,129
	Urban 60 mph	1,569,569	1,177,177	N/A	N/A
	Urban 55 mph	141,723	106,292	105,320	78,990
	TOTAL	2,812,961	2,330,055	600,192	549,119
Non-Commercial	Rural	6,720,721	6,384,685	7,749,079	7,361,625
	Urban 70 mph	17,030,735	12,773,051	N/A	N/A
	Urban 55 mph	2,552,603	1,914,452	2,503,603	1,877,802
	TOTAL	26,304,059	21,072,188	10,252,681	9,239,327

[a] Estimated for National Functional Classes (NFC) 1 and 2 for rural facilities posted at 70/60 mph and urban facilities posted at 70/60 mph and 55/55 mph. Free flow conditions were assumed for 95 percent of rural VMT and 75 percent of urban VMT.

[b] Estimated for NFC 3, 4, and 5 for rural and urban facilities posted at 55 mph. Uninterrupted free flow conditions were assumed for 95 percent of rural VMT and 75 percent of urban VMT.

It was also necessary to estimate the average retail unit cost of fuel in Michigan. The average diesel cost in Michigan in late March 2014 was \$4.14 per gallon, while the average regular unleaded gasoline cost was \$3.75 per gallon [*145*]. Using these values, the annual increased statewide fuel consumption costs associated with increasing the posted speed limit were estimated using the following method, with the results displayed in Table 29:

Increased Fuel Consumption Costs (annual statewide, in dollars) =

$$(VMT / Fuel\ Economy_{Orig\_SL} - VMT / Fuel\ Economy_{New\_SL}) * Fuel\ Unit\ Cost\ (\$/gallon)$$

Table 29. Estimated Annual Fuel Consumption Cost Increase

Facility Type	Truck Speed Limit Increase Scenario	Estimated Truck Mean Speed Increase (mph)	2012 Comm. VMT[a] (thousands)	Annual Fuel Consumption Increase (gal)	Annual Truck Fuel Consumption Cost Increase[b] (\$)
Freeway	60 to 65 mph	62.01 to 63.70 mph	2,223,763	9,737,897	\$40,314,893
Freeway	60 to 70 mph	62.01 to 64.99 mph	2,223,763	17,517,055	\$72,520,606
Urban Freeway	55 to 70 mph	58.38 to 64.99 mph	106,292	1,756,893	\$7,273,539
Non-Freeway	55 to 65 mph	56.00 to 59.00 mph	549,119	3,617,383	\$14,975,968
Facility Type	**Passenger Veh. Speed Limit Increase Scenario**	**Estimated Passenger Veh. Mean Speed Increase (mph)**	**2012 Non-Comm. VMT[a] (thousands)**	**Annual Fuel Consumption Increase (gal)**	**Annual Psgr. Veh. Fuel Consumption Cost Increase[b] (\$)**
Freeway	70 to 75 mph	73.51 to 75.81 mph	19,157,736	32,939,132	\$123,521,746
Freeway	70 to 80 mph	73.51 to 78.11 mph	19,157,736	68,664,020	\$257,490,075
Urban Freeway	55 to 70 mph	65.66 to 73.51 mph	1,914,452	9,532,806	\$35,748,024
Non-Freeway	55 to 65 mph	58.00 to 61.00 mph	9,239,327	13,008,861	\$48,783,229

[a] Free flow only

[b] Fuel unit cost assumptions: diesel = \$4.14 per gallon; gasoline = \$3.75 per gallon

TRAVEL TIME IMPACTS

Any observed increases in the vehicle operating speeds will result in travel time savings for motorists. It was first necessary to determine average hourly value-of-time estimates for typical users of the Michigan highway network. MDOT provides separate value-of-time unit estimates for passenger vehicles and commercial trucks for use with the Construction Congestion Cost (CO3) estimation software [*146*]. The MDOT value-of-time unit estimates are based on the FHWA publication *Life-Cycle Cost Analysis in Pavement Design* [*147*] and are currently displayed in 2012 dollars. It was necessary to index these values to current conditions using a ratio of the February 2014 Consumer Price Index (CPI) to the 2012 annual CPI, as follows: 234.781 / 229.594 = 1.0226 [*148*]. These values are displayed in Table 30.

Table 30. Value-of-Time Unit Costs by Vehicle Type and Year

	User Costs (dollars per hour per vehicle)	
Vehicle Type	2012	Feb 2014*
Passenger Vehicle	$17.70	$18.10
Truck	$31.22	$31.93

*Assumes increase of 2.26 percent from 2012 based on CPI.

It was also necessary to determine the annual net decrease in travel time that would be expected to occur after increasing speed limits statewide. These values may be estimated based on the estimated change in mean speeds and annual vehicle-miles traveled during free flow conditions, displayed in the preceding section in Tables 27 and 28, respectively. The annual statewide value-of-time savings associated with increasing the posted speed limit were estimated using the following method with the results displayed in Table 31:

$$\textit{Travel Time Cost Savings (annual statewide, in dollars)} =$$
$$\textit{(VMT / Mean Speed}_{Orig\_SL}\textit{ - VMT / Mean Speed}_{New\_SL}\textit{) * User Cost (\$/veh-hour)}$$

Table 31. Estimated Annual Travel Time Savings

Facility Type	Truck Speed Limit Increase Scenario	Estimated Truck Mean Speed Increase (mph)	2012 Commercial VMT[a] (thousands)	Annual Travel Time Reduction (hours)	Annual Truck Value-of-Time Savings[b] ($)
Freeway	60 to 65 mph	62.01 to 63.70 mph	2,223,763	952,063	$30,399,364
Freeway	60 to 70 mph	62.01 to 64.99 mph	2,223,763	1,643,461	$52,475,703
Urban Freeway	55 to 70 mph	58.38 to 64.99 mph	106,292	185,178	$5,912,721
Non-Freeway	55 to 65 mph	56.00 to 59.00 mph	549,119	498,595	$15,920,124
Facility Type	**Passenger Veh. Speed Limit Increase Scenario**	**Estimated Passenger Veh. Mean Speed Increase (mph)**	**2012 Non-Commercial VMT[a] (thousands)**	**Annual Travel Time Reduction (hours)**	**Annual Passenger Veh. Value-of-Time Savings[b] ($)**
Freeway	70 to 75 mph	73.51 to 75.81 mph	19,157,736	7,906,982	$143,116,371
Freeway	70 to 80 mph	73.51 to 78.11 mph	19,157,736	15,348,305	$277,804,324
Urban Freeway	55 to 70 mph	65.66 to 73.51 mph	1,914,452	3,115,496	$56,390,469
Non-Freeway	55 to 65 mph	58.00 to 61.00 mph	9,239,327	7,834,364	$141,801,990

[a] Free flow only
[b] Value-of-time unit cost assumptions: truck = $31.93 per vehicle-hour; passenger veh. = $18.10 per vehicle-hour

IMPACTS ON TRAFFIC FATALITIES

Annual fatal crash estimates were generated for MDOT freeways and non-freeways for the following speed limit policy scenarios:

- Freeways
  - Increase truck speed limit from 60 to 65 mph or 70 mph (maintain 70 mph maximum speed limit)
  - Increase maximum speed limit on urban freeways from 55 to 70 mph
  - Increase maximum speed limit from 70 to 75 mph
  - Increase maximum speed limit from 70 to 80 mph
- Non-Freeways
  - Increase speed limit to 65 mph

Due to inconsistencies between non-fatal crash reporting practices throughout the United States, only fatal crashes were considered for this analysis. Thus, it is acknowledged that the crash values estimated herein underestimate the costs (or benefits) associated with each speed limit policy scenario. For the freeway scenarios, the speed-associated fatal crash impacts were determined using crash prediction models developed based on recent nationwide FARS data, as described in Chapter 3. Non-freeway fatal crash impacts were estimated based on research by Kockelman [*54*].

Minimal changes in fatal crashes were predicted for scenarios that only involved raising the truck/bus speed limit. For scenarios involving an increase in the maximum freeway speed limit, increases in fatal crashes of 17.6 and 29.4 percent were estimated after raising the speed limit from 70 mph to 75 or 80 mph, respectively. Raising the speed limit from 55 mph to 70 mph on urban freeways is expected to result in an estimated 27.1 percent decrease in fatal crashes. It is important to note that this reduction is based on the assumption that these roadways would be reconstructed to a higher standard (i.e., design speed) in order to accommodate the higher posted limit. As the analysis of data from recent speed limit increases on Michigan urban freeways showed (described in Chapter 3), increasing the speed limit without such modifications would potentially increase total and injury crashes. Based on research by Kockelman [*54*], raising the speed limit from 55 to 65 mph on non-freeways is expected to result in a 28 percent increase in fatal crashes.

The expected increase (or decrease) in fatal crash frequency was determined by applying the appropriate estimated percent change to fatal crashes that occurred on MDOT roadways affected by the proposed speed limit policy change. The resulting annual statewide fatal crash estimates are displayed in Table 32 for each of the aforementioned speed limit policy scenarios. As the aforementioned estimates are based on a cross-sectional analysis of the applicable nationwide crash data, it is assumed that typical design speeds and associated geometric conditions generally exist within each particular class of roadway. To that end, in order for these estimates to be used for prediction of fatal crashes associated with speed limit increases in Michigan, it must be assumed that the roadway design speeds are in compliance with the increased posted speed limit.

The average economic cost per fatal crash was estimated as $1,548,564 based on data obtained from the National Safety Council [*149*] for 2012 and indexed to February 2014 dollars based on the CPI [*148*]. This value considers only the tangible costs of motor-vehicle crashes, which include wage and productivity losses, medical expenses, administrative expenses, motor vehicle damage, and employers' uninsured costs. It does not include additional comprehensive costs, which measure the value of lost quality of life, which would greatly increase this cost. The annual statewide fatal crash costs (or benefits) were estimated for each speed limit scenario using the following method with results displayed in Table 32:

$$\textit{Fatal Crash Cost or Benefit (annual statewide, in dollars)} =$$
$$(\textit{Expected Annual Fatal Crashes}_{Orig\_SL} - \textit{Expected Annual Fatal Crashes}_{New\_SL}) * \textit{Fatal Crash Cost (\$/crash)}$$

Table 32. Changes in Estimated Annual Fatal Crashes and Associated Costs by Speed Limit Policy Scenario

	Speed Limit (pass. veh/trucks)		Estimated Annual Fatal Crashes (based on 2012 crash data)			
Facility Type	Current Policy	Proposed Policy	Current Policy	Proposed Policy	Increase (Decrease)	Estimated Annual Fatal Crash Cost Increase (Decrease)[a]
Freeway	70/60 mph	70/65 mph	91	91	0	$0
Freeway	70/60 mph	70/70 mph	91	95	4	$6,194,256
Freeway	70/60 mph	75/70 mph	91	107	16	$24,777,024
Freeway	70/60 mph	80/70 mph	91	118	27	$41,811,288
Urban Freeway	55/55 mph	70/70 mph	12	9	(3)	($4,645,692)
Non-Freeway	55/55 mph	65/65 mph	118	151	33	$51,102,612

[a]Assumes a cost per fatal crash of $1,548,564 (2014 dollars)

BENEFIT/COST ANALYSIS

Benefit/cost ratios were computed for several potential statewide speed limit policy modifications in Michigan. In all cases, the proposed changes were compared to the current speed limit of 70/60 mph on freeways and 55 mph on non-freeways and freeways in dense urban areas to determine the magnitude of each benefit or cost. Costs estimates related to geometric upgrades to achieve compliance with state and federal design speed requirements were based on unit cost estimates generated based on data provided by MDOT, as described in previous sections. Note that geometric upgrade costs will only apply to scenarios where the passenger vehicle speed limit is increased above 70 mph on freeways and 55 mph on non-freeways and dense urban freeways. Geometric modifications will not be required for scenarios that only involve increasing the truck/bus speed limit, as compliance with state and federal design speed requirements will not be impacted. In such cases, the infrastructure costs were assumed to only include costs related to upgrading the speed limit signage. It is also important to note that the estimated increase (or decrease) in fatal crashes associated with the particular speed limit increase assume that the roadway design speed is in compliance with the increased posted speed limit. Utilizing the procedures described in the preceding sections for calculation of the itemized statewide costs and benefits, separate benefit/cost ratios were computed for each of the possible speed limit scenarios as follows, with results displayed in Table 33:

$$\frac{B}{C} = \frac{Travel\ Time\ Savings + Crash\ Reductions\ (if\ Differential\ Speed\ Limit\ Eliminated)}{Increased\ Fuel\ Consumption + Infrastructure\ Modifications + Crash\ Increases\ (if\ Speed\ LImit\ Increased)}$$

Table 33. Results of Systemwide Benefit/Cost Analysis by Speed Limit Policy Scenario

Facility Type	Current Speed Limit	Proposed Speed Limit	Travel Time Cost (Benefit)	Increased Fuel Consumption Cost	Infrastructure Modification Cost	Fatal Crash Cost (Benefit)	B/C
Freeway	70/60 mph	70/65 mph	($30,399,364)	$40,614,893	$113,100[a]	$0	0.75
Freeway	70/60 mph	70/70 mph	($52,475,703)	$72,520,606	$113,100[a]	$6,194,256	0.67
Freeway	70/60 mph	75/70 mph	($195,592,074)	$196,042,352	$81,937,550[b]	$24,777,024	0.65
Freeway	70/60 mph	80/70 mph	($330,280,027)	$330,010,681	$163,875,100	$41,811,288	0.62
Urban Freeway	55/55 mph	70/70 mph	($62,303,190)	$43,021,563	$203,810,400	($4,645,692)	0.27
Non-Freeway	55/55 mph	65/65 mph	($157,722,114)	$63,759,197	$509,643,000	$51,102,612	0.25

Note: All monetary values are annualized 2014 dollars.
[a]Includes costs related to upgrading the speed limit signage only
[b]Assumes 50% of costs associated with speed limit increase to 80/70

The benefit/cost results displayed in Table 33 suggest that none of the proposed speed limit policy scenarios present a favorable economic condition compared to the current policy. The most favorable (albeit economically undesirable) of these proposed scenarios include cases where only the freeway truck speed limit is increased, either from 60 to 65 mph or 60 to 70 mph, while preserving the 70 mph maximum speed limit. This is largely due to the expected absence of any infrastructure upgrades aside from the speed limit signs, in addition to minimal expected impacts on fatal crashes. However, the benefit/cost ratio remains less than 1.0, largely due to the expectation that the increased fuel consumption costs associated with higher operating speeds will outweigh the resulting travel time savings.

All proposed speed limit policy scenarios involving an increase in the maximum speed limit will undoubtedly result in substantial infrastructure costs associated with geometric modifications necessary to increase the design speed to comply with state and federal requirements. The majority of the MDOT highway network is currently designed for compliance with posted speed limits of 70 mph on freeways and 55 mph on non-freeways and freeways in dense urban areas. Consequently, system-wide increases in the posted speed limit beyond these levels will result in geometric upgrade costs that will greatly outweigh any net user benefits, resulting in benefit/cost ratios well below 1.0. This is especially true for urban freeways and non-freeways currently posted at 55 mph where geometric modification costs are expected to be especially severe. Furthermore, as only fatal crashes were considered in the crash estimation process, the crash costs are likely underestimated for all scenarios included in the benefit/cost analysis. Inclusion of injury and property damage crashes would likely increase the crash costs for all scenarios, thereby further reducing the corresponding benefit/cost ratios.

Increasing the maximum speed limits on freeways and non-freeways should only be considered for sections of roadway where design speed compliance is maintained after the increase to avoid costly geometric improvements. However, even if design speed compliance can be maintained, careful consideration must be given to the potential safety impacts that may result from such increases. To those ends, it is recommended that comprehensive engineering and safety analyses be performed prior to any speed limit increase for those roadway segments under consideration.

NOISE IMPACTS

The noise impacts associated with the proposed speed limit increases were modeled using the following equation [*150*]:

$$L_{eq} = 42.3 + 10.2*\log(V_C+6V_T) – 13.9*\log D + 0.13*S$$

Where: L_{eq} = mean hourly noise (A-weighted decibels [dB_A])

V_C = hourly passenger vehicle volume (vph)

V_T = hourly heavy truck volume (vph)

D = receiver offset distance from edge of roadway (m)

S = average speed of traffic stream (kph)

Estimates for the average speed of the traffic stream during uncongested conditions were determined based on the speed prediction model displayed in. Average noise levels (L_{eq}) were estimated for the following scenarios:

- Speed limits (cars/trucks): 55/55; 65/65; 70/60; 70/70; 75/70; 80/70
- Total hourly volume: 2,500; 7,500
- Truck percentage: 10 percent; 25 percent
- Receiver offset distance: 30 meters; 60 meters

The noise prediction results for various speed limit increase scenarios at a receiver distance of 30 meters are displayed in Table 34.

Table 34. Predicted Mean Noise (L_{eq}) versus Speed Limit at 30 Meters

	Mean Traffic Speed (mph) 10% Trucks			L_{eq} (dBA): 2,500 vph, 10% Trucks			L_{eq} (dBA): 7,500 vph, 10% Trucks		
Speed Limit Increase Scenario	Current	Proposed	Increase	Current	Proposed	Increase	Current	Proposed	Increase
70/60 to 70/70	71.8	71.8	0	73.2	73.2	0	78.1	78.1	0
70/60 to 75/70	71.8	74.1	2.3	73.2	73.7	0.5	78.1	78.6	0.5
70/60 to 80/70	71.8	76.4	4.6	73.2	74.2	1.0	78.1	79.1	1.0
55/55 to 70/70 (Urban Fwy)	64.7	71.9	7.2	71.8	73.3	1.5	76.6	78.1	1.5
55/55 to 65/65 (Non-Freeway)	57.8	60.8	3.0	70.3	70.9	0.6	75.2	75.8	0.6
	Mean Traffic Speed (mph) 25% Trucks			L_{eq} (dBA): 2,500 vph, 25% Trucks			L_{eq} (dBA): 7,500 vph, 25% Trucks		
Speed Limit Increase Scenario	Current	Proposed	Increase	Current	Proposed	Increase	Current	Proposed	Increase
70/60 to 70/70	71.5	71.5	0	75.0	75.0	0	79.8	79.8	0
70/60 to 75/70	71.5	73.8	2.3	75.0	75.5	0.5	79.8	80.3	0.5
70/60 to 80/70	71.5	76.1	4.6	75.0	76.0	1.0	79.8	80.8	1.0
55/55 to 70/70 (Urban Fwy)	64.4	71.5	7.1	73.5	75.0	1.5	78.4	79.9	1.5
55/55 to 65/65 (Non-Freeway)	57.5	60.5	3.0	72.0	72.6	0.6	76.9	77.5	0.6

Table 34 presents several interesting findings. First, based on the range of values considered here, traffic volume and truck percentage are predicted to have a greater impact on L_{eq} than the speed limit increase. As traffic volumes increase from 2,500 to 7,500, L_{eq} increases by nearly 5 decibels. Increasing the truck percentage from 10 to 25 percent resulted in a nearly 2 decibel increase in L_{eq}, although little impact on average speeds of the traffic stream is expected.

Depending on the proposed speed limit scenario, average travel speeds were predicted to increase between 0.1 mph to 7.2 mph, resulting in modest L_{eq} increases of 0 to 1.5 dBA. Due to the nature of the noise prediction model, for each speed limit increase scenario, the predicted noise increase remains constant as the traffic volume or truck percentage was varied. Although the results for the 60 meter offset distance are not displayed here, this also holds true for receiver distance. Thus, for a proposed speed limit increase, the difference between the current and proposed L_{eq} may be predicted based solely on the expected increase in average speed of the traffic stream, with consistent results expected across all traffic volumes, truck volumes, and receiver distances. The predicted increases in mean noise and mean speed resulting from the various speed limit increase scenarios are reflected in Figure 44.

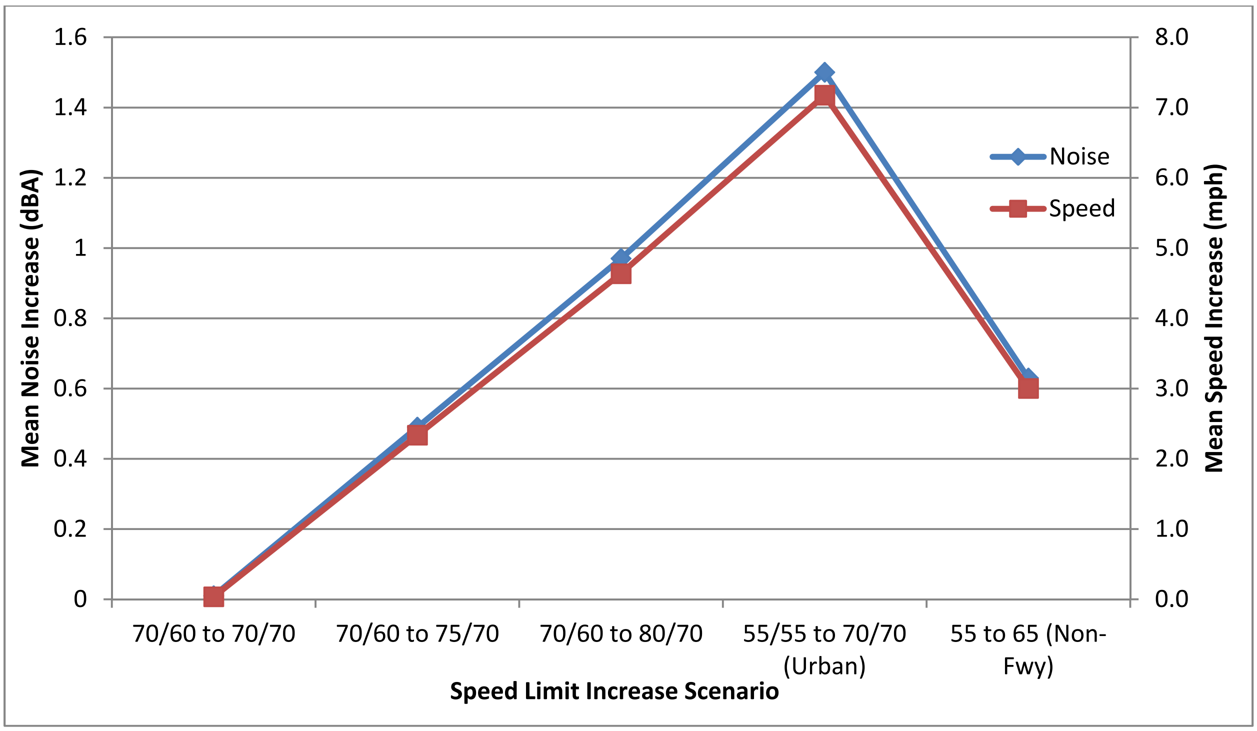


Figure 44. Predicted Impacts of Speed Limit Policy on Mean Speed and Mean Noise

Not surprisingly, raising only the truck speed limit (i.e., from 70/60 to 70/70) will likely have no impact on noise. Increasing the passenger vehicle and truck speed limits from 70/60 to 80/70 on freeways is expected to result in a modest 1.0 decibel increase in mean noise. Increasing the speed limit from 55 to 65 mph on non-freeways is expected to result in a 0.6 decibel increase.

The largest increase in noise will result from increasing the speed limit on urban freeways from 55/55 to 70/70, which is expected to increase L_{eq} by 1.5 decibels.

ADDITIONAL IMPACTS – AIR QUALITY

Beyond the economic factors discussed previously, speed limit increases are likely to result in additional impacts, such as air quality. The National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) were initially developed as part of the 1990 Clean Air Act (CAA). The NAAQS includes two standards: the primary standards, which were developed to protect the health of the public, and the secondary standards, which were developed to ensure adequate visibility as well as prevent damage to crops and animals [*151*]. Six common air pollutants (often referred to as "criteria pollutants") are regulated by the United States Environmental Protection Agency (USEPA) and are protected under the NAAQS [*151*]. The six criteria pollutants are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), fine particulate matter that is less than 2.5 microns ($PM_{2.5}$), inhalable coarse particulate matter that is between 2.5 and 10 microns in size (PM_{10}), and sulfur dioxide (SO_2). The NAAQS for the criteria pollutants are summarized in Table 35. In all cases, these pollutant concentration levels are based on ambient concentrations from mobile and stationary sources throughout a given region.

The USEPA, following regulations in 40 CFR, Part 58, requires all states to monitor the ambient concentration levels for the six criteria pollutants at the county level on an annual basis [*151*]. A listing of all the state monitoring sites as well as annual air quality reports may be found on the website of the Air Quality Division of the Michigan Department of Environmental Quality [*152*]. If the ambient levels of the six criteria pollutants in an area are within the appropriate ambient air quality standards, the area is considered to be in "attainment." However, if the ambient level for one of the criteria pollutants in an area persistently exceeds the ambient air quality standards, the area may be considered as "nonattainment" for that specific pollutant.

Table 35. National Ambient Air Quality Standards

Pollutant	Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)	Primary	8-hour	9 ppm	Not to be exceeded more than once per year.
		1-hour	35 ppm	
Lead (Pb)	Primary and Secondary	Rolling 3 month average	0.15 $\mu g/m^3$	Not be exceeded
Nitrogen Dioxide (NO_2)	Primary	1-hour	100 ppb	98th percentile, averaged over 3 years
	Primary and Secondary	Annual	53 ppb	Annual mean
Ozone (O_3)	Primary and Secondary	8-hour	0.075 ppm	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
$PM_{2.5}$	Primary	Annual	12 $\mu g/m^3$	Annual mean averaged over 3 years
	Secondary	Annual	15 $\mu g/m^3$	Annual mean averaged over 3 years
	Primary and Secondary	24-hour	35 $\mu g/m^3$	98th percentile, averaged over 3 years
PM_{10}	Primary and Secondary	24-hour	150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)	Primary	1-hour	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year
Note: This table is developed from the EPA [*151*]				

The State of Michigan is currently within the attainment levels for carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, and particulate matter less than 10 microns (PM_{10}) [*153*]. The state is out of compliance (and is therefore considered by EPA to be in nonattainment) for annual and 24-hour for particulate matter less than 2.5 microns ($PM_{2.5}$) in the following counties: Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne – all of which are within the Detroit metropolitan area. Additionally a portion of Wayne County is in non-attainment for SO_x . Lastly, the city of Belding in Ionia County does not meet NAAQs levels for lead (Pb) [*153*].

The Clean Air Act (CAA) requires all states to develop a State Implementation Plan (SIP)to achieve and maintain the NAAQS. The objectives of the SIP are to "1) demonstrate the state has the basic air quality management programs in place to implement a new or revised NAAQS and

2) identify the emissions control requirements the state will rely upon to attain and/or maintain the primary and secondary NAAQS" [*154*]. The Michigan SIP may be found at the USEPA website [*155*]. The emission's budget contained in the SIP directly specifies the total mass of pollutant emissions that are allowed from both stationary and mobile sources.

Case Study of Emission Impacts

As a result of the importance of estimating mobile source emissions, the USEPA has developed the Motor Vehicle Emissions Simulator (MOVES), modeling software for estimating emissions from cars, trucks, motorcycles, and buses that can be used for planning and analysis. The MOVES software is a front end graphical user interface (GUI) that runs a series of structured query language (SQL) databases to simulate the effects of vehicles in a given area on the environment.

For the purposes of this study, case studies were conducted to examine prospective air quality impacts associated with increasing speed limits. The EPA's MOVES software was used to estimate changes in vehicle emissions associated with increases in travel speeds from 60 mph to 75 mph.

In this research, case studies using county-level run specifications were developed for six counties across Michigan, including Oceana, Sanilac, Shiawassee, St. Joseph, Tuscola, and Van Buren. These six counties were chosen based on the availability of the required input data; which were provided by MDOT. Detailed traffic data is the major attributed difference between these counties, other than the geographic composition. A series of simulations were conducted in order to establish baseline emissions at 60 MPH, which were compared with estimated emissions for additional simulations at a speed limit of 75 MPH. For the six-county case study, a total of 60 MOVES simulations were completed. Figure 45 indicates the flow of data and the anticipated completed results of the simulations.

Results of Emissions Case Study

Table 36 shows the net percent difference between the individual emissions factors. It is important to mention that in some cases, the final results may not be valid due to the limited amount of information presently known about a particular vehicle. For these situations, no values are included in the table. The results presented in this section are based on the methodology described in the previous section (Figure 44) for the counties of Oceana, Sanilac, Shiawassee, St. Joseph, Tuscola, and Van Buren. In each case, the final emissions are averaged over all vehicle ages and fuel types associated with each type of vehicle. For example, the emission results for passenger cars will include all ages of vehicles and all six engine technologies on a weighted distribution. Due to the sheer volume of data (more than 500 gigabytes of results), individual emissions factors for a specific vehicle type are not included in this report.

Table 36. Average Pollutant Emission Change with Increases in Travel Speeds from 60 mph to 75 mph

Vehicle Type	Average CO	Average NOx	Average SOx	Average THC	Average PM_{10}	Average $PM_{2.5}$
Motorcycle	-2.5%	-4.7%	3.3%	-9.2%	-13.3%	-13.3%
Passenger Car	20.2%	12.7%	7.1%	1.9%	12.3%	12.3%
Passenger Truck	21.7%	9.8%	9.6%	-2.6%	-2.3%	-2.4%
Light Commercial Truck	21.5%	9.7%	9.9%	-4.4%	-2.5%	-2.6%
Intercity Bus	-2.8%	8.7%			-0.3%	-0.3%
Transit Bus	-0.2%	6.2%	6.4%	-5.6%	0.1%	0.1%
School Bus	21.8%	20.6%	5.2%	-3.8%	-4.6%	-4.5%
Refuse Truck	9.5%	7.7%	2.6%	-1.6%	-3.5%	-3.4%
Single Unit Short-Haul Truck	5.2%	4.8%	-7.0%	-15.0%	-15.5%	-15.5%
Single Unit Long-Haul Truck	0.3%	0.2%	-10.6%	-17.7%	-17.6%	-17.6%
Motorhome	21.7%	20.3%	3.5%	-6.1%	-11.4%	-11.4%
Combination Short-Haul Truck	8.2%	7.4%	4.7%	-3.2%	2.0%	2.0%
Combination Long-Haul Truck	-7.2%	7.5%	3.3%	-9.8%	4.0%	4.0%

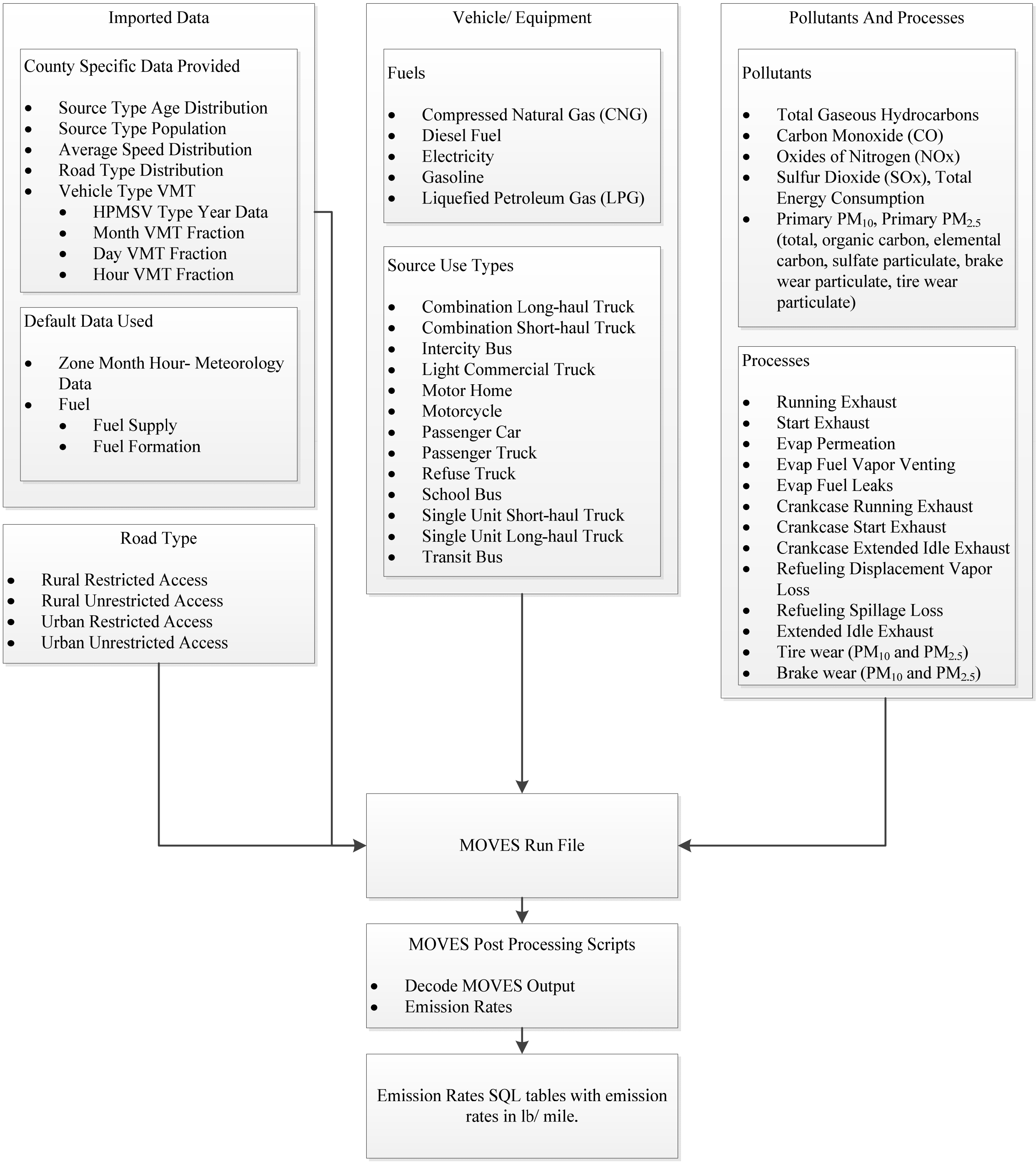


Figure 45. Flow of Data and Anticipated Results of the Simulations

Carbon monoxide results are the first finding in Table 36. With the exception of motorcycles, intercity buses, transit buses and combination long-haul trucks, the results suggest that there would be an increase in carbon monoxide emissions if the posted speed limits are increased.

The largest increases in emissions are from passenger cars, passenger trucks, school buses, and motor homes. With the exception of transit buses, the general results as shown by the standard deviation of the findings are consistent between the counties. This suggests that the overall fleet distribution and vehicle activity within each county is similar.

With the exception of motorcycles, the results for NO_x show an increase in the overall emissions for all other vehicle types. These findings suggest that an increase in speed limits will increase the emissions of NO_x for most vehicle types. The largest percent increase, which approaches 20%, comes from school buses and motorhomes. Other results of significance show that the more common vehicles such as passenger cars and passenger trucks, as well as single unit and combination trucks in general, will increase the emissions range from 0.2% to 12.7%.

Similar to CO and NO_x, the majority of the vehicles – with the exception of single unit short-haul and single unit long-haul trucks – have increased SO_x vehicle emissions with the faster suggested speeds. The results for THC show that emissions per vehicle type, with the exception of passenger cars, decreases with increasing speeds. The most significant decreases are related to single unit short- and long-haul trucks. Finally, the results for PM_{10} and $PM_{2.5}$ are consistent between both pollutant types. The results with the exception of passenger cars suggest that particulate matter emissions decrease with the increasing speeds.

These simulations provide general results of how air quality would be affected by increases in vehicles speeds. It should be noted that these case studies were conducted for a six-county sample, which did not include any high impact non-attainment areas. If speed limit increases were to occur, additional consideration should be paid to nonattainment regions, such as the Detroit metropolitan area. In order to capture the particular effects in the nonattainment areas as well as other geographically large areas of Michigan, it would be necessary to create several additional case studies using more detailed project-scale data based on field-captured information (as opposed to the more general county-level data used herein). Such research is beyond the scope of this report.

ADDITIONAL IMPACTS – PAVEMENT CONDITION

A number of studies have been conducted to consider various vehicle characteristics on pavement performance and life expectancy. Vehicle speed, weight, and suspension type, in conjunction with pavement type and surface, play a significant role in the deterioration rate of the pavement. A study conducted by researchers at Qingdao University in China looked at the impact of vehicle speeds on pavement performance. Using speeds ranging from 30 to 50 mph and vehicles overloaded by 25, 50, and 75 percent, they found that the vertical, transverse, and horizontal stresses decreased as speeds increased [*156*].

A study looking at the relationship between vehicle speed and pavement performance was conducted in New Zealand to analyze the effects of increasing the heavy vehicle speed limit from 50 to 100 km/h. Impact factors were calculated which represented the ratio of dynamic loading effects to their static loading counterparts [*157*]. While the researchers were unable to identify a defined trend, they did consider it reasonable to assume a 10 percent increase in the impact factor over that speed increase [*157*].

An additional concern is the effect of dynamic vs. static loading on pavement performance. This is an important consideration as the dynamic load is a combination of the weight of the vehicle and the response of the vehicle's suspension and as such, can be greater than its static equivalent [*158*]. Research by Misaghi et al. showed a correlated increase in dynamic loading with increases in vehicle speed and even greater increases on rough pavement [*158*].

The effect of rough or deteriorated pavement, as well as axle spacing, was explored in the National Cooperative Highway Research Program (NCHRP) Report 353. This particular study considered the response of both rigid and flexible pavements, ultimately coming to the conclusion that, "…generally, higher speeds are slightly more damaging to rigid pavements, and slightly less damaging to flexible pavements" [*159*]. This was due in part to the condition of the pavement itself, meaning that there is no reason to limit vehicle speeds to reduce pavement deterioration on roads in good condition. Supporting this conclusion, a series of tests performed by Izquierdo et al. in 2002 found that speed had little effect on concrete pavements, but that a rougher pavement surface would likely increase dynamic loading [*160*].

A study conducted by Hardy and Cebon in 1994 considered the effects of speed and frequency on pavement response. Simplified and complex models were developed, which took vehicle speed, frequency, and structural characteristics into account [*161*]. Holding the load constant as it moved across the pavement surface and increasing the speed from 11 to 90 mph, the study found that the base and soil strains decreased as the speed increased. They also noted, however, that at higher frequencies the speed of the vehicle had less of an impact on strain measurements than the frequency itself [*161*].

The effect of pavement surface roughness on the frequency, and consequently, magnitude of dynamic loading, was tested at the Minnesota Road Research Project. Several test sections with varying levels of roughness were used to study their combined effects. Truck speeds used for the study ranged from 10 to 103 km/h (6 to 64 mph) [*162*]. The results of the study suggested that vehicle speed and pavement roughness played conflicting roles in effecting the strain placed on pavement. On smoother test sections as the speed increased the strain decreased. However, when conducted on rougher sections of flexible pavement the strains decreased as the truck approached 65 km/h and then increased as the vehicle speed increased further to 103 km/h [*162*].

During the course of this project, the Michigan Department of Transportation conducted some preliminary analyses to estimate potential pavement condition impacts that would be associated with a speed limit increase. Consistent with the aforementioned findings from Minnesota, the results suggested that distress propagation would not be substantially more severe on smooth sections of pavement. In contrast, it is expected that rough pavements would experience accelerated deterioration due to dynamic vertical impact forces.

CHAPTER 6:

CONCLUSIONS AND RECOMMENDATIONS

Speed management and the establishment of maximum speed limit policies in consideration of safety impacts have long been important concerns of transportation agencies. The Emergency Highway Energy Conservation Act of 1974 established a federally national maximum speed limit (NMSL) of 55 mph. In 1987, the NMSL was relaxed, allowing states to increase speeds on rural interstates to 65 mph. In 1995, the NMSL was fully repealed, providing states with full authority to establish appropriate speed limits on all roadways. Given the potential implications on safety, these speed limit policy decisions have been the subject of extensive research. Research has examined the effects of maximum vehicular speed limits, as well as the influence of differential speed limits, where trucks and buses are subject to a lower limit than passenger vehicles.

Recently, legislation has been introduced in Michigan (SB 896) that would create a new "Rural Freeway General Speed Limit" of 80 mph and a new "Urban Freeway General Speed Limit" of 70 mph, in addition to increase the maximum speed limit for trucks and buses from 60 mph to 70 mph. Additional speed limit increases have been proposed for non-limited access roadways, as well.

In order to ascertain the potential impacts of these proposed speed limit increases, this research examined a broad range of traffic safety, operational, environmental, and economic data. Ultimately, the objective of this study was to collect and analyze empirical data from across the United States in order to develop recommendations for the consideration of speed limit increases in Michigan. Against this backdrop this research study involved:

- A comprehensive state-of-the-art review of research examining the relationships between traffic speed, safety, and crash risk. This included a survey of state agency practices with respect to speed limit establishment, as well as a survey of the trucking industry to obtain feedback on differential vs. uniform limits.
- Collection and analysis of national interstate fatality data to ascertain the effects of speed limit policies on traffic fatalities, with specific emphasis on maximum speed limits and the effects of uniform vs. differential limits on urban and rural interstates.

- Collection and analysis of traffic crash, injury, fatality, and vehicle-miles of travel data for Michigan freeways. These analyses compared differences in safety performance between freeways with different speed limits, as well between urban and rural settings.
- Analysis of field collected speed data from Michigan, Indiana, and Ohio to ascertain differences in mean speeds, 85th percentile speeds, and the standard deviation in speeds among passenger cars, trucks, and buses. These states have 10-mph differential, 5-mph differential, and uniform speed limits, respectively.
- A comprehensive economic analysis of the proposed speed limit changes in consideration of both road user and agency costs.

CONCLUSIONS

Prior research on maximum speed limits has generally shown that higher speed limits tend to result in increases in traffic fatalities. This is particularly true for rural freeways, which have the highest limits among all functional roadway classes in the United States, ranging up to as high as 85 mph on select facilities in Texas. The research on differential limits has generally been inconsistent, with some states demonstrating higher fatality rates and others exhibiting lower rates as compared to states with uniform limits.

Data from 1999 through 2011 were examined as part of this study in order to assess fatality trends on both rural and urban interstates, as well as to examine the issue of differential limits. Random effects negative binomial regression models were estimated to quantify the relationship between fatalities and speed limits while controlling for additional factors such as vehicle-miles of travel.

The results showed traffic fatalities to increase consistently with maximum speed limits in rural environments. Compared to interstates with 60 or 65 mph limits, fatalities increased by 31.0 percent in states with 70 mph maximum limits and by 54.0 percent in states with maximum limits of 75 mph or above. Truck- and bus-involved fatalities on rural interstates were 20.5 percent higher in states with uniform speed limits as compared to states with differential limits for larger vehicles. States with higher speed limits showed a higher percentage of single-vehicle crashes, a possible reflection of drivers being less capable of safely navigating interstates at higher speeds. In contrast, states with lower maximum limits experienced a higher percentage of rear-end collisions. Marginal differences were found with respect to light conditions and work zone activity.

Consistent trends were not observed on the urban interstate network with respect to maximum speed limits. It is important to note that this does not necessarily imply that speed limits do not have a substantive impact in an urban setting. Urban environments are generally subject to higher levels of congestion and more challenging roadway geometry and alignment issues, which limit the design speed in such environments. As a result, speed limits are generally lower in an urban setting, which potentially leads to increased variability in travel speeds.

In Michigan, a small subset of such urban freeways is posted at a uniform 55-mph limit. These segments were examined in greater detail as a part of this study. The results of this analysis showed that the 55-mph segments experienced total, injury, and fatal crash rates that were 49 percent, 97 percent, and 45 percent higher than those segments that were posted at 70 mph for passenger vehicles and 60 mph for trucks and buses. Crash and injury rates were slightly higher among urban segments posted at 70 mph/60 mph than similar rural segments. Additional research into this issue was conducted by comparing data for seven freeway segments on which speed limits were increased from 55 mph to 65 or 70 mph (and 60 mph for trucks/buses) between 2004 and 2012. A comparison of crash data for these segments with adjacent control locations (all of which were posted at 70 mph) showed that total and injury crashes increased on the segments where speeds were increased and decreased on the adjacent control locations. Consequently, these results suggest that the lower crash, injury, and fatality rates shown at the aggregate level among freeways posted at 70 mph is reflective of freeways with higher design speeds. This illustrates the importance of segment-specific geometric and traffic characteristics when considering speed limit increases.

Returning to the issue of truck and bus speed limits, the analysis of fatality data showed that total fatality rates were not significantly different between states with uniform and differential truck and bus limits. However, rural truck- and bus-involved fatalities were higher in states with uniform limits than states with differential limits. One of the reasons that many states have transitioned from differential to uniform limits has been due to the fact that uniform limits have been shown to reduce the variance in travel speeds, which may in turn reduce the risk of traffic crashes and resultant injuries/fatalities. Responses from the trucking industry survey reinforce this argument. In order to quantitatively assess this issue, as well as general speed selection behavior, spot speed studies were conducted at 160 freeway locations in Michigan, Indiana, and Ohio. These sites were split among urban and rural freeways and provide geographic diversity. Further, a subset of the locations were on freeways that passed through these neighboring states, allowing for a controlled comparison of speed limit impacts.

Analysis of these speed data show that mean and 85th percentile travel speeds for passenger were quite consistent among the three states when a common limit of 55 mph or 70 mph was in effect. Conversely, truck and bus speeds were more variable, which is likely due to the existing differential limits in Indiana (5 mph) and Michigan (10 mph). However, the differences in mean and 85th percentile speeds were much less pronounced at 2.1 mph and 4.2 mph, respectively. While the mean and 85th percentile truck and bus speeds were above the posted limit of 60 mph in Michigan, compliance increased substantially in Indiana and Ohio, in particular.

The variability in travel speeds was also found to vary significantly based upon the posted speed limit. For all vehicles combined, the highest standard deviation in travel speeds was found on freeways posted at 70 mph for passenger vehicles and 60 mph for trucks and buses (6.9 mph on average). This was higher than the standard deviation at locations with a uniform 55-mph limit or with a 5-mph differential (70 mph/65 mph), which was 6.2 mph on average. Standard deviations in travel speeds were significantly less on those segments with uniform speed limits. Segments posted at 65/65 showed a standard deviation of 5.7 mph while those posted at 70/70 showed the lowest standard deviation at 5.4 mph. Collectively, these findings present some evidence to potentially explain some of the trends that were observed in the urban fatality data.

Based upon the results of the fatality and speed data analyses, estimates were obtained as to prospective impacts of increasing Michigan's existing speed limits for trucks and buses, as well as for passenger vehicles. Using these estimates, an economic analysis was conducted to compare the following scenarios:

- Increasing the maximum freeway truck/bus speed limit to 65 or 70 mph
- Increasing rural freeway speed limits to 75 or 80 mph
- Increasing existing 55 mph urban speed limits to 70 mph
- Increasing speed limits on non-freeway facilities from 55 to 65 mph

This economic analysis focused on road user costs and benefits, installation costs for speed limit sign upgrades, and estimates of system-wide costs for geometric upgrades necessary to accommodate higher design speeds. The results of the economic analysis suggest that none of the proposed speed limit policy scenarios present a favorable economic condition compared to the current policy when considering the costs necessary for full reconstruction that will accommodate the design standards required for higher speed facilities. The most favorable of these proposed scenarios include cases where only the freeway truck speed limit is increased, either from 60 to 65 mph or 60 to 70 mph, while preserving the 70 mph maximum speed limit. This is largely due to the expected absence of any infrastructure upgrades aside from the speed limit signs, in addition to minimal expected impacts on fatal crashes. However, the benefit/cost ratio remains less than 1.0, largely due to the expectation that the increased fuel consumption costs associated with higher operating speeds will outweigh the resulting travel time savings.

RECOMMENDATIONS

While several states have enacted speed limit increases over the past four to five years, these increases have been selective and based on extensive analyses of existing traffic speeds and historical crash trends. Given the relatively short time period for which post-increase data are available, surveyed agencies were unable to determine whether any substantive safety impacts had resulted. This is a particular concern at the highest speed limit ranges as only Idaho, Texas, Utah, and Wyoming have implemented 80-mph or higher limits (and these limits have been imposed very selectively).

Any scenarios involving an increase in the maximum speed limit will result in substantial infrastructure costs associated with geometric modifications necessary to increase the design speed to comply with state and federal requirements. The majority of the MDOT highway network is currently designed for compliance with posted speed limits of 70 mph on freeways and 55 mph on non-freeways and freeways in dense urban areas. System-wide increases in the posted speed limit beyond these levels will result in geometric upgrade costs that will greatly outweigh any net user benefits, resulting in benefit/cost ratios well below 1.0. This is especially true for urban freeways and non-freeways currently posted at 55 mph where geometric modification costs are expected to be especially severe. Thus, increasing the maximum speed limits on freeways and non-freeways should only be considered for sections of roadway where design speed compliance is maintained after the increase to avoid costly geometric improvements.

Ultimately, it is recommended that detailed engineering and safety analyses be performed prior to increasing the posted speed limit for any roadways under consideration. Prior to enacting any speed limit increases, it is recommended that more detailed historic data is examined, including but not limited to:

- Mean and 85th percentile speeds – Research suggests that crashes are generally minimized when the posted speed limit is near the 85th percentile of free-flowing traffic. Consequently, locations with large variations between the posted and 85th percentile speeds represent prospective candidate locations for speed limit increases.
- Variability in travel speeds – Research has also demonstrated that crashes tend to increase as the variability in travel speeds increases. The speed data from this project suggest that variability is greatest at freeway locations with a 10-mph differential (70/60), followed by those with a 5-mph differential (70/65) or uniform 55 mph limit.
- Crash history and roadway geometry – It is important to consider whether a location has a history of crashes, particularly those that may be speeding-related when determining whether an increase is appropriate. Locations with high densities of entry/exit ramps, sight distance restrictions (often due to horizontal and vertical curvature), or other design exceptions (where the design speed of the roadway is less than the posted limit) should be examined very cautiously.
- Traffic volumes – Even if the 85th percentile speed under free-flow conditions suggests that an increase may be appropriate, this must be balanced with the level of traffic volume on specific roadways. If a roadway is subject to heavy congestion over prolonged periods of the day, higher speed limits in these areas may greatly increase the potential for collisions as faster moving traffic enters congested areas.

AREAS FOR FUTURE RESEARCH

This study provides important information that can be used as an input in guiding speed limit policy decisions. However, further research is warranted prior to introducing such limits, specifically:

1. More detailed, disaggregate analyses of the relationships between speeds and traffic crashes, injuries, and fatalities on Michigan highways is warranted. Michigan has introduced two speed limit increases during the past 20 years, providing an opportunity to examine trends on specific road segments. By analyzing these segments at a more detailed level, additional insights may be obtained as to those locations that may be reasonable candidate for speed limit increases.
2. Further research is necessary into the potential effects of speed limits on non-limited access facilities, particularly two-lane highways where the maximum posted speed limit is currently 55 mph. On these types of facilities, road geometry plays a much larger role than the posted speed limit on speed selection as drivers generally travel at speeds as dictated by prevailing road conditions. Nationally, most states recognize a 55 mph limit on such facilities. The analysis of traffic speed and crash data for a diverse range of two-lane facilities, in combination with economic data required for infrastructure upgrades, represent important areas of research prior to increasing speeds on these roadways.

APPENDIX: Field Speed Data

Table 37. Summary of Michigan Speed Data

Route #	Passenger Vehicles						Trucks/Buses						All Vehicles		
	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-75	55	67.5	6.10	74.00	0.88	0.61	55	57.9	4.25	62.00	0.22	0.04	65.94	6.79	73.0
I-75	55	69.2	6.46	76.00	0.92	0.72	55	59.7	4.04	63.00	0.44	0.06	67.16	7.17	75.0
I-75	55	68.5	5.58	74.00	0.90	0.71	55	59.2	3.77	63.00	0.34	0.03	66.33	6.53	74.0
I-75	55	65.9	6.42	73.00	0.79	0.51	55	58.4	4.27	62.00	0.29	0.04	64.54	6.70	71.0
I-75	55	67.0	6.89	74.00	0.82	0.61	55	57.4	4.25	61.00	0.19	0.04	65.71	7.38	74.0
I-75	55	68.0	5.71	74.00	0.90	0.65	55	57.2	4.84	61.00	0.17	0.07	66.61	6.65	73.0
I-75	70	70.0	6.01	76.00	0.16	0.02	60	59.1	3.64	63.00	0.01	0.00	67.82	7.08	75.0
I-94	55	62.3	7.52	70.00	0.62	0.35	55	54.6	5.31	59.15	0.11	0.02	61.32	7.73	69.0
I-94	55	68.2	6.85	75.00	0.84	0.69	55	59.0	4.81	63.00	0.38	0.05	66.86	7.33	75.0
I-94	55	67.6	6.35	74.00	0.87	0.63	55	58.7	4.62	64.00	0.35	0.08	66.81	6.70	74.0
I-94	55	67.8	6.15	74.00	0.91	0.66	55	59.5	4.22	63.00	0.36	0.06	66.89	6.46	74.0
I-94	55	66.4	6.85	73.15	0.79	0.57	55	58.5	3.94	62.00	0.30	0.02	65.29	7.04	73.0
I-94	55	65.7	6.19	72.15	0.80	0.52	55	57.8	4.38	62.00	0.23	0.01	64.82	6.48	72.0
I-94	55	64.3	6.05	70.00	0.75	0.44	55	57.9	3.98	62.00	0.30	0.01	63.63	6.16	69.0
I-94	55	68.3	7.48	75.00	0.88	0.65	55	60.9	5.20	65.15	0.50	0.15	67.75	7.57	74.0
I-94	55	66.7	6.59	73.00	0.81	0.63	55	58.4	3.80	62.00	0.29	0.02	65.89	6.82	72.0
I-94	55	61.6	7.58	69.00	0.57	0.30	55	55.0	4.73	60.00	0.14	0.01	60.62	7.57	68.0
I-94	55	63.8	6.97	71.00	0.67	0.44	55	57.5	4.74	62.00	0.28	0.02	62.74	7.05	70.0
I-94	55	65.8	6.41	72.15	0.77	0.54	55	58.3	4.82	63.00	0.33	0.03	65.23	6.56	72.0
I-94	55	70.5	5.95	76.00	0.94	0.81	55	61.4	3.91	65.00	0.59	0.13	68.93	6.58	76.0

Table 37. Summary of Michigan Speed Data (Cont'd)

Route #	Passenger Vehicles						Trucks/Buses						All Vehicles		
	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-94	70	66.4	6.27	72.15	0.06	0.02	60	59.1	3.35	62.00	0.01	0.00	65.59	6.41	72.0
I-96	70	70.4	7.51	77.00	0.22	0.07	60	60.6	5.11	65.00	0.11	0.03	69.66	7.75	77.0
I-96	70	70.0	6.50	76.00	0.17	0.05	60	60.6	4.65	64.15	0.11	0.02	69.16	6.88	75.0
I-96	70	71.8	5.73	78.00	0.24	0.08	60	61.3	3.61	64.15	0.12	0.02	70.87	6.31	77.0
I-96	70	73.0	5.69	79.00	0.34	0.09	60	61.9	4.36	65.00	0.14	0.04	72.16	6.25	79.0
I-96	55	67.0	5.38	73.00	0.91	0.57	55	58.4	4.67	62.00	0.31	0.05	66.15	5.86	72.0
I-96	70	70.8	5.64	76.15	0.20	0.04	60	60.3	4.09	64.00	0.08	0.00	70.22	5.99	76.0
I-96	55	67.4	6.03	73.00	0.87	0.62	55	56.3	5.29	62.00	0.21	0.01	66.34	6.75	72.0
I-96	70	72.7	5.36	78.00	0.29	0.07	60	61.0	4.29	64.00	0.12	0.03	71.94	6.05	78.0
I-96	55	69.2	6.67	76.00	0.89	0.70	55	58.7	4.99	63.00	0.35	0.08	68.00	7.30	76.0
M-10	55	65.7	6.15	72.00	0.83	0.48	55	56.4	5.16	62.15	0.24	0.01	65.43	6.30	72.0
M-10	55	61.4	5.99	67.15	0.54	0.22	55	53.1	6.66	58.15	0.12	0.05	61.19	6.15	67.0
M-10	55	69.5	6.75	77.00	0.91	0.74	55	60.1	4.70	65.00	0.44	0.13	69.27	6.86	76.0
M-10	55	67.1	6.19	73.00	0.88	0.61	55	57.7	5.17	63.00	0.26	0.05	66.71	6.39	73.0
M-10	70	69.3	6.29	75.15	0.15	0.06	60	61.0	4.33	65.00	0.10	0.01	69.03	6.38	75.0
M-10	55	69.2	6.07	75.00	0.94	0.72	55	58.1	4.47	62.15	0.35	0.02	68.77	6.37	75.0
M-39	55	67.6	6.95	75.00	0.86	0.61	55	59.9	4.60	65.00	0.45	0.12	67.28	7.02	75.0
M-39	55	60.7	5.74	66.15	0.48	0.18	55	56.0	3.48	60.00	0.09	0.00	60.42	5.72	66.0
M-39	55	63.4	5.80	69.00	0.70	0.32	55	56.3	4.33	61.00	0.16	0.03	63.11	5.89	69.0
M-39	55	64.0	5.85	70.00	0.70	0.41	55	58.7	3.45	62.00	0.26	0.04	63.63	5.86	70.0

Table 37. Summary of Michigan Speed Data (Cont'd)

Route #	Passenger Vehicles Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Trucks/Buses Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	All Vehicles Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-69	70	70.82	4.72	76	0.185	0.000	60	62.01	2.74	65	0.010	0.000	69.47	5.81	72.0
I-69	70	73.42	3.74	77	0.290	0.045	60	62.77	3.38	65	0.020	0.010	70.96	6.38	75.0
I-196	70	74.94	4.36	79	0.425	0.085	60	63.27	3.18	65	0.150	0.060	74.26	7.09	76.0
I-196	70	73.17	4.82	78	0.275	0.030	60	63.28	3.68	66	0.210	0.050	72.64	6.51	75.0
I-196	70	73.66	4.39	78	0.350	0.035	60	62.71	3.71	65	0.140	0.040	73.32	6.72	76.0
I-69	70	74.19	4.34	78	0.330	0.040	60	63.19	3.04	65	0.150	0.050	71.70	6.46	74.0
I-69	70	74.75	4.77	79	0.385	0.120	60	62.02	2.66	64	0.070	0.010	71.95	7.46	75.0
I-69	70	74.39	4.52	78	0.340	0.070	60	62.20	2.77	64	0.060	0.010	70.92	7.12	75.0
I-69	70	72.27	4.52	76	0.195	0.030	60	60.30	2.90	63	0.020	0.000	70.04	7.18	74.0
I-69	70	74.24	3.14	77	0.355	0.000	60	63.40	2.04	65	0.070	0.000	71.14	5.88	75.0
I-69	70	74.19	5.42	79	0.405	0.095	60	61.51	2.87	64	0.020	0.010	71.15	7.73	76.0
I-69	70	76.48	1.70	78	0.695	0.005	60	63.08	1.61	65	0.050	0.000	74.34	6.87	77.0
I-75	70	76.33	4.86	81	0.530	0.175	60	62.76	2.94	65	0.110	0.020	75.51	8.07	78.0
I-75	70	76.28	4.44	80	0.570	0.135	60	62.55	3.45	65	0.130	0.040	75.34	7.91	78.0
I-75	70	75.90	4.55	80	0.490	0.145	60	63.18	3.99	67	0.230	0.070	75.05	7.78	78.0
I-75	70	73.59	4.09	77	0.290	0.045	60	62.80	2.80	65	0.090	0.020	68.76	6.08	73.0
I-75	70	74.30	5.39	79	0.385	0.100	60	62.84	2.61	65	0.100	0.000	69.54	7.00	74.0
I-94	70	73.87	4.31	78	0.335	0.065	60	62.42	2.99	65	0.100	0.020	70.98	6.79	75.0
I-94	70	74.23	4.08	78	0.335	0.055	60	62.28	2.87	65	0.100	0.010	70.45	6.76	74.0
I-94	70	75.28	4.43	80	0.435	0.120	60	61.72	2.73	64	0.060	0.000	74.07	7.28	75.0

Table 37. Summary of Michigan Speed Data (Cont'd)

	Passenger Vehicles						Trucks/Buses						All Vehicles		
Route #	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-94	70	74.28	5.03	78	0.330	0.070	60	62.32	2.90	64	0.060	0.020	70.57	7.13	74.0
I-94	70	74.02	4.22	78	0.370	0.045	60	62.30	3.05	65	0.120	0.000	72.11	6.97	76.0
I-94	70	74.04	4.04	78	0.325	0.065	60	62.40	2.44	65	0.090	0.010	70.57	6.58	74.0
I-94	70	74.88	4.37	79	0.440	0.055	60	63.65	3.61	67	0.190	0.060	74.55	6.64	76.0
I-94	70	76.95	2.43	79	0.720	0.030	60	62.44	2.05	65	0.040	0.000	74.86	7.40	77.0
I-94	70	73.29	4.21	78	0.285	0.050	60	62.57	2.95	65	0.120	0.030	70.51	6.40	74.0
I-96	70	75.01	5.32	79	0.505	0.115	60	62.95	3.28	65	0.140	0.030	73.61	7.63	78.0
I-96	70	73.55	4.89	79	0.340	0.080	60	62.62	3.62	66	0.170	0.030	72.04	7.22	76.0
I-96	70	75.15	4.15	79	0.510	0.080	60	62.87	3.07	65	0.130	0.040	74.77	6.88	77.0
I-96	70	75.92	4.20	80	0.600	0.125	60	63.82	3.51	66	0.180	0.070	75.35	7.35	78.0
I-96	70	73.81	5.04	79	0.385	0.095	60	61.65	2.77	64	0.090	0.010	71.09	7.24	75.0
I-96	70	73.38	4.56	78	0.300	0.055	60	62.85	2.74	66	0.160	0.010	71.44	6.33	74.0
US-127	70	73.39	4.18	78	0.260	0.065	60	61.80	2.88	64	0.100	0.000	69.69	6.66	73.0
US-127	70	72.44	4.07	76	0.255	0.015	60	61.19	2.87	64	0.070	0.000	71.50	6.60	75.0
US-23	70	74.33	4.64	79	0.415	0.080	60	63.18	4.04	66	0.200	0.050	73.60	7.15	77.0
US-23	70	73.52	4.80	79	0.330	0.080	60	62.43	3.09	65	0.120	0.010	72.21	6.64	74.0
US-23	70	72.30	5.04	77	0.270	0.030	60	63.11	3.47	66	0.180	0.040	69.76	6.35	75.0
US-23	70	74.71	4.83	79	0.420	0.115	60	62.79	2.70	65	0.130	0.010	72.39	7.07	75.0
US-23	70	74.93	4.35	80	0.435	0.090	60	63.27	3.71	67	0.210	0.040	74.35	6.87	76.0
US-31	70	71.59	5.54	77	0.225	0.030	60	61.55	3.08	64	0.090	0.000	70.11	6.95	74.0

Table 38. Summary of Indiana Speed Data

Route #	Passenger Vehicles						Trucks/Buses						All Vehicles		
	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-265	55	62.1	5.71	67.00	0.60	0.25	55	58.3	3.69	62.00	0.30	0.02	61.80	5.66	67.0
I-265	55	59.6	4.77	65.00	0.37	0.11	55	55.4	4.65	60.00	0.11	0.02	59.18	4.88	64.0
I-265	55	61.5	5.50	67.00	0.54	0.21	55	57.8	4.21	62.00	0.22	0.05	61.08	5.48	67.0
I-465	55	65.3	5.16	70.00	0.84	0.48	55	60.1	3.25	64.00	0.43	0.04	64.94	5.20	70.0
I-465/74	55	65.9	5.48	72.00	0.84	0.48	55	60.7	3.79	65.00	0.50	0.14	65.42	5.55	71.0
I-65	55	63.7	5.37	69.00	0.71	0.35	55	59.4	3.85	63.00	0.39	0.05	63.40	5.39	69.0
I-65	55	61.9	forma	67.00	0.58	0.21	55	57.7	3.19	61.00	0.21	0.00	60.84	4.68	66.0
I-65	55	60.5	5.17	65.00	0.43	0.15	55	57.0	2.97	60.00	0.11	0.00	59.77	4.99	65.0
I-65	55	65.6	5.62	71.00	0.82	0.51	55	59.2	3.80	62.15	0.34	0.05	65.11	5.74	71.0
I-70	50	59.3	5.09	65.00	0.37	0.13	50	54.2	4.11	59.00	0.05	0.00	58.69	5.25	65.0
I-70	55	64.3	5.32	70.00	0.77	0.39	55	58.0	3.46	62.00	0.25	0.01	62.88	5.59	69.0
I-869	55	68.4	5.98	73.00	0.93	0.69	55	61.4	3.80	65.00	0.62	0.11	67.26	6.22	73.0
I-94/80	55	70.7	6.56	77.15	0.94	0.77	55	60.9	3.02	64.00	0.49	0.06	69.54	7.00	77.0
I-94/80	55	70.1	6.56	77.15	0.93	0.76	55	59.9	3.19	63.00	0.42	0.03	68.37	7.20	76.0
I-94/80	55	70.4	6.83	77.00	0.92	0.76	55	60.0	4.76	65.00	0.49	0.08	68.22	7.70	76.0
I-94/80	55	68.7	5.72	74.15	0.92	0.71	55	58.7	3.67	63.00	0.28	0.06	67.39	6.42	74.0
I-94/80	55	72.3	6.08	79.00	0.99	0.88	55	60.8	3.79	65.00	0.55	0.06	70.50	7.11	78.0
I-94/80	55	70.1	7.07	77.00	0.90	0.74	55	59.5	3.88	63.00	0.35	0.06	68.76	7.61	76.0
I-94/80	55	69.8	7.34	77.00	0.89	0.72	55	60.8	3.34	64.00	0.53	0.06	68.49	7.56	76.0
I-94/80	55	70.8	6.88	78.00	0.92	0.79	55	60.8	4.23	65.00	0.52	0.12	69.14	7.49	78.0

Table 38. Summary of Indiana Speed Data (Cont'd)

Route #	Passenger Vehicles						Trucks/Buses						All Vehicles		
	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-65	70	73.87	5.36	79	0.365	0.095	65	62.47	3.62	66	0.030	0.000	72.60	7.37	76.0
I-65	70	74.41	4.92	80	0.360	0.105	65	64.40	2.97	67	0.030	0.000	72.66	6.36	75.0
I-65	70	73.30	5.18	79	0.315	0.065	65	63.55	2.90	66	0.020	0.000	71.11	6.47	75.0
I-65	70	73.82	4.97	78	0.365	0.080	65	61.88	3.13	64	0.010	0.000	71.44	7.19	75.0
I-69	70	74.42	4.00	78	0.405	0.060	65	65.59	2.99	69	0.040	0.000	72.84	5.61	76.0
I-69	70	72.87	4.26	77	0.255	0.030	65	65.30	2.93	68	0.060	0.000	71.39	5.22	74.0
I-69	70	71.29	4.24	75	0.130	0.010	65	63.71	3.14	66	0.030	0.000	70.56	5.20	73.0
I-69	70	73.81	3.83	78	0.310	0.050	65	64.94	2.93	68	0.010	0.000	71.74	5.56	75.0
I-69	70	71.76	4.60	76	0.200	0.010	65	64.20	3.13	67	0.010	0.000	70.12	5.56	74.0
I-70	70	73.20	4.09	77	0.250	0.040	65	64.06	2.78	67	0.010	0.000	70.20	5.68	74.0
I-70	70	73.67	4.25	78	0.320	0.065	65	63.74	3.23	67	0.020	0.000	70.21	6.09	74.0
I-70	70	72.74	4.35	77	0.250	0.025	65	64.34	3.63	68	0.040	0.000	70.44	5.75	74.0
I-80/90	70	73.56	4.40	77	0.280	0.040	65	64.31	2.94	67	0.030	0.000	70.69	5.93	74.0
I-80/90	70	74.26	4.17	79	0.360	0.065	65	64.86	3.46	67	0.050	0.010	72.31	5.87	74.0
I-80/90	70	74.25	3.64	78	0.360	0.035	65	65.71	3.70	69	0.070	0.010	71.15	5.41	74.0
I-80/90	70	72.40	4.12	76	0.245	0.020	65	65.29	3.22	67	0.050	0.000	69.14	5.04	72.0
I-80/90	70	72.74	4.07	77	0.215	0.020	65	65.64	2.58	68	0.030	0.010	69.31	4.99	73.0
I-94	70	74.81	5.02	80	0.410	0.100	65	64.34	2.95	67	0.010	0.000	71.30	6.62	75.0
I-94	70	73.53	5.15	79	0.330	0.080	65	61.61	3.66	65	0.020	0.000	72.78	7.10	75.0
US-31	70	69.02	5.29	74	0.360	0.105	65	62.78	3.97	66	0.030	0.010	67.89	5.92	73.0

Table 39. Summary of Ohio Speed Data

	Passenger Vehicles						Trucks/Buses						All Vehicles		
Route #	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-280	65	64.6	4.89	70.00	0.12	0.01	65	60.2	3.77	64.00	0.00	0.00	63.57	5.00	69.0
I-280	60	67.2	4.81	72.00	0.62	0.25	55	62.0	3.77	65.15	0.63	0.02	65.35	5.12	71.0
I-475	55	67.6	5.44	73.15	0.91	0.63	55	61.3	3.16	65.00	0.56	0.10	66.92	5.58	73.0
I-475	60	67.8	4.87	72.15	0.67	0.26	55	61.7	3.15	64.15	0.63	0.01	66.98	5.14	72.0
I-480	55	65.6	4.47	70.00	0.89	0.50	55	61.3	3.31	64.00	0.59	0.10	65.19	4.54	70.0
I-480	55	64.2	4.92	69.15	0.79	0.37	55	60.5	3.19	64.00	0.48	0.05	63.42	4.84	68.0
I-670	55	64.0	5.83	70.00	0.75	0.38	55	59.6	4.92	64.00	0.47	0.07	63.78	5.86	70.0
I-670	55	59.2	5.33	64.00	0.36	0.12	55	55.4	3.88	60.00	0.08	0.00	58.85	5.32	64.0
I-70	55	62.4	5.20	67.15	0.66	0.24	55	56.0	3.89	61.00	0.17	0.00	61.72	5.45	67.0
I-70	55	61.7	6.07	68.00	0.63	0.28	55	57.9	4.61	62.00	0.27	0.03	61.43	6.04	68.0
I-71	65	63.9	5.13	69.00	0.07	0.02	65	57.7	6.66	64.00	0.01	0.00	63.57	5.43	69.0
I-71	55	61.8	5.48	67.00	0.59	0.21	55	56.9	4.60	62.00	0.23	0.01	61.59	5.52	67.0
I-71	55	65.5	4.72	70.00	0.88	0.52	55	60.3	4.83	65.00	0.49	0.12	64.96	4.98	70.0
I-71	55	65.4	5.44	70.00	0.83	0.48	55	58.5	3.98	62.15	0.28	0.03	65.10	5.61	70.0
I-71	55	55.6	5.09	60.00	0.12	0.03	55	50.5	4.62	54.00	0.02	0.01	55.10	5.25	60.0
I-74	65	62.9	5.46	69.00	0.09	0.02	65	58.5	5.05	64.00	0.01	0.00	62.83	5.43	69.0
I-75	55	68.6	6.39	75.00	0.90	0.67	55	61.2	3.55	65.00	0.60	0.10	65.65	6.51	72.3
I-75	55	64.8	4.86	69.00	0.84	0.44	55	60.3	4.39	64.15	0.48	0.12	64.45	4.95	69.0
I-90	55	59.5	5.93	66.00	0.41	0.18	55	53.7	6.05	60.00	0.14	0.01	59.00	6.13	66.0
I-90/271	65	65.1	4.13	70.00	0.11	0.02	65	61.7	3.77	65.00	0.01	0.00	64.03	4.30	68.0

Table 39. Summary of Ohio Speed Data (Cont'd)

Route #	Passenger Vehicles						Trucks/Buses						All Vehicles		
	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85th % Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Speed Limit (mph)	Mean Speed (mph)	Std. Dev (mph)	85% Speed (mph)	% 5 mph above Sp. Limit	% 10 mph above Sp. Limit	Overall Mean Speed (mph)	Overall Std. Dev (mph)	Overall 85% Speed (mph)
I-70	65	73.50	3.72	77	0.285	0.030	65	64.98	3.42	69	0.040	0.000	72.11	5.52	75.0
I-70	65	72.77	4.80	77	0.265	0.055	65	65.44	3.68	70	0.070	0.000	70.62	5.63	73.0
I-71	65	74.61	4.47	79	0.435	0.080	65	65.94	3.39	70	0.090	0.000	73.98	6.02	77.0
I-71	65	73.93	4.13	78	0.345	0.055	65	65.83	4.34	70	0.130	0.020	73.27	5.80	76.0
I-71	65	72.26	4.23	76	0.185	0.015	65	65.12	4.56	69	0.090	0.010	71.72	5.64	75.0
I-71	65	73.80	4.03	77	0.320	0.040	65	64.13	4.96	69	0.060	0.000	72.82	6.55	76.0
I-71	65	74.94	4.11	79	0.435	0.080	65	64.25	5.35	70	0.140	0.000	74.23	7.24	77.0
I-75	70	71.60	4.41	76	0.180	0.025	70	64.91	3.09	68	0.000	0.000	69.41	5.10	71.0
I-75	70	73.46	4.29	78	0.270	0.055	70	64.85	3.29	68	0.000	0.000	72.62	5.70	75.0
I-75	70	72.61	3.75	76	0.225	0.015	70	65.99	3.24	70	0.010	0.000	71.82	4.86	74.0
I-75	70	72.18	3.97	76	0.160	0.020	70	65.28	3.15	68	0.000	0.000	71.14	4.86	73.0
I-75	70	72.69	4.72	77	0.240	0.050	70	65.00	3.82	69	0.000	0.000	71.53	5.89	74.0
I-75	70	71.23	3.86	75	0.120	0.005	70	64.89	3.77	68	0.010	0.000	70.06	4.89	72.0
I-80/90	70	72.49	3.86	76	0.170	0.040	70	64.29	3.46	68	0.000	0.000	69.06	5.28	72.0
I-80/90	70	74.34	3.46	78	0.330	0.030	70	66.32	3.62	70	0.010	0.000	72.50	5.32	75.2
I-80/90	70	74.25	4.09	78	0.375	0.045	70	66.10	4.33	70	0.010	0.010	72.48	5.74	76.0
I-80/90	70	74.53	3.69	78	0.400	0.050	70	66.29	3.85	70	0.010	0.000	72.65	5.55	76.0
I-80/90	70	73.86	3.91	77	0.330	0.045	70	66.32	3.55	70	0.010	0.000	71.24	5.18	75.0
I-80/90	70	74.64	4.29	78	0.395	0.075	70	67.08	3.36	70	0.000	0.000	73.18	5.62	77.0
I-80/90	70	74.90	3.60	79	0.415	0.060	70	66.07	4.30	70	0.010	0.010	73.11	5.85	76.0

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