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Evaluating the Impacts of Speed Limit Changes on Identified Case Studies

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16. Abstract

Raising speed limits on freeways has an impact on both crashes and operational speeds as documented in many previous studies. This study aimed at determining the impacts of changing speed limits on crash frequency and severity, as well as operational speeds in Michigan. Selected sites where the speed limit changed were used to study the impacts of such changes. The analyses included similar sites that did not have a change in the speed limit. Crash data and speed data were collected and analyzed to achieve the goals of the study. A more robust statistical analysis method using the mixed effects negative binomial regression model was used to model crashes and quantify the impact of changing speed limits while controlling for other confounding factors. Speed analysis included estimation of parameters such as the mean, the 85th percentile, the 50th percentile and the standard deviation of speeds in the time before changing the speed limits and compared them with those estimated for the period after changing the speed limits.

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EXECUTIVE SUMMARY

Introduction and Motivation

After the National Maximum Speed Limit (NMSL) law was repealed in 1995, the Michigan legislature passed a bill requiring the Michigan Department of Transportation (MDOT) and the Michigan State Police (MSP) to increase the speed limit from 65 mph to 70 mph in designated rural freeways. An evaluation study conducted by Taylor (1997) to evaluate the impact of this change in the initially approved 500 miles concluded that there was a small increase in speed for some of the locations (1-2 mph) but less than one mile per hour at the majority of the evaluated sites.

On January 1, 1997, the Michigan legislature approved additional 1,000 miles of rural freeways to have a similar change in speed limit. A before and after study carried out in order to observe the impacts of increasing speed limit on these additional miles revealed a small increase in speeds in the period after the changes were made (Taylor 2000). While there was an increase in the total number of crashes, the increase was lower than the increase in the vehicle-miles-traveled VMT. The number of fatal crashes also increased after the change in speed limit. While the speed limit for trucks remained 55 mph in the before and after periods of the previous analysis by Taylor (2000), a new legislation enacted in 2006 allowed the speed limit for trucks to be 60 mph if the maximum speed limit on that freeway was 70 mph for other vehicles. Such changes, as well as other traffic changes, called for a new evaluation of the impact of raising speed limit on freeways. Updated findings were needed to provide MDOT a better understanding of the impact of raising the speed limit of freeway corridors on crashes and the overall speed profiles. The main purpose of this study was to evaluate the impacts of raising the speed limit on selected Michigan freeways. Specifically, the study aimed at determining:

I. The impact of changing speed limit on crash frequency and severity.

II. The impact of changing speed limit on driver's operating speed.

Study approach

To achieve the goals of this study, the research team conducted a comprehensive literature review to uncover similar studies that evaluated the effects of raising speed limits on crash types/severity and drivers' operating speed. The survey to other state Departments of Transportation (DOTs) was administered to determine if they had implemented speed limit changes and what impacts they observed following such speed limit changes. The survey was used to identify more published and unpublished literature from state DOTs which evaluated the impact of speed limit changes. The literature review helped in identifying relevant factors associated with increasing the speed limit on freeways.

The next task was collecting and analyzing speed data before and after raising the speed limit on the selected freeway segments. This task helped in studying operational speed parameters such as the mean speed, the 85th percentile speed, the 50th percentile speed, the standard deviation and the percentage of vehicles complying with the posted speed limit before and after changing the speed limits. Thereafter, analyses of crash data were conducted to assess the impact of changing speed limit on crashes. The analyses included the before and after study using crash rates, followed by application of the mixed-effects negative binomial regression model to develop crash modification factors (CMF) by crash frequency and severity. Lastly, the research team conducted a cost-benefit analysis of the impacts associated with changing the speed limit, including crash changes, travel time changes, fuel consumption and infrastructure impacts.

Research Results

Literature Review Results

The literature review involved reviewing past studies which evaluated the impacts of changing speed limits. Specific focus was on how the change in speed limit, particularly on freeways, impacts traffic crash occurrence and operational speed. Methodologies that were used in the analyses and presented in the literature were also documented and summarized.

For Michigan, a study conducted by Wagenaar et.al (1990) to evaluate the impact of raising the speed limit from 55 mph to 65 mph showed a significant increase in fatal, incapacitating and minor injury crashes by 19.2 percent, 39.8 percent and 25.4 percent, respectively. With the speed limit increase from 65 mph to 70 mph and truck speed limit remaining at 55 mph in Michigan, findings from additional evaluation studies (Taylor 1997 and Taylor 2000) showed a 4.5 percent increase in fatal crashes and a decrease of 9.3 percent in incapacitating injuries. Overall, there was an increase of 10.5 percent in total crashes, which was lower than the increase in Vehicle-Miles-Traveled (VMT), which increased by 11.9 percent. For trucks, there was a reduction in fatal and incapacitating injury by 14.5 percent and 24.2 percent, respectively. Total truck-related crashes increased by 7 percent. Changes in operational speed before and after raising the speed limit were also investigated. There was an average increase of 0.8 mph and 0.9 mph for the 50th percentile speed and the 85th percentile speed, respectively.

For other states, most of the studies which focused only on individual states indicated an increase in fatal crashes, fatalities, fatality rate and total crashes, especially in rural interstate freeways. The percentage increase in fatal crashes were in most cases higher than the percentage increase in total crashes. However, studies performed in Kansas and Indiana showed no significant change in crashes by severity after changing the speed limit. Studies that investigated the overall impact of raising the freeway speed limits in multiple US states grouped together showed an increase in fatality and fatality rates.

The key limitation that was observed in most past studies was the inability to control for other confounding factors that would have contributed to the observed changes of speed and traffic crashes. In most cases, simple descriptive statistics were utilized to compare the number of crashes before and after raising the speed limit. Confounding factors that may have a profound impact on operational speed, crash frequency and severity include seatbelt enforcement, vehicle miles travelled, impaired driving, vehicle fleet mix, improved vehicle safety measures such as antilock brakes, speed limit on other roadways, driver expectation and adaptation to risk. The effects of most confounding factors may vary over time. Therefore, the time effect is of critical importance to account for in such evaluations.

In previous studies, the evaluations of the impact of speed limit changes on drivers' operational speed involved simple comparison of the 85th percentile speed and the percentage of speed violations before and after changing the speed limit. In some cases, the analyses were supported by simple statistical tests such as the *t*-test, which compares the mean speeds of two groups of speed data. Overall, the results for all states including Michigan indicated an increase in the 85th percentile speed after changing the speed limit. Conflicting results were obtained for the percentage of speed violation. While some studies showed speed limit violations to have doubled (Davis. 1998) in the after period, other studies showed a reduction in speed limit violations by 12 to75 percent (Souleyrette, 2009 & Freedman et al, 2007).

Results from the analysis of speed data

Speed analysis was performed to determine the impact of speed limit changes on drivers' operating speed. A comparison of speed parameters such the 50th percentile speed, the 85th percentile speed and the standard deviation before and after changing the speed limit at sample sites was made. Speed trends and distributions at sites with change in speed limit (referred to as test sites) and sites without change in speed limit (referred to as control sites) were examined to discern any association between speed limit change and the corresponding change in drivers' operating speed. The following results were obtained:

- The change in speed limit exhibited an effect on operating speed when the trend and sthe distribution of speeds at the test sites before and after changing the speed limit were compared with those at the control sites.
- The analysis of speed parameters indicated an increase in the 85th percentile speed by 1.8-4.7 mph and 3.5-4.2 mph for test sites that had the speed limit change margin of 5 mph and 10 mph, respectively. At control sites, there was an average reduction of 0.4mph in the 85th percentile speed (ranging from 1.6mph to -2.8mph).

Using field speed data collected at I-69 (test site) where the speed limit changed from 55 to 70 mph and M-39 (control site) where its speed limit was maintained at 55 mph, a cross-sectional analysis was conducted. The analysis revealed the following results:

- The difference in the 85th percentile speed between the test site and control site for passenger cars was 4.5 – 8.0 mph while the difference for trucks was 1.0 - 4.6 mph. In all cases, the speeds at the test site were higher than those at the control site.
- Truck drivers had more compliance with their respective posted speed limit (60 mph) compared to passenger car drivers (70 mph) for both test and control sites.
- At the site where the speed limit changed from 55 mph to 70 mph (i.e., test site), there were lower percentages of drivers who exceeded the speed limit by 5 mph, 10 mph or 15 mph compared to the control site. Vehicle drivers at test site had higher compliance with the posted speed limit compared to vehicle drivers observed at the control site.

Results from the analysis of crashes

The analysis of crash data comprised of three steps. First, trends of crashes in the before and after periods at test sites and all other freeways in Michigan were analyzed. Second, a simple before and after analysis using crash rates (crashes per 100 million VMT) was carried out. Third, modeling of crashes using mixed-effects negative binomial regression analysis was performed. The before and after study using crash rates controlled for the exposure by incorporating VMT in the procedure but other confounding factors were not taken into consideration. The use of mixed-effects negative binomial regression considered the intra-correlation of crash data on freeway corridors and segments nested within the corridors. The time effect and individual specific random effects which contributed to the observed pattern in crashes were also considered in the model. The results obtained using the mixed effects negative binomial regression were used to derive crash modification factors (CMF) for raising speed limits on freeways. The effects of raising speed limit on crashes which was estimated by using the mixed-effects negative binomial model revealed the following;

- Total crashes increased by 8.1 percent (CMF of 1.081). The effect was more pronounced on curved segments which had a 24.7 percent increase (CMF of

1.247) compared to straight segments which had a 5.8 percent increase (CMF of 1.058).

- Overall, road departure crashes increased by 13.2 percent (CMF of 1.132). On curved segments, however, a 21 percent increase (CMF of 1.21) in road departure crashes was estimated.
- Raising the speed limit increased fatal (K), incapacitating injury (A), and non-incapacitating injury (B) crashes (combined) by 10.2 percent (CMF of 1.102).

Other confounding factors were also discussed in this study such as time effect, effect of ramps and site heterogeneity. Time effect was modeled and exhibited a quadratic and linear shape for total crashes and road departure crashes, respectively. Significant variation in crashes due to individual heterogeneity was observed between freeway corridors and segments nested within the corridors. The presence of a ramp on a segment was associated with an increased likelihood of crashes on curved segments when compared to straight segments.

The crash analysis results from this study concurred with the findings of the study by Taylor (2000) which showed an increase in fatal (4.5 percent) and total crashes (10.5 percent) after changing the speed limit on rural interstate freeways. However, it should be noted that the Taylor (2000) study focused on rural freeways while this study focused mainly on urban freeways.

Results from economic analysis

An economic analysis of the costs and benefits associated with raising the speed limit on the selected freeway corridors was performed. The costs and benefits (or dis-benefits) considered in this analysis included those associated with the infrastructure, crashes, travel time, and fuel consumption. The calculated ratio of benefit to dis-benefits was 1.73:1 while the ratio of net-benefits to cost was 3,182:1. It should be noted that the corridors that were selected in this study did not have significant geometric changes such as horizontal and vertical curve realignment before increasing the speed limit. Therefore, the results of cost-benefit analysis in this study provide an indication of potential benefits that might accrue from raising the speed limit on freeways that do not require major geometric upgrades.

Conclusions and Recommendations

Conclusions

The primary goal of this project was to determine if the change in speed limit on the selected freeway corridors in Michigan had an impact on crash pattern and operational speeds. The following conclusions were drawn from the analyses undertaken in this study:

- Increasing speed limits on freeways results in higher operational speeds but not as much as the speed limit increase. The analysis indicated an increase in the 85^{th} percentile speed by 1.8-4.7 mph and 3.5-4.2 mph when the speed limit raised by 5 mph and 10 mph, respectively.
- Increase in speed variation is associated with an increase in the likelihood of collisions. Study sites that had an increase in speed standard deviation after increasing the speed limit were observed to have an increase in total crash rate and fatal crash rate.
- Compliance of the speed limits is affected by the posted speed limit and the geometric conditions of the location. Higher driver compliance was observed at the test site than that of the control site. Drivers at the control site (M-8) might expect a higher speed limit since the geometrics at M-8 were similar to the test site (I-69 with the speed limit of 70 mph).
- Increasing speed limits on freeways resulted in an increase in the number of crashes. This study showed that the total number of crashes increased by 8.1 percent at all studied sites. The impact of raising speed limits on straight freeway segments was lower than that on curved segments. While the number of crashes increased on straight segments by 5.8 percent, the increase on curved segments was 24.7 percent.

- Specific types of crashes were affected more than others by the increase in speed limit. This study found that road departure crashes increased by 13.2 percent while the overall crashes increased by 8.1 percent. Road departure crashes on curved segments increased by 21 percent.
- The severity of crashes increase as a result of increased speed limit. For example, compared to the 8.1 percent overall increase in crashes, this study showed that fatal, incapacitating injury, and non-incapacitating injury (KAB) crashes increased by 10.2 percent.
- The benefits of raising the speed limits on freeways (e.g., travel time savings) outweighs the dis-benefits (crash costs and fuel consumption costs) by a ratio of 1.73:1.

Recommendations

When modifying speed limits on freeways, geometrics of the freeway should be among the key considerations. Straight freeway segments are most likely to have lower safety impacts resulting from speed limit increases. Also, sites that do not require major geometric upgrades to accommodate the raised speed limit should be given a priority.

1 Introduction

1.1 Problem statement and research background

The National Maximum Speed Limit (NMSL) law which allowed the federal government to set speed limit ceilings on interstate highways and similar limited access roads was repealed by the United States of America (USA) Congress in 1995. Responding to the change in the national policy, the Michigan legislature passed a bill requiring the Michigan Department of Transportation (MDOT) and the Michigan State Police (MSP) to increase the speed limit from 65 mph to 70 mph in designated rural freeways. In a six-month period, the departments were to report back to the legislature on the impact the change in speed limit had on operational speeds and traffic crashes.

An evaluation study conducted by Taylor (1997) concluded that there was a small increase in speed for some of the locations (1-2 mph) but less than one mile per hour at the majority of the evaluated sites. On January 1, 1997, the Michigan legislature approved additional 1,000 miles of rural freeways to have a similar change in speed limit. A before and after study carried out by Taylor (2000) in order to observe the impacts of increasing speed limit on these additional miles revealed a small increase in speeds in the period after the changes were made. While there was an increase in the total number of crashes, the increase was lower than the increase in the vehicle-miles-traveled (VMT). The number of fatal crashes also increased after the change in speed limit. While the speed limit for trucks remained 55 mph in the before and after periods of the previous analysis by Taylor (2000), a new legislation enacted in 2006 allowed the speed limit for trucks to be 60 mph if the maximum speed limit on that freeway was 70 mph for non-commercial vehicles. Such changes as well as other traffic changes called for a new evaluation of the impact of raising speed limit on freeways. Updated findings were needed to provide MDOT a better understanding of the impact of raising the speed limit of freeway corridors on crashes and the overall speed profile.

1.2 Objectives of the study

The main purpose of this study was to evaluate the impacts of raising speed limit on selected Michigan freeways. The analysis of the impacts of speed limit changes was subdivided into three primary areas:

I. The impact of changing speed limit on crash frequency and severity.
II. The impact of changing speed limit on driver's operating speed.
III. Costs and benefits associated with changing the speed limit.

1.3 Research tasks

The research team examined the impacts of changing the posted speed limit on selected freeways in Michigan. First, the research team conducted a comprehensive literature review to uncover similar studies that evaluated the effects of raising speed limits on crashes of different types/severity and drivers' operating speed. The survey to other state Departments of Transportation (DOTs) was administered to determine if they had implemented speed limit changes and what impacts they observed following such changes. The survey was used to identify additional published and unpublished literature from state DOTs which evaluated the impact of speed limit changes. The literature review helped in identifying relevant factors associated with increasing the speed limit on freeways. The next task was collecting and analyzing speed data before and after raising the speed limit on the selected freeway segments. This task helped in studying drivers' speed parameters such as the 85^{th} percentile speed, the 50^{th} percentile speed, the standard deviation and the percentage of vehicles complying with the posted speed limit before and after changing the speed limits. Thereafter, analysis of crash data was conducted to assess the impact of changing speed limit on crashes. The analyses included the before and after study using crash rates, followed by application of the mixed-effects negative binomial regression model to develop crash modification factors (CMF) by crash frequency and severity. Lastly, the research team conducted a cost-benefit analysis of the impacts associated with changing the speed limit, including crash changes, travel time changes, fuel consumption and infrastructure impacts.

1.4 Fundamental concepts relating speed and safety

1.4.1 Relationship between speed and crash severity

The relationship between speed and the severity of injury sustained by a person once a motor vehicle crash occurred can be explained and supported by the laws of physics. As speed of a motor vehicle increases, the kinetic energy dissipated during collision increases. An increase in the kinetic energy dissipated during collision reduces the chances of survival for the parties involved in the crash. A study by Solomon (1964) found that the risk of being involved in fatal crashes increased with speed. The sharp increase in the risk was observed at speeds greater than 70 mph. A similar pattern was also observed for other injury severity levels. Apart from the observed pattern of crashes with respect to change in speed, some studies attempted to formulate a mathematical relationship between speed changes and the risk of fatal crash occurrence. For instance, Joksch (1993) studied the probability of a driver being killed in a crash with respect to the speed change. The study found that the fatality risk was proportional to the fourth power of speed change.

1.4.2 Relationship between speed and crash involvement

The first study to establish the relationship between speed and crash involvement was conducted by Solomon (1964). The study investigated how the accidents on two and four lane rural highways were related to speed. The study findings showed that the greater the variation of driver speed from average speed, the more the chances of drivers being involved in an accident. Figure 1-1 adopted from Solomon's study shows the relationship between accident involvement rates (accidents per 100 million VMT) and speed variation from the average speed. It can be observed that crash involvement rates were higher with higher (in absolute terms) variation from the average speed of the traffic stream. From Figure 1-1, it can be concluded that reducing the deviation of driver's speed from the average speed will likely have substantial impact on reducing the potential for crash involvement.

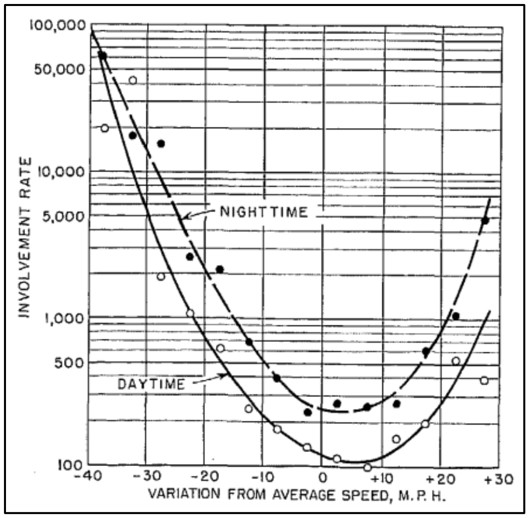

Figure 1-1 Relationship between crash involvement rates and variation from average speed (Solomon 1964)

Additional studies were later conducted with the aim of addressing some of the issues that were not addressed in Solomon's study. For example, West and Dun (1971) showed that higher crash involvement for the slow-moving vehicle as indicated in Solomon's U-shaped curve was exaggerated and could have been reduced by excluding slow moving vehicles which were preparing to make turning movements. Stuster et al (1998) complied similar studies which explored speed-safety relationship. For all the studies compiled, the U-shaped crash involvement curve was noticeable as shown in Figure 1-2. These findings further supported the argument that speed variance increases the chance of vehicle collisions.

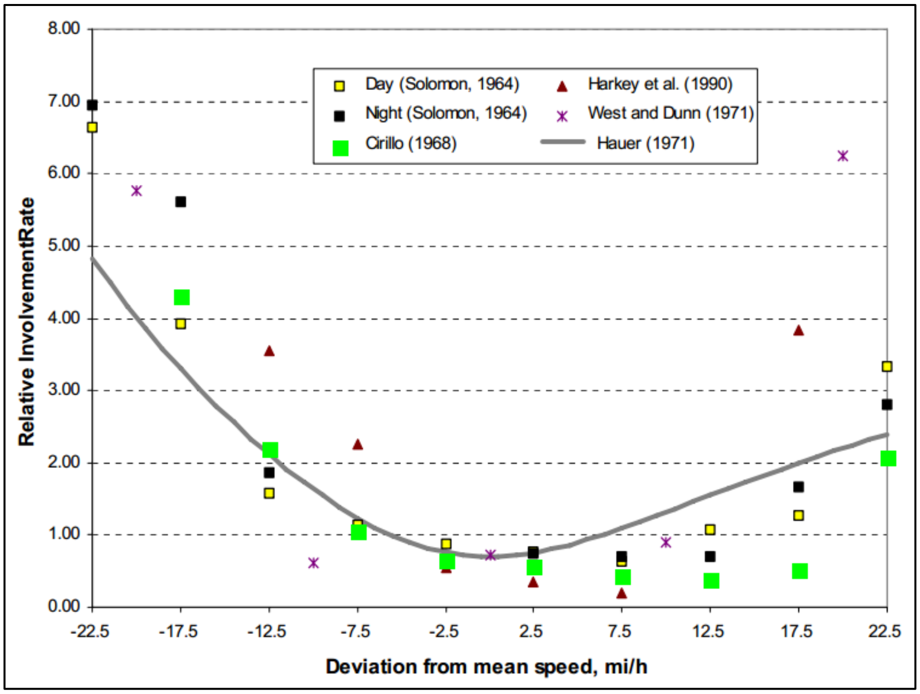

Figure 1-2 Comparison of studies that explored speed-safety relationships (Stuster et al, 1998)

1.5 Scope of the study and report organization

The analyses conducted in this report primarily focused on selected freeway segments including freeways segments that had an increase in speed limit and freeways that had no change in speed limit for comparison purpose. However, in some cases (for example in a section of crash data analysis), the results from these selected freeway sites were compared with crashes from all freeways in Michigan. The results obtained from the crash data analysis, speed data analysis and economic analysis specifically apply to the sites that were studied and generally to sites that have similar geometric characteristics.

Chapter two of this report covers the literature review and a survey on speed limit changes and lessons learned by other state DOTs. A state by state review of studies that evaluated the impact of speed limit was conducted. Chapter three covers the speed data analysis which aimed at evaluating the impact of speed limit changes on motorists' speed. Different speed parameters such as the 85th percentile speed, the 50th percentile speed and driver's compliance with the posted speed limit before and after changing the speed limit, were computed and analyzed. Chapter four presents the analysis of the impacts of speed limit changes on crash frequency and severity. The analysis includes before and after study using crash rates, followed by modeling of crash data in an effort to develop crash modification factors. Details of the modeling approach are provided in the chapter. Chapter five discusses the results of an economic analysis on the freeway segments that had speed limit changes. The chapter covers the comparison costs and benefits and dis-benefits associated with the speed limit increase. The last chapter presents the study conclusions and summaries from crash, speed and economic analyses.

2 Literature Review

2.1 Introduction

This chapter covers a review of past studies which evaluated the impacts of changing speed limits. Specific focus was on how the change in speed limit, particularly on freeways, impacts traffic crashes and motorists' speed. Methodologies that were used in the analyses are also documented and summarized. The chapter also presents general feedback on speed limit changes, particularly on freeways, collected from other state DOTs through a survey. A summary of the findings from this chapter is also given at the end.

2.2 Impacts of speed limit changes: Michigan

The first notable study which evaluated the impacts of speed limit changes in Michigan was conducted by Wagenaar *et al.* (1990) after the 1987 federal bill which allowed states to raise their rural interstate freeway speed limits from 55 mph to 65 mph. The before and after analysis using autoregressive moving average approach (ARIMA) was conducted to assess changes in the number and severity of crashes. The methodology controlled for multi-year trend and seasonal cycles. It also accounted for seatbelt enforcement, alcohol involvement, unemployment and vehicle-mile-travelled (VMT). The results showed a significant increase in fatal, incapacitating and minor injury crashes by 19.2 percent, 39.8 percent and 25.4 percent, respectively. At segments where the speed limit was unchanged, there was also an increase in fatality. This was intuitively connected with the spillover effect of the 65 mph rural freeway segments. Speed analysis showed an increase of 21.3 percent for motorist who were travelling above the speed limit after the change.

On August 12, 1996, the speed limit on 500 miles of rural freeways in Michigan were changed from 65 mph to 70 mph in response to the repeal of the NMSL law. An initial study of the impacts of this change was conducted by Taylor (1997). The analysis included freeways with the speed limit increase from 65 mph to 70 mph (test sites), freeways that had no change in speed limit (control sites) and non-freeways. Non-freeways nearby the control sites were included in the analysis for detecting any spillover effect. Criteria used for selection of test and control sites included freeway direction, road function, level of service and sufficiency rating. Descriptive statistics using speed data were conducted to observe changes in the 50th and the 85th percentile speed before and after the speed limit increase. The results depicted no substantial change in observed speed for the control sites. For the test sites, there was an overall increase in the 50th and the 85th percentile speed by 1 mph and 0.5 mph, respectively. Also, there was no spillover effect to the sites near the test sites. It was also desirable to obtain the impact of increasing speed limit on number and severity of crashes. However, this was not possible at that time due to lack of sufficient crash data.

In January 1997, the Michigan legislature passed a bill which allowed MDOT to increase passenger car speed limit from 65 mph to 70 mph for 1,000 miles of rural freeways (in addition to the 500 miles of rural freeways approved for increasing speed limit in August 1996). Truck speed limit remained at 55 mph. Taylor (2000) investigated the impact of the speed limit change on these rural freeways. Crash data covering three years before and after changing the speed limit was used in a simple before-after study. The results showed a 4.5 percent increase in fatal crashes and a decrease of 9.3 percent in incapacitating injuries. Overall, there was an increase of 10.5 percent in total crashes, which was lower than the increase in VMT (11.9 percent). For trucks, there was a reduction in fatal and incapacitating injury by 14.5 percent and 24.2 percent, respectively. Total truck-related crashes increased by 7 percent. Changes in operational speed before and after raising the speed limit were also investigated. There was an average increase of 0.8 mph and 0.9 mph for the 50th percentile speed and the 85th percentile speeds, respectively.

Savolainen et al (2014) investigated the changes in fatal, injury and total crashes for urban freeways in Michigan that had a raise in posted speed limit. A case control study was conducted which included test sites (where the speed limit changed) and control sites (where the speed limit remained the same). A simple before and after study using the crash rates (crashes per 100 million VMT) showed a decrease in fatality rate for the test sites by 49 percent while an increase in fatality rate by 23.2 percent was observed at control sites. Injury and total crashes at the test sites increased in the after period by 14.5 percent and 15.8 percent, respectively. At control sites, there was a decrease in injury and total crashes by 3.3 percent and 7.2 percent, respectively. A negative binomial regression model showed a significant impact of speed limit changes only for injury and total crashes but not on fatal crashes.

Gates et al (2015) evaluated the outcomes of the proposed changes on speed limit on non-freeways in Michigan from 55 mph to 65 mph. By adopting the procedure developed by Kockelman (2006), it was generalized that increasing the speed limit from 55 mph to 65 mph for all non-freeways in Michigan would result to an annual increase of crash rate for fatal, incapacitating injury, non-incapacitating/minor injury and property damage by 28.1 percent, 12.1 percent, 5 percent and 2.7 percent, respectively.

2.3 Impacts of speed limit changes: Other US States

Following the repeal of the NMSL law, Kansas raised their rural interstate speed limit from 65 mph to 70 mph in July 1996. Najjar et al. (2000) investigated possible impacts of increasing rural interstate freeway speed limits on operating speed and crash rates in Kansas. Using a simple *t*-test to estimate the speed changes, the study found that the 85^{th} percentile speed increased by 3 mph. Analysis of crash rates was performed by comparing monthly crash rates before (1993-1995) and after period (1997-1998) and examining the time series plot. The results showed no significant change in fatality and fatality rate after raising speed limit.

Souleyrette (2009) evaluated the effects of speed limit change from 65 mph to 70 mph on crashes and speeds in Iowa. The change in speed limit was adopted on July 1, 2005. The analysis results indicated an increase of the 85^{th} percentile speed by 2 mph and the speed violation (exceeding speed limit by 10 mph) decreased from 20 percent to 8 percent. Furthermore, the analysis results indicated an increase in crash frequency and severity. Specifically, the study found that night time fatal crashes increased by 52 percent, serious injury cross median crashes increased by 25 percent and total crashes increased by 25 percent.

In Louisiana, the speed limit was increased from 65 mph to 70 mph on their rural interstate freeways on August 15, 1997. An evaluation study was conducted by Schneider (2001) by comparing crashes before and after the change. The study indicated an increase of fatal crashes by 37 percent, minor injury by 1 percent and property damage only crashes by 14 percent. The study also considered other safety related factors such as seatbelt enforcement, weather condition, gender, day of the week and time of the day.

In New Mexico, the speed limit on rural interstate freeways was raised from 65 mph to 75 mph on May 15, 1996. A case study was carried out by Davis (1998) to determine the impact of these changes on crash patterns and operational speeds. The study found that fatalities increased by 50 percent, incapacitating injury by 44 percent, minor injury by 31 percent and property damaged only crashes (PDO) by 29 percent. For the remaining interstate freeways, there was a small but insignificant decrease in crash severity. An analysis of speeds indicated that the 85th percentile speed on two of the rural interstates increased by 2 mph while on other interstate freeways there was an increase of 1 mph. The analysis further showed that the percentage of speed violation (driving above 80mph) doubled.

In Texas, speed limit changes following the 1995 NMSL repeal were effective on September 1, 1996. The established speed limits in Texas varied by time of the day, whereby in rural interstates, passenger car speed limits of 70 mph and 65 mph were imposed for daytime and nighttime, respectively. For trucks, a speed limit of 60mph was set during day time while the 55 mph speed limit was set for night time. Griffin et al (1998) investigated the impact of these changes on crash frequency and driver's speed. Other safety related factors which were assumed to potentially affect crash occurrence were also investigated, including changes in percentage of drivers who were driving while intoxicated (DWI), roadway conditions and lighting condition. The time series analysis of the crash data before and after raising the speed limit indicated an increase in the total number of crashes in rural interstates by 16 percent in a duration of 15 months after the speed limit was raised. In urban interstates, fatal and incapacitating injuries (KA) increased by 75 percent while fatal, incapacitating injuries and non- incapacitating injuries (KAB) increased by 49 percent.

Freedman et al (2007) conducted a study in Mississippi to check if raising speed limit coupled with publicity and targeted enforcement resulted into better driver compliance and reduced speed variation. The speed limit on a test sites was raised by 5 mph to 15 mph in five zones and data were collected over a one year period. Original speed limits at the test sites were between 35 mph to 55 mph. The results showed that the number of speed violations decreased by three quarters. The crash trend showed a decrease in the number of crashes as compared to the immediate preceding year. The speed variation, however, increased despite the strict enforcement.

Hu *et.al* (2013) investigated the impact of raising speed limit in rural interstate freeways from 75 mph to 80 mph in Utah. Initially, Utah raised the posted speed limit on their rural state and interstate freeways from 65 mph to 75 mph in January, 1996. Later the speed limit on some freeways was raised to 80 mph in three phases namely, in year 2008, 2013 and 2014. The study by Hu *et. al.* particularly investigated the I-15 freeway segment which had a change in posted speed limit from 75 mph to 80 mph in 2009. The Log-linear regression model was used to quantify the change in vehicle speeds associated with the increase in speed limit. The results showed the odds of a passenger car exceeding the speed limit to be 31 percent higher in 2010 (after increasing speed limit) than what would be expected if the speed limit remained the same. At nearby sites, there was an increase of 10.3 percent, but the change was not statistically significant.

Donnell et.al (2016) studied the effects of increasing speed limit from 65 mph to 70 mph in some of Pennsylvania sections of rural interstates which was effective from August, 2014. The operating speed of cars was found to increase in the after period with a magnitude less than 5 mph. The safety assessment was limited because there was no enough crash data in the after period. The observed crash changes in that short period of time could have occurred due to the normal fluctuation of crashes, commonly known as regression-to-the mean effect, and not because of speed limit increase. A framework for developing safety performance functions (SPFs) was developed for future observational before and after studies using the Empirical Bayes method.

Arkansas changed the speed limit of their rural and suburban freeways in August 1996. The change also covered rural expressways with partial access. The speed limit on rural freeways changed from 65 mph to 70 mph for cars while for trucks it was changed to 65 mph (Arkansas Department of Transportation, 1997). A safety analysis study was conducted on freeways and partial access expressways covering one year before and one year after raising the speed limit. Overall, the results showed an increase in fatal crashes by 5.1 percent and fatalities by 15.1 percent. However, there was a reduction in fatal crashes per 100 million vehicle miles travelled by 2.4 percent.

Idaho raised the speed limit on some sections of rural interstates from 75 mph to 80 mph in July of 2014. The heavy vehicle speed limit was changed from 65 mph to 75 mph. A speed study on three interstate highways, namely; highway 15, 84 and 86, showed an increase in the 85th percentile speed by 3 mph (Idaho Department of Transportation, 2016). There were no changes in the differential average speed between light and heavy vehicles in the before and after speed increase periods. The difference in average speed between light and heavy vehicles remained at 1-2 mph. A simple before and after crash comparison showed minor changes in crashes after changing the speed limit.

A speed study was carried out in 2008 which evaluated the impact of 70 mph speed limit (Agent, 2008) in Kentucky. In rural interstate highways, the study found that the 85th percentile speed of cars increased from 74.6 mph to 75.5 mph, while for trucks there was an increase of 0.6 mph. There was no spillover effect of speed limit changes on other highway types.

Haselton et al (2002) assessed the crash patterns on California highways in relation to the posted speed limit. Three methodologies were compared, which were simple regression, analysis of variance (ANOVA) and observational before and after study. The crash counts and rates were analyzed successively for sites that had the speed limit change of 55 mph to 65 mph and 65 mph to 70 mph. The ANOVA and before and after studies indicated a significant impact of speed change on crash counts and crash rates. The before and after study showed a significant increase in fatal crashes for both 55 to 65 mph and 65 to 70 mph change groups.

Malyshkina and Mannering (2007) investigated the effect of speed limit increases in Indiana on crash frequency and severity. Indiana raised the speed limits on interstate highways and some multilane highways from 65 mph to 70 mph effective from July 1, 2005. The Multinomial Logit (MNL) model was preferred for modeling crash severities as it can relax parameter restriction, which allows the effect of speed limit to vary across injury outcomes. The model estimation showed no statistical significant change of accident severity on Indiana interstate highways. The association between speed limit and injury severity was significant only for non-interstate highways.

Weinstein (2001) studied the changes in crash frequency and severity in New Jersey interstate freeways following the speed limit change from 55 mph to 65 mph in 1997. A nominal change in operating speed was observed in the period after changing the speed limit. This was associated with the corresponding change in speed enforcement strategies such as increased fines. A simple before and after study showed an increase in crash frequency by 27 percent within the 36-months after changing the speed limit. Crashes in control sites were reported to increase by 30 percent.

Renski et al (1999) analyzed the changes in single vehicle crashes in terms of frequency and severity following the increase in speed limit in North Carolina interstate highways. The analysis utilized a paired-comparison analysis and an ordered probit model to control for the confounding factors which might have contributed to crash severity such as age, gender, use of occupant restraints devices, road geometry, weather, and visibility, among many others. It was found that 55 mph to 65 mph increase in speed limit was associated with high likelihood of involved parties who sustained minor and non-incapacitating injuries. No significant effect of speed on injury severity was found for the 65-70 mph increase in speed limit.

Ossiander & Cummings (2002) studied the changes in traffic fatalities, vehicle speeds and speed variance as a result of changes in Washington state's highway speed limit from 55 mph to 65 mph. A Poisson regression model was used to study the association between fatality rates and changes in posted speed limit. It was found that the fatalities doubled compared to the expected number of fatality if the speed limit would have remained the same. This was equivalent to 26.4 more deaths per year. The total crash rates (crash per 100MVMT) did not change significantly in the after period. The average speed of the vehicles increased by 5.5 mph with no apparent change in speed variance. In another study, Kweon & Kockelman (2006) investigated the safety effects of speed limit changes in Washington state highways with the posted speed limit greater than 55 mph using random effects negative binomial model. Segments that had speed data were used to construct models for average speed and speed variance. These models were used to estimate speed in other segments where speed data was not available. The estimated speed data, speed limit information and roadway design features were finally used to estimate crash counts. The findings showed all speed-related variables to be statistically insignificant for fatal crash model. Geometric features such as wider shoulder and gentle horizontal curve were associated with lower fatal and non-fatal crashes.

After the repeal of the 1995 NMSL act, the National Highway Traffic Safety Administration (NHTSA) complied a general summary of safety effects associated with the increase in speed limits. A comparison was made for the states that increased the speed limit on their rural freeways against those which did not take any action. The results of the study indicated that states that increased the speed limit of their rural interstate freeways had a 9 percent increase in fatality above the expectation which was derived from historical trends. It was also found that the increase in fatalities after the repeal of the NMSL law in 1995 was of small magnitude compared to the increase in fatalities which resulted from the 1987 speed limit increase from 55 mph to 65 mph. Most states considered these findings to be preliminary as no sufficient crash data were available after raising the speed limits.

Balkin & Ord (2001) studied the relationship between the number of fatal crashes in rural and urban interstate highways and speed limit increases. They used fatal crashes for each month from 1975 to 1998 in rural and urban interstate highways. Structural time series modelling approach was used to incorporate seasonal patterns such as monthly effects. The results revealed that 19 out of 40 states had a significant increase in fatal crashes during 1987 change in speed limit from 55 mph to 65 mph. Also, 10 of 36 states had a significant increase in fatal crashes following the 1995 repeal of the NMSL law. The study also found that in urban interstate highways, 6 out of 31 states had an increase in fatal crashes.

Farmer (2006) analyzed the impact of raising speed limit on traffic fatality rates from 1993-2013 on freeways and other roads. A Poisson regression model was used for modeling fatality rates while controlling for other factors such as unemployment rates, and per capital alcohol consumption. State-by-state analysis showed an increasing trend of fatality rates as the result of raising the posted speed limit. For each 5 mph increase in posted speed limit, there was a chance of 8 percent and 4 percent increase in fatality rates on freeways and other roadways, respectively.

Friedman et al (2009) performed a similar study looking at all states, which investigated the long-term effect of repealing the NMSL law in the US. The study used the mixed-effects Poisson regression, which controls for the individual specific random effects within and between states. The number of fatalities from 1999 to 2005 were found to increase as a result of raising the posted speed limit. Rural interstate highways had the highest increase in fatalities (9.1 percent) followed by urban interstate highways (4.0 percent).

Patterson et al (2002) analyzed the trend of fatalities in interstate highways in 23 states that raised their rural interstate highway speed limit to either 70 mph or 75 mph one year after the repeal of the NMSL law. The fatalities were modelled using the negative binomial regression model. The results showed that fatalities increased by 35 percent and 38 percent for states that changed their rural interstate highway speed limits to 70 mph and 75 mph, respectively. These percent increase in fatalities were obtained by comparing between states that raised the speed limit and those that did not raise their speed limit following the repeal of the NMSL law.

Review of studies conducted in other states indicate that the findings about the impacts of changing speed limits on crashes and operational speed are inconsistent. However, all studies that analyzed the impact of raising speed limit on operational speed found that speeds increase as a result of changing the speed limits. There are also many studies which show that increasing speed limits increased crashes (especially fatalities), although some studies found that there was no significant impact. Table 2-1 provides a summary of methodologies and results obtained from studies conducted in other US states to evaluate the impact of changes in speed limits on crashes. Similarly, Table 2-2 presents a summary of methodologies and results obtained from studies conducted in other states to evaluate the impact of speed limit changes on operational speeds.

Table 2-1 Summary of studies on the effects of speed limit changes on crashes in other states

Study and location	Methodology and sites	Results
Kockelman *et al*., 2006; Washington state	– Cross sectional analysis. – High speed highways.	– 13 percent increase in fatal crashes. – 0.64 percent increase in total crashes for highways that changed the speed limit from 65 mph to 75 mph.
Davis, 1998; New Mexico	– Naïve before and after study on rural interstates.	– Fatality increased by 30 percent, incapacitating injury by 44 percent and minor injury by 31 percent.
New Jersey DOT, 2001	– Simple before and after study on rural interstate highways.	– Total crashes increased by 27 percent. – The rate of fatal crash accidents remained the same.
Schneider, 2001; Louisiana	– Before and after on rural interstate freeways. Accounted for other confounding factors.	– Increase in fatal, injury and property damage crashes by 37 percent, 1 percent and 14 percent, respectively.
Griffin *et al*., 1998; Texas	– Before and after study in rural and urban interstates using time series models. – Controlled for other confounding factors such as roadway conditions, lighting conditions and alcohol involvement.	– Increase in total crashes by 16 percent in rural freeways. – Increase in KA and KAB crashes by 75 percent and 49 percent respectively for the urban interstates.
Ossiander and Cummings, 2002; Washington state	– Poisson regression models. – Rural interstates.	– 110 percent increase in fatal crashes. – No significant increase in total crashes.
Haselton *et al*., 2002; California	– Observational before and after study, simple regression analysis and analysis of variance (ANOVA). – California state highways.	– 33.9 percent and 8.9 percent increase in fatal and total crashes, respectively, for interstates that changed the speed limit from 65 mph to 70 mph.
Najjar *et al*. 2000; Kansas	– Before and after study on rural interstate freeways using time series plots.	– No significant change in fatality and fatality rate.
Malyshkina & Mannering, 2007; Indiana	– Multinomial logit models. – Rural interstates.	– No significant change in crash severities.

Study and location	Methodology and sites	Results
Balkin & Ord, 2001; Multiple states	– Structural time series models. – Rural and urban interstates.	– 10 out of 31 states had an increase in fatal crashes on urban interstates. – 10 out of 36 states had an increase in fatal crashes on rural interstates.
Petterson *et al.*, 2002; Multiple states	– Cross sectional regression analysis.	– 35 percent and 38 percent increase in fatality rates for freeways that changed from 55/65 mph to 70 mph and to 75 mph, respectively.
Friedman *et al.*, 2009; Multiple states	– Poisson mixed effects regression model. – Rural and urban interstates.	– Rural interstates; 9.1 percent and 11.9 percent increase in fatality and total crashes, respectively. – Urban interstates; 4 percent and 5.6 percent increase fatality and total crashes, respectively.
Farmer *et al.*, 2017; Multiple states	– Poisson regression model. – Rural interstates.	– 8 percent increase in fatality for each 5 mph increase in posted speed limit.

Table 2-2 Summary of studies on the effect of speed limit changes on operating speed in other states

Study and location	Methodology and site	Results
Souleyrette (2009); Iowa	– Simple comparison of driver's operating speed before and after raising the speed limit. – Rural interstates.	– The 85th percentile increased by 2 mph. – Speed violation decreased from 20 percent to 8 percent.
Najjar *et al*. (2000); Kansas	– Simple comparison of operating speed before and after raising the speed limit using t-test. – Rural interstates.	– The 85th percentile speed increase by 3 mph.
Davis (1998); New Mexico	– Simple comparison of operating speed before and after raising the speed limit. – Rural interstates.	– The 85th percentile speed increased by 2 mph and 1mph on rural interstates and other interstates, respectively. – Percentage of speed violation (above 80mph) doubled.
Freedman *et al*. (2007); Mississippi	– Study on driver compliance by comparing percentage of vehicles above the speed limit before and after raising the speed limit.	– Speed violations were reduced to three quarter in the after period.

Hu *et al*. (2013); Utah	– Log linear regression model. – Rural interstates.	– Odds of passenger cars exceeding the speed limit was 31 percent higher after speed limit increase compared to if the speed would have remained the same.
Donnel *et al*. (2016); Pennsylvania	– Simple comparison of speed parameters before and after raising the speed limit. – Rural interstates.	– The 85th percentile speed in the after period increased by the magnitude less than 5 mph.
Idaho DOT (year); Idaho	– Simple comparison of operating speed before and after raising the speed limit – Rural interstates	– The 85th percentile speed increased by 3 mph. – No change in differential speed limit between the light and heavy vehicles before and after raising the speed limit.
Agent (2008); Kentucky	– Simple comparison of operating speed before and after raising the speed limit. – Rural interstates.	– The 85th percentile speed increased by 1.3 mph for passenger cars and 0.6mph for trucks. – No spillover effect on operating speed on other highway types.

2.4 Feedback from State DOTs on freeway speed limit changes

In addition to a comprehensive literature review conducted in this study as documented above, the research team conducted a survey of other states to identify any unpublished records on the impact of raising speed limits on crashes and speeds. Specifically, the survey sought information about the important factors that different states consider before raising their speed limits. A total of 16 states responded to the survey. In addition to what was revealed by the literature review, the survey revealed that, "*crashes increased the last time Missouri raised the speed limit on (their) interstates. Total crashes increased in first year following speed limit change (decreased in years 2 & 3). Fatal crashes increased in each of the three years following the speed limit change. Speed increased in each of the three years following the speed limit change (from 71.9 to 74.6 mph)*."

Regarding the important factors considered by states before raising speed limits, the survey found that engineering studies, crash history or safety analysis and current legal speed limits are the top three considerations for raising speed limits. Other factors included design speed, public opinions and political influence. Additional factors reported to prompt speed limit changes were requests to re-evaluate a current speed limit (e.g., from municipality), road geometrics, roadside conditions, median protections and interchange spacing.

2.5 Summary of literature review

The literature section reviewed studies that evaluated the impact of changing speed limits on crash frequency and drivers' operational speed. A study by Wagenaar et.al (1990) conducted in Michigan to evaluate the impact of raising the speed limit from 55 mph to 65 mph showed a significant increase in fatal, incapacitating and minor injury crashes by 19.2 percent, 39.8 percent and 25.4 percent, respectively. With the speed limit increase from 65 mph to 70 mph and truck speed limit remaining at 55 mph in Michigan, findings from evaluation studies (Taylor 1997 and Taylor 2000) showed a 4.5 percent increase in fatal crashes and a decrease of 9.3 percent in incapacitating injuries. Overall, there was an increase of 10.5 percent in total crashes, which was lower than the increase in VMT (11.9 percent). For trucks, there was a reduction in fatal and incapacitating injury by 14.5 percent and 24.2 percent, respectively. Total truck-related crashes increased by 7 percent. Changes in operational speed before and after raising the speed limit were also investigated. There was an average increase of 0.8 mph and 0.9 mph for the 50th percentile speed and the 85th percentile speed, respectively.

For other states, most of the studies which focused only on individual states indicated an increase in fatal crashes, fatalities, fatality rate and total crashes especially in rural interstate freeways. The percentage increases in fatal crashes were in most cases higher than the percentage increases in total crashes. However, studies conducted in Kansas and Indiana showed no significant change in crashes by severity after the change in speed limit. Studies that investigated the overall impact of raising the freeway speed limits in multiple US states showed an increase in fatality and fatality rates.

The key limitation observed in most past studies was the inability to control for other confounding factors that would have contributed to the observed changes of speed and traffic crashes. In most cases, simple descriptive statistics were utilized to compare the number of crashes before and after raising the speed limit. Confounding factors such as seatbelt enforcement, vehicle miles travelled, alcohol use and driving, vehicle fleet mix, improved vehicle safety measures such as antilock brakes, speed limit on other roadways, driver expectation and adaptation to risk may have a profound impact on operational speed, crash frequency and severity. Since the effects of most confounding factors may vary over time, the time effect is very important to account for in such evaluations.

Evaluations of the impacts of speed limit changes on drivers' operational speed involved simple comparison of 85^{th} percentile speed and speed violation before and after changing the speed limit. In some cases, the analysis was supported by simple statistical test such as *t*-test. Overall for all states including Michigan, the results indicated an increase in the 85^{th} percentile speed after changing the speed limit. Conflicting results the percentage of speed violations were obtained: some studies showed speed violations to have doubled (Davis. 1998) in the after period while other studies showed a reduction in speed violation by 12 to 75 percent (Souleyrette, 2009 & Freedman et al, 2007).

3 Speed Data Analysis

3.1 Introduction

One of the primary goals of this project was to determine if the increase in speed limit on selected freeway segments had any impacts on operational speeds. For this study, MDOT selected and provided a list of study sites where the speed limit changed (i.e., test sites). MDOT also provided freeway segments which had no change in the speed limit for the period covered in the analysis (i.e., control sites). This chapter covers the analysis of speed data collected from selected freeway segments that had a raise in the speed limit and control sites that had no speed limit change. The analysis encompasses studying speed trends and speed distributions before and after the change in speed limits. The speed summary for each site is provided, containing speed parameters such as the mean speed, the 50th percentile speed, the 85th percentile speed and the standard deviation. The percentage of vehicles exceeding the speed limit above a certain threshold before and after increasing the speed limit are also provided so as to measure and compare driver compliance with the posted speed limit in the before and after periods. The change in speed standard deviation after raising the posted speed limit for each site was compared with the percentage change in crash rates obtained in the crash analysis (Chapter 4) so as to discern any possible association between changes in speed parameters and crash rates.

The speed data used in this analysis was provided by MDOT from their continuous count stations (CCS) from year 2003 to year 2016. The speed and volume data were already aggregated in hourly basis and grouped in speed bins with the class interval of 5 mph. Therefore, the speed parameters provided in the analysis are based on grouped vehicle speed data but not individual vehicle speed data. Other potential data sources for speed included those collected by a mapping data company called HERE (formerly NAVTEQ) and those collected under the MDOT's Intelligent Transportation Systems (ITS) program. However, data from these sources (especially ITS data) did not cover the entire period of analysis needed for some sites or were not available for the study sites as there was no ITS sensors in these segments. Also, the CCS data was preferred over HERE data because it presents data from all vehicles while HERE data is from probe vehicles.

Field spot speed studies were conducted at selected sites which included freeway sites that had an increase in the speed limit, freeways sites with no change in the speed limit and non-freeway sites where the speed limits were to be changed from 55-65 mph in response to Michigan's Public Act 445 of 2016. The last subset of data (from non-freeway sites where the speed limits were to be changed in response to Michigan's Public Act 445) was collected for future use.

3.2 Speed trends and distributions from historical data

Historical speed data were obtained from CCS records stored by MDOT for sites with permanent data recording stations. The speed trends were then plotted to show the 50^{th} percentile speed and the 85^{th} percentile speed before and after changing the speed limit. The test sites and control sites that had historical speed information before and after changing the speed limit were used to plot and study speed trends. The test sites included in the analysis were US-2 (Mather Road to US-41) and I-75 (Outer Dr. to Pennsylvania Ave) while the control sites were I-94 (M-153 to 9 Mile Rd, Lapeer/I-94 Connector to M-25) and M-39 (I-94 to M-10). The speed distribution shows the frequency of vehicles in each speed bin. It assisted in visualizing the corresponding shift in vehicle speed distributions following the increase in posted speed limit.

3.2.1 Speed trends and distributions at test sites

Figure 3-1 and Figure 3-2 show the speed trend and speed distribution at US-2. US-2 had speed limit changed from 55 mph to 65 mph in 2010. From the speed trend, it can be clearly seen that there was an increase in the 85^{th} percentile speed of about 4-5 mph after speed limit was increased in 2010. The 50^{th} percentile speed also increased by 4-5 mph in the after period. The speed distribution in Figure 3-2 shows a shift by most of the drivers to higher speeds in the after-period compared to the before-period. A slight change in the 50^{th} percentile and the 85^{th} percentile speed was observed for I-75 section which had the speed limit changed in 2007 from 65 mph to 70 mph as shown in Figure 3-3 and Figure 3-4.

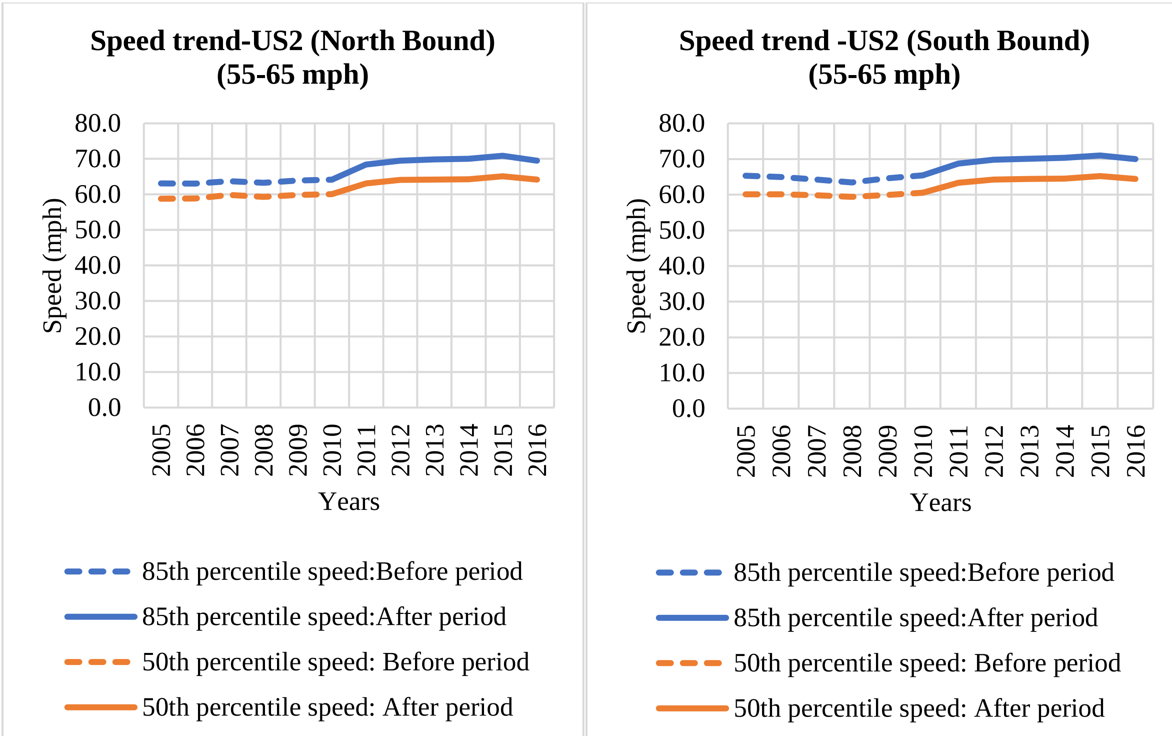

Figure 3-1 Speed profiles for US2 (Mather Road to US-41)

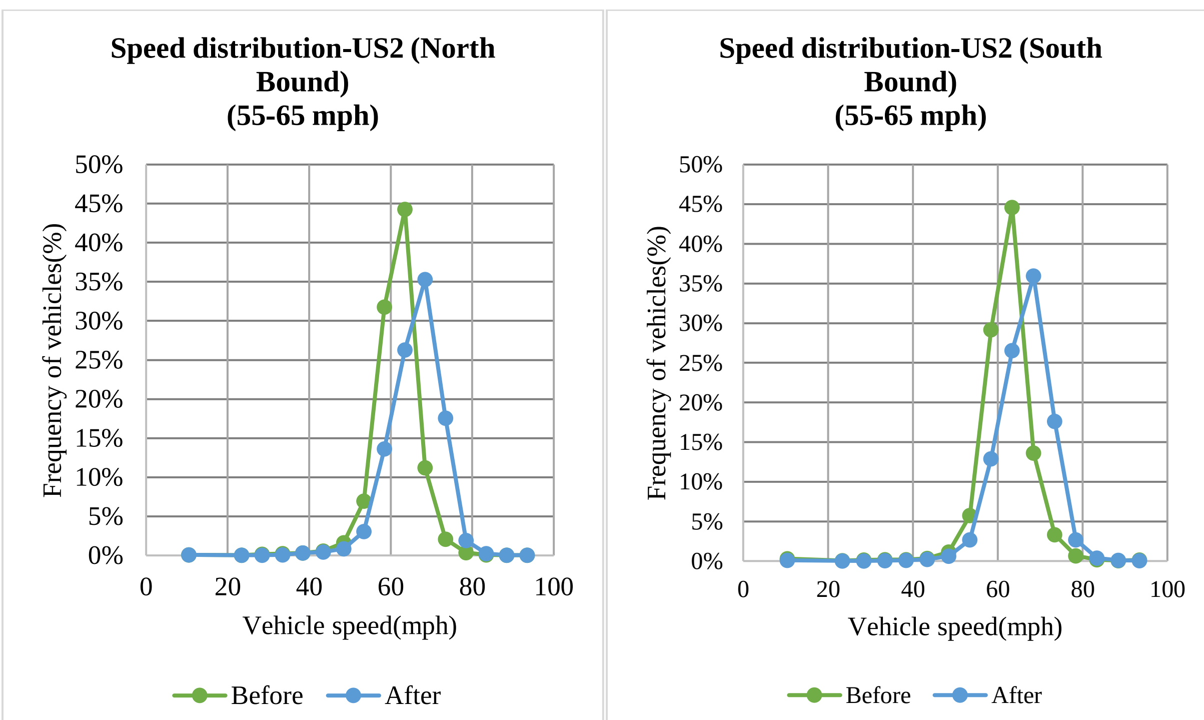

Figure 3-2 Speed distribution of US-2 (Mather Road to US-41)

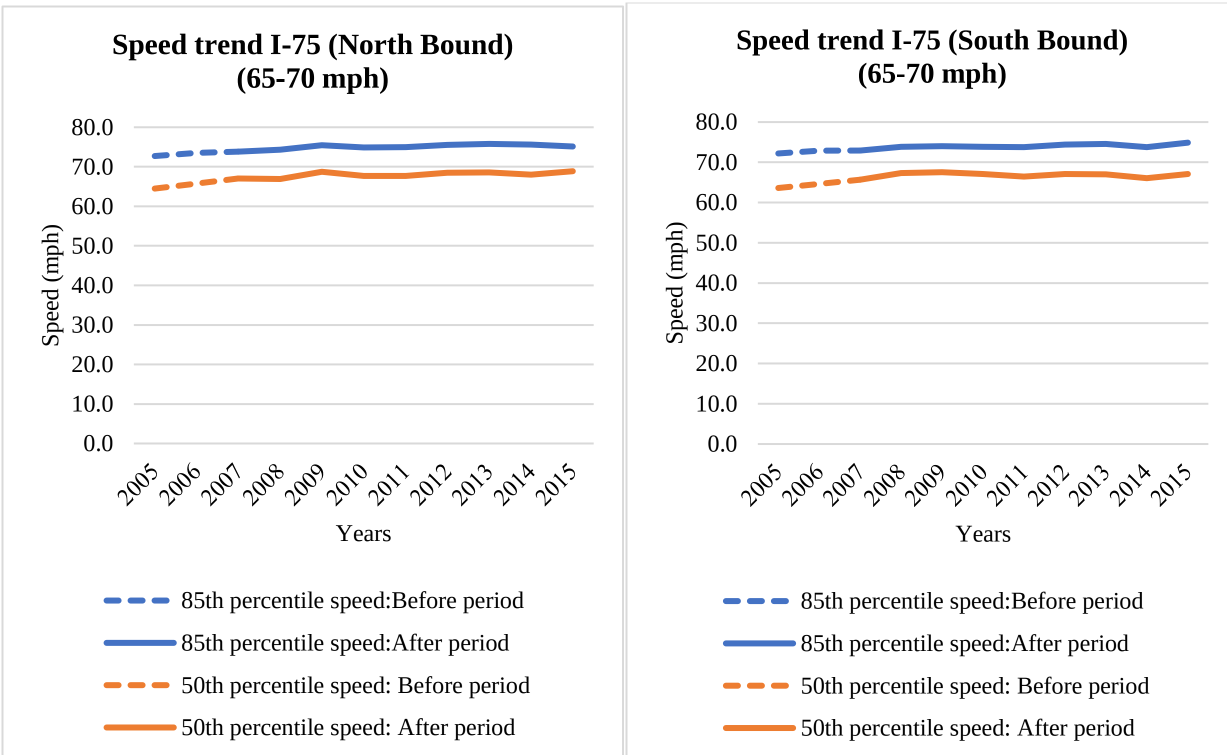

Figure 3-3 Speed distribution for I-75 (Outer Dr. to Pennsylvania Ave)

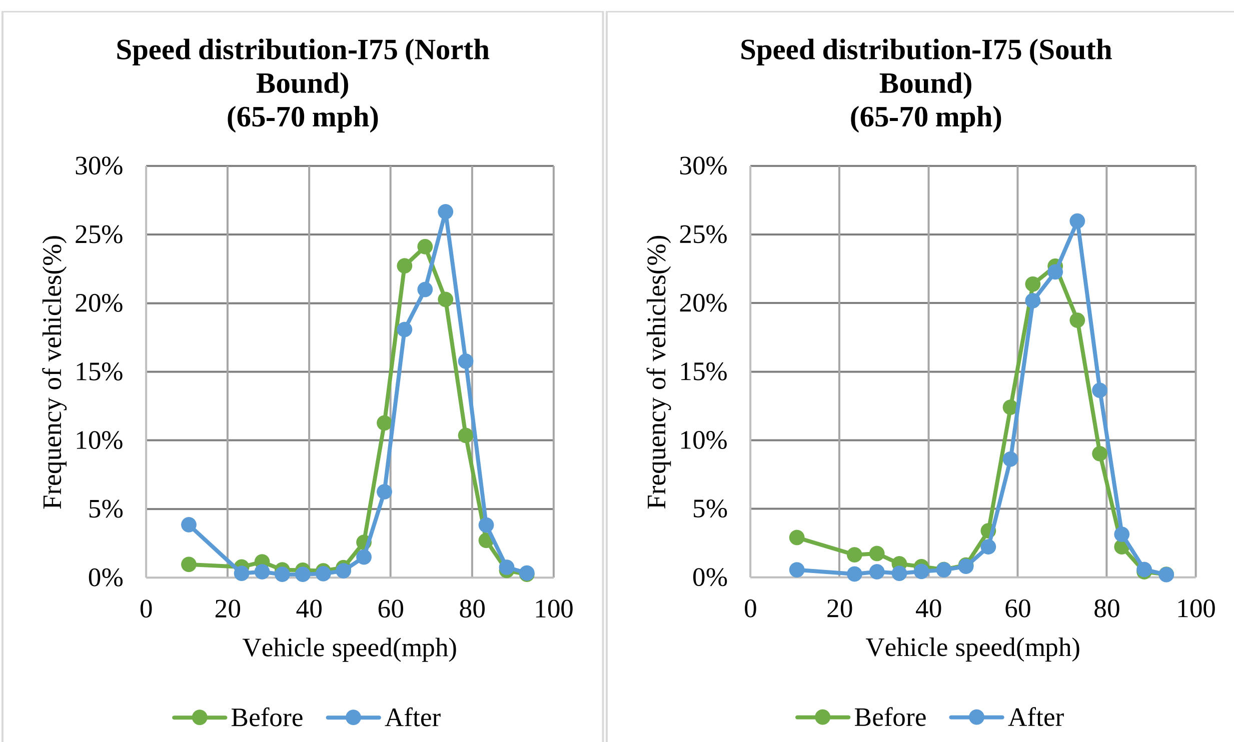

Figure 3-4 Speed distribution for I-75 (Outer Dr. to Pennsylvania Ave)

3.2.2 Speed trends at the control sites

Figure 3-5 and Figure 3-6 show the speed trends for I-94 (M-153 to 9 Mile Road, Lapeer/I-94 Connector to M-25) and M-39 (I-94 to M-10) freeway segments which maintained the same speed limit of 55 mph. Overall, the 50th percentile speed and the 85th percentile speed appeared to be uniform with no significant changes over time. Therefore, by comparing the speed trends and distribution between the test sites (Figure 3-1 to Figure 3-4) and control sites (Figure 3-5 and Figure 3-6), it can be suggested that raising speed had an impact on operational speeds.

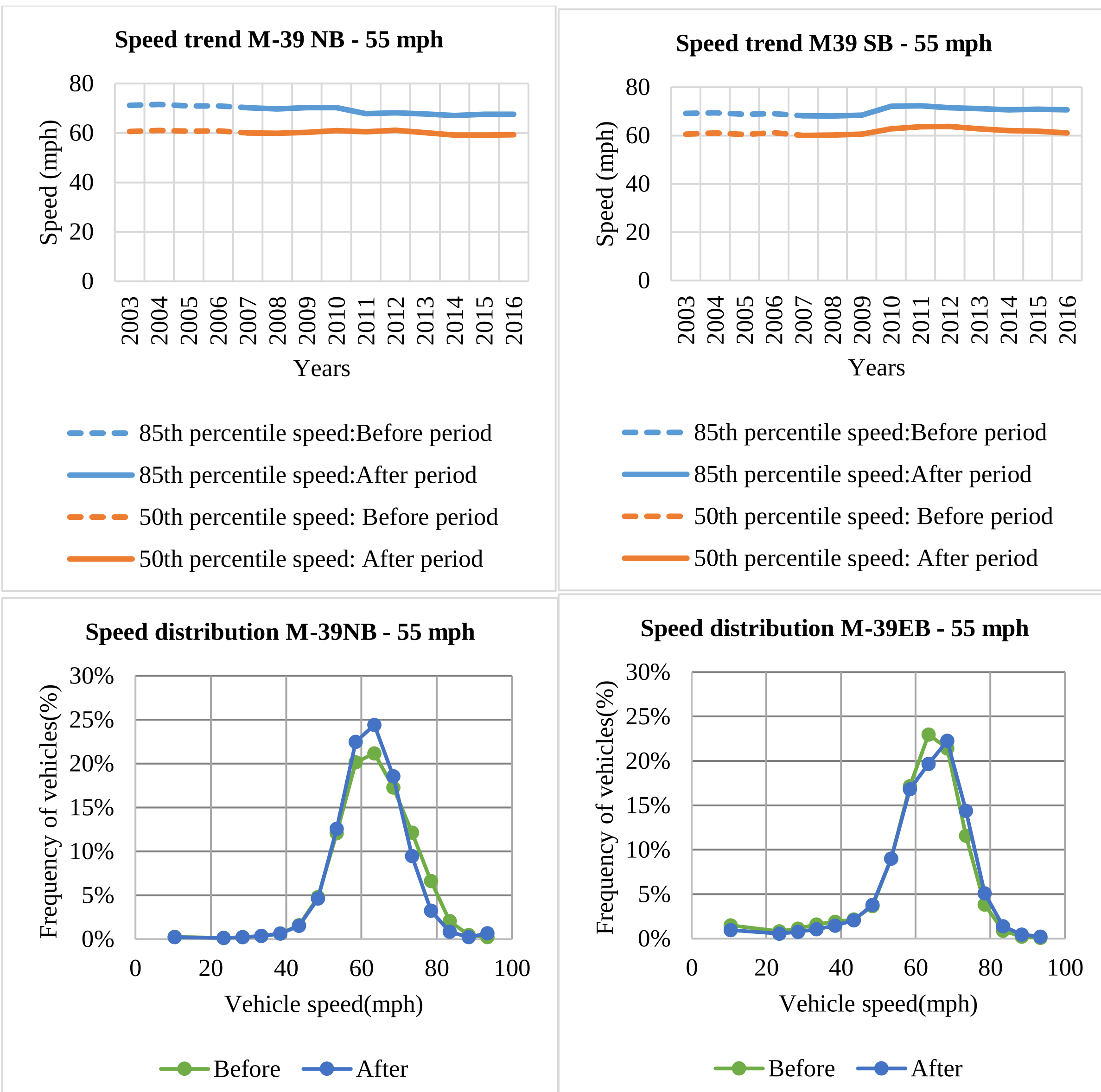

Figure 3-5 Speed trend and speed distribution of M-39 (I-94 to M-10)

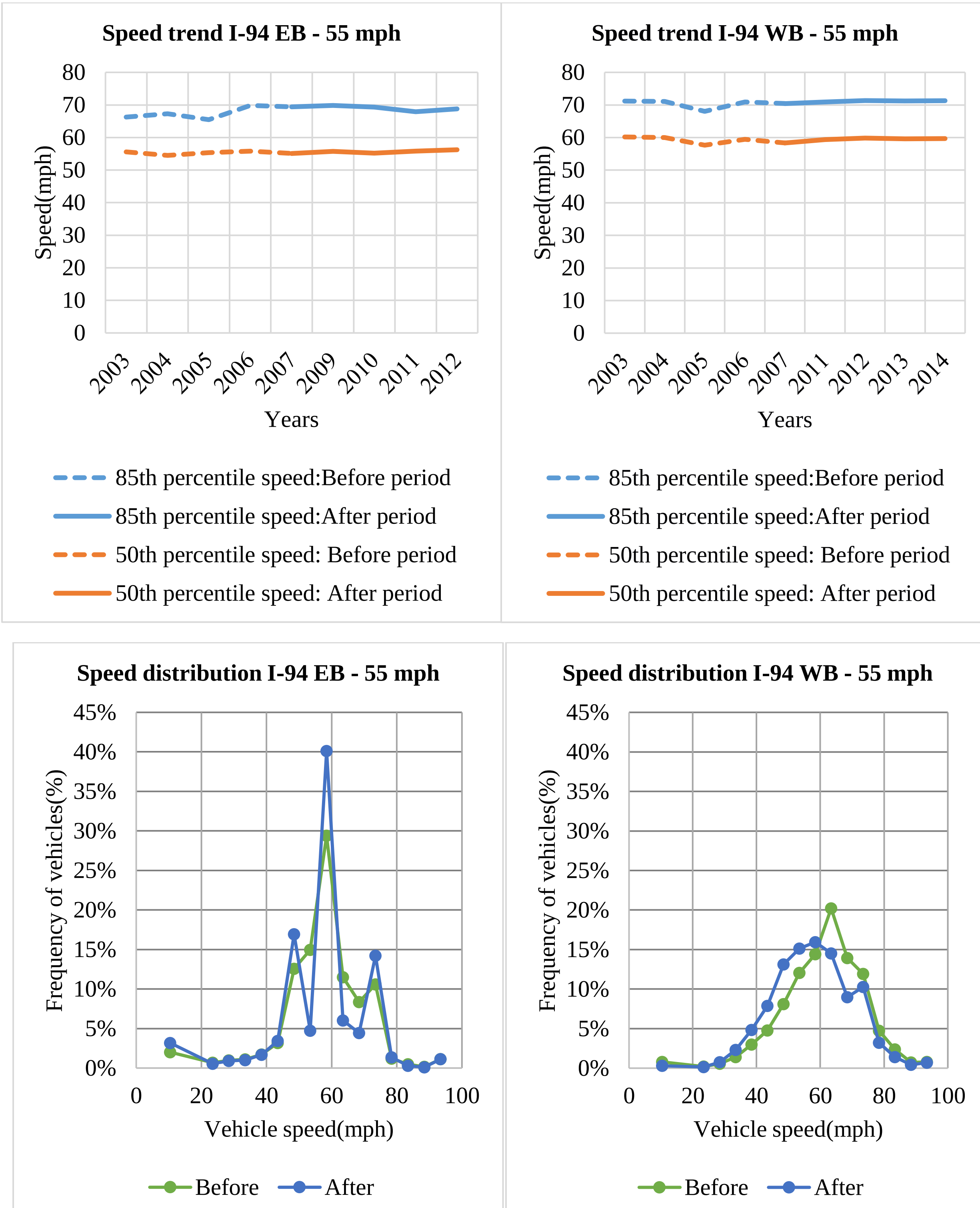

Figure 3-6 Speed trend and distribution for I-94 (M-153 to 9 Mile Road, Lapeer/I-94 Connector to M-25)

Table 3-1 provides the summary of speed parameters before and after changing the speed limit. These speed parameters include the 50th percentile speed, the 85th percentile speed, the mean speed and the standard deviation. The sites from which the speed parameter are summarized include US-2 (with the speed limit change margin of 10 mph (55-65 mph) in 2010); I-75 and M-59 (with the speed limit change margin of 5 mph (65-70 mph) in 2007); and I-94 and M-59 (which had no change in the speed limit). The before and after periods for US-2 were 2005-2009 and 2011-2016, respectively, while for I-75 and M-59, the before and after periods were 2005-2006 and 2008-2015, respectively. Before and after period for the corresponding control sites were made similar to I-75 and M-59 for comparison purpose. The results for the quarterly analysis of vehicle speeds which considers seasonal variation of speed before and after changing the speed limit are provided in the appendices (see Table 8-8 to Table 8-11).The following results were observed for US-2 (which had a speed limit change margin of 10 mph):

- The 50th percentile speed increased in the after period by 2.4-3.4 mph. The 85th percentile speed increased by 3.5-5.2 mph.
- In both before and after periods, the 50th percentile speed was above the posted speed limit. The 50th percentile speed was 3.8-5.1 mph above the speed limit in the before period, but was reduced to 1-1.4 mph in the after period.
- The change in the standard deviation in the after period was less than 1 mph.

The following were observed at I-75 and M-59 sites with the posted speed limit change margin of 5 mph (65-70 mph):

- There was an increase in the 50th percentile speed and the 85th percentile speed by 1-4.8 mph and 1.8-4.7 mph, respectively.
- The standard deviation decreased by 0.1-4.9 mph in the after period for I-75SB, M-59EB and M-59WB. Only I-75NB had an increase in the standard deviation by 2.8 mph in the after period.

The following were observed at I-94 and M-39 control sites which had no change in speed limit:

- M-39 NB and I-94 WB had a reduction in the 85th percentile speed in the after period while the other directions (M-39 SB, I-94 EB) had a slight increase in the 85th percentile speed. The reduction in the 85th percentile speed was only observed at some control sites but not at any test site.
- Overall, the change in the 85th percentile speed at the control site was lower compared to that at the test sites. The maximum change in the 85th percentile speed observed at the control site was +1.6mph while at the test site it was +4.8mph.

Table 3-1 Summary of speed parameters at the test sites

Sites		50th percentile speed			85th percentile speed			Speed Std. Dev.		
		Before	*After*	*Change*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
Test sites	US-2NB	58.8	62.2	3.4	63.1	68.3	5.2	5.7	6.5	0.7
	US-2SB	60.1	62.5	2.4	65.1	68.6	3.5	6.4	6.3	-0.1
	I-75NB	65.2	67.8	2.7	73.2	75.2	2.1	11.3	14.2	2.8
	I-75SB	64.2	67.0	2.8	72.6	74.4	1.8	14.5	9.6	-4.9
	M59-EB	69.1	70.9	1.8	76.4	77.4	1.0	12.1	10.8	-1.2
	M59WB	66.0	70.7	4.7	73.0	77.8	4.8	11.6	11.4	-0.1
Control sites	M-39 NB	60.8	60.0	-0.8	71.1	68.3	-2.8	9.9	9.1	-0.8
	M-39SB	60.8	61.9	1.0	69.2	70.7	1.6	12.3	11.6	-0.7
	I-94 EB	55.6	55.6	0.0	67.6	69.2	1.6	12.6	13.6	1.0
	I-94 WB	59.6	55.2	-4.4	70.8	69.0	-1.8	12.6	12.4	-0.2

3.3 Field data collection of vehicle speeds

Speed and volume data were collected on selected sites across Michigan as shown in Figure 3-7. Details about the sites where field data was collected are given in Table 3-2. Collection of field speed data aimed at mainly achieving the following:

1. Conducting a cross-sectional speed analysis by comparing speed data from a test site and a control site that had similar characteristics. The test sites and

control sites included in this analysis were those that had no historical CCS speed data. Therefore, vehicle speed cross-sectional analysis was preferable.

2. Obtaining the before-period volume and speed data from non-freeway sites that do not have permanent count station (CCS) but were expected to have their speed limits changed from 55 mph to 65 mph following the Michigan's Public Act 445 of 2016. The data collected in this study can be used in the future to evaluate the impact of this change in speed limit.

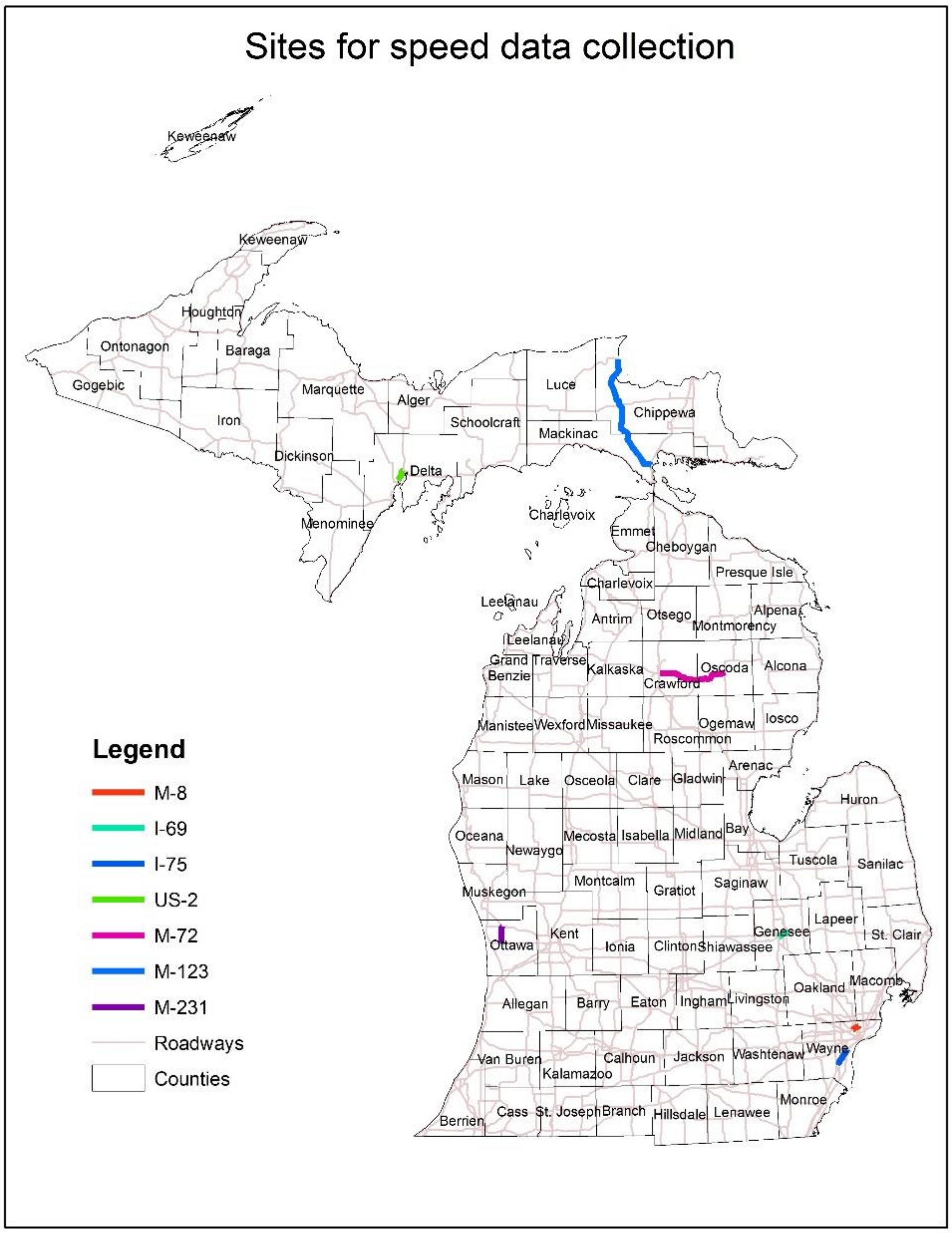

Figure 3-7 Freeway and non-freeway sites for field data collection

Table 3-2 Sites that were used for field data collection and their associated purpose

Site	Purpose of data collection	Data collection date	Data collection location coordinates	City/Township, County
M-8(Rosa Park to Joseph Campau St)	Speed cross-sectional analysis Test site(I-69) vs Control site (M-8)	May 31, 2017	42.403418, -83.095621	Highland Park, Wayne
I-69 (Flint)		June 05, 2017	43.000724, -83.701123	Flint, Genesee
US-2(Mather Road to US-41)	Economic analysis- Average speed for passenger cars and trucks	June 08, 2017	45.918533, -86.992994	Massonville, Delta
I-75(Outer Dr. to Pennsylvania Road)		May 31, 2017	42.259376, -83.179698	Lincoln Park, Wayne
M-231 (M-45 to M-104)	Before data for non-freeways that do not have CCS.	May 30, 2017	43.019212, -86.091506	Grand Haven, Ottawa
M-72 (Grayling to Luzerne)		June 06, 2017	44.656623, -84.674805	Grayling, Crawford
M-123(Moran to Trout Lake)		June 07, 2017	46.059885, -84.898544	Moran, Mackinac

The speed data were collected using a radar speed gun during the off-peak hours to avoid the effect of traffic congestion on the observed vehicle speeds. The observers were positioned at an overpass bridge (where available) or alongside the shoulder, inconspicuous from oncoming vehicles when recording the vehicle speeds. Volume data were collected simultaneously with speed data by using video recordings which were post processed in the laboratory. The speed data was separated by vehicle type (passenger car vs trucks) and lane position (inner lane vs outer lane).

3.4 Vehicle speed cross-sectional analysis

Vehicle speed cross-sectional analysis was conducted for I-69 and M-8 sites. While I-69 site had a change in the speed limit from 55 mph to 70 mph for passenger cars and 55 mph to 60 mph for trucks in 2005, the posted speed limit at M-8 remained at 55 mph. Both test site and control site had the same number of lanes (4 lanes) and average annual daily traffic (AADT) between 30,000 and 40,000 vehicles per day. The I-69 section had an average AADT of about 36000 vehicles per day while M-8 had an average AADT of about 33,000 vehicles per day. Figure 3-7 shows the locations where the speed data were collected and their respective site characteristics.

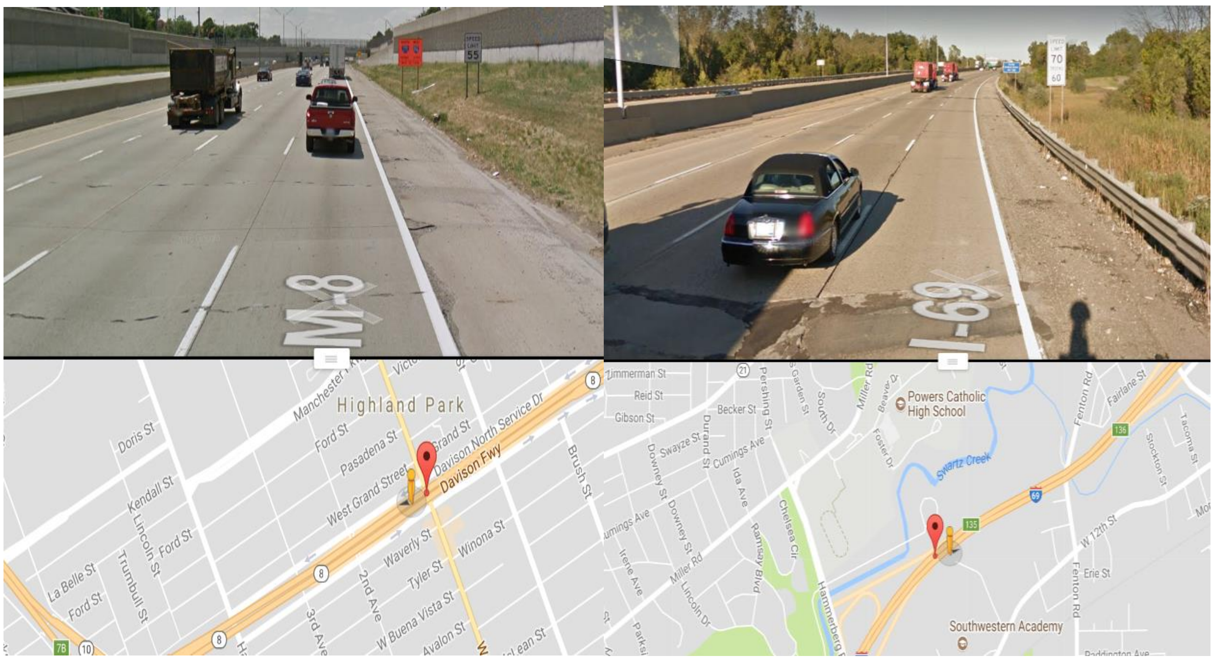

Figure 3-8 Description of the site locations for I-69 and M-8 (Source: Google maps)

Overall, the vehicle speeds were higher at the test site (I-69) compared to the control site (M-8) as shown in Figure 3.8 and Figure 3-9. The 85^{th} percentile speed of the I-69 site was about 5.2 - 7.7 mph higher than that of the M-8 site.

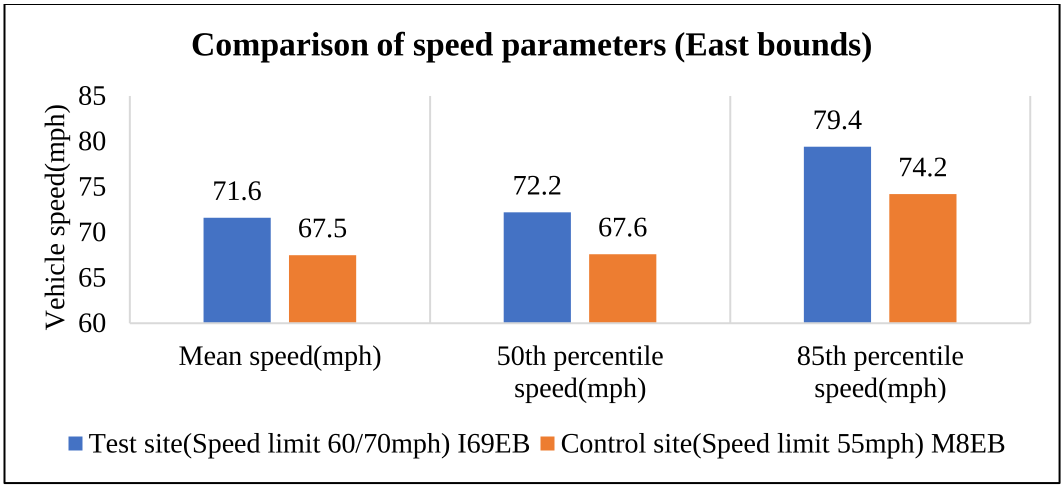

Figure 3-9 Comparison of speed parameters between I-69 EB and M-8 EB

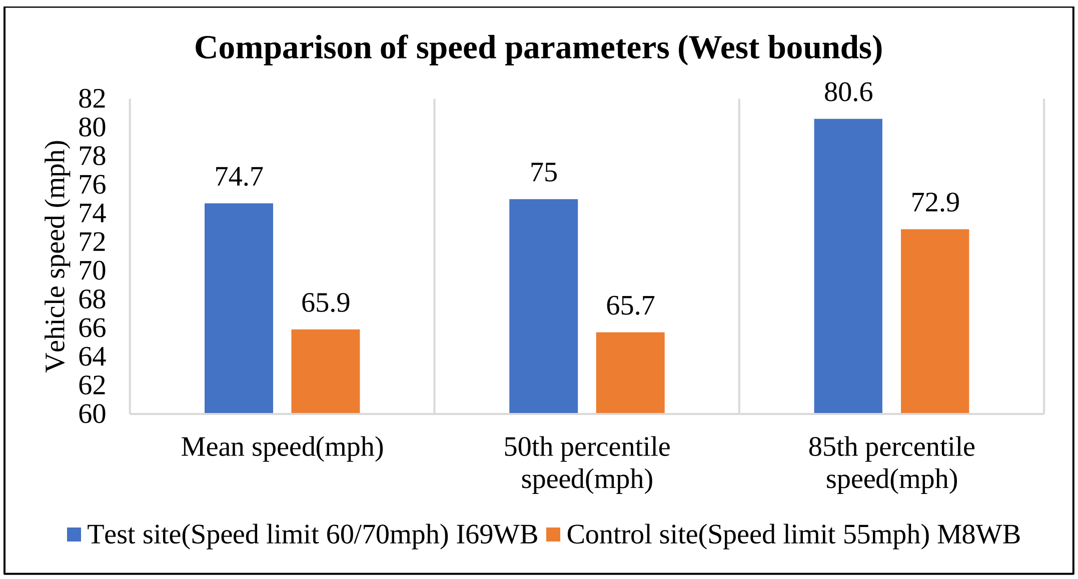

Figure 3-10 Comparison of speed parameters between I-69 WB and M-8 WB

The percentages of vehicles driving above the posted speed limit by 5 mph, 10 mph and 15 mph were computed for both I-69 and M-8. Overall, the speed violations were higher at the control site (M-8) compared to the test site (I-69) as show in Figure 3-10 and Figure 3-11. About 50 – 65 percent of recorded vehicles at M-8 were travelling at speeds which were at least 10 mph above the posted speed limit (55 mph) while only 12 – 21 percent of recorded vehicles at I-69 were travelling at speeds which were at least 10 mph above the posted speed limit (70 mph). This was expected as the geometric and traffic conditions at M-8 site (speed limit of 55 mph) were similar to those of the I-69 site (with the speed limit of 70 mph).

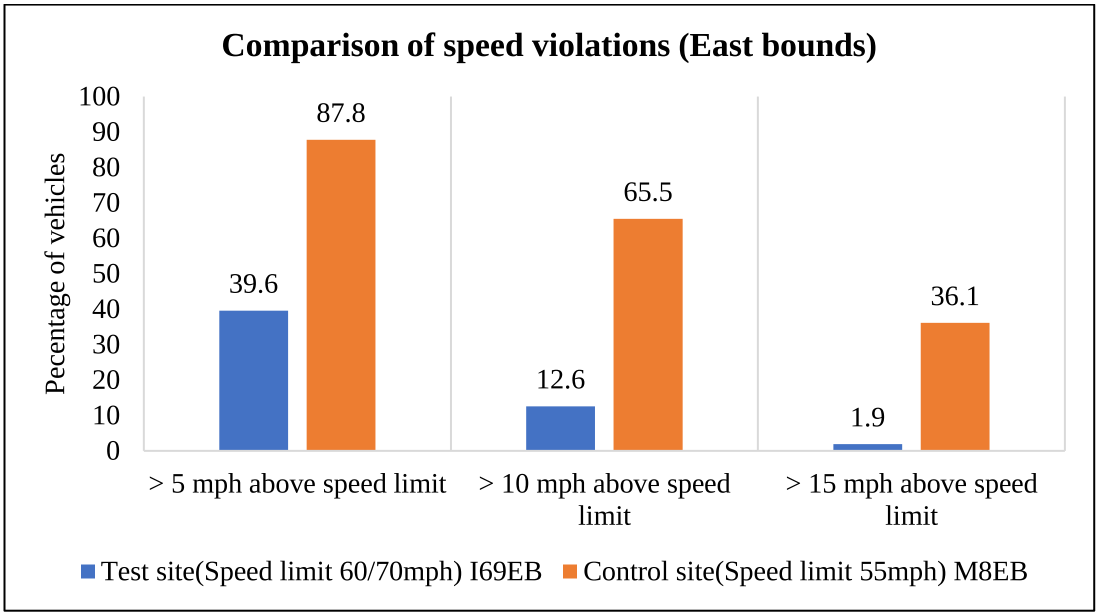

Figure 3-11 Comparison of speed violations between I-69 EB and M-8 EB

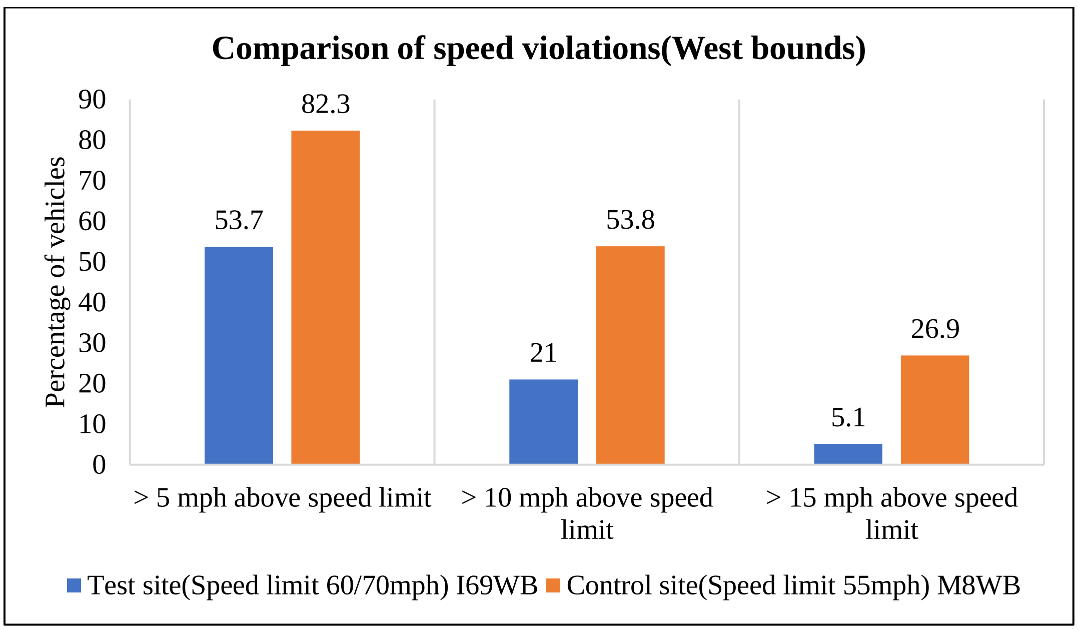

Figure 3-12 Comparison of speed violations between I-69 EB and M-8 EB

Table 3-3 provides a breakdown of speed parameters and speed violation estimates by vehicle type. In summary, the following results were observed from cross-sectional analysis of speeds:

- There was a difference of 5.3-9.4 mph in the 50th percentile speed of passenger cars between the test site and control site. For trucks, the difference was 1.8-2.5 mph.
- The difference in the passenger cars' 85th percentile speed between the test sites and control site for was 4.8-8 mph, while the difference was 1-4.6 mph for trucks.
- Speed variations were higher for passenger cars compared to trucks for both test site and control site.
- Trucks had more compliance with posted speed limit compared to passenger cars for both test site and control site.

Table 3-3 Cross-sectional analysis results of speed data

Bound	Vehicle type	Speed limit (mph)	Sample size	Mean speed	50th perc. speed	85th perc. speed	Std. Dev.	Percent above speed limit		
								5 mph	10 mph	15 mph
I69EB	Passenger	70	643	72.8	73.7	79.6	6.89	42.3	13.7	2.2
	Trucks	60	79	61.2	61.3	65.9	4.48	17.7	3.8	0.0
	All	60/70	722	71.6	72.2	79.4	7.59	39.6	12.6	1.9
I69WB	Passenger	70	1134	75.5	75.5	81.1	5.90	54.1	20.0	4.7
	Trucks	60	120	66.8	64.9	73.1	5.40	49.2	30.0	9.2
	All	60/70	1254	74.7	75	80.6	6.39	53.7	21.0	5.1
M8EB	Passenger	55	397	68.5	68.4	74.8	6.17	93.5	71.5	39.8
	Trucks	55	46	59.1	58.8	64.9	5.50	39.1	13.0	4.3
	All	55	443	67.5	67.6	74.2	6.74	87.8	65.5	36.1
M8WB	Passenger	55	644	66.2	66.1	73.1	6.68	83.9	55.6	28.9
	Trucks	55	81	63.5	63.1	68.5	6.23	70.4	39.5	11.1
	All	55	725	65.9	65.7	72.9	6.68	82.3	53.8	26.9

3.5 Summary of the impacts of raising speed limit on operational speeds

A comparison was made of speed parameters such as the 50th percentile speed, the 85th percentile speed and the standard deviation before and after changing the speed limit at selected sites. Speed trends and distributions at test sites and control sites were examined to discern any association between speed limit changes and the corresponding change in drivers' operating speed. The following results were obtained:

- Change in the speed limit exhibited an effect on operating speed when speed trend and speed distribution for the test sites (sites where speed limit changed) before and after changing the speed limit were compared with the speed trend and distribution for the control sites (sites where speed limit did not change).
- The analysis of speed parameters indicated an increase in the 85th percentile speed by 1.8-4.7 mph and 3.5-4.2 mph for test sites that had the speed limit change margin of 5 mph and 10 mph, respectively.

Using field speed data collected in this study, the cross-sectional speed data analysis between I-69 (test site) which had a speed limit change from 55 to 70 mph and M-39 (control site) which had its speed maintained at 55 mph had the following results:

- The difference in the 85th percentile speed between the test site and the control site for passenger cars was 4.5 - 8 mph while for trucks the difference was 1 - 4.6 mph.
- Truck drivers had higher compliance rate with their respective posted speed limit (60 mph) compared to passenger car drivers (70 mph) for both test site and control site.
- At the site where the speed limit changed from 55 mph to 70 mph (i.e., test site), there were lower percentages of drivers who exceeded the speed limit by 5 mph, 10 mph or 15 mph compared to the test site. Vehicles at test sites had a relatively higher compliance rate with the posted speed limit compared to vehicles observed at the control sites.

4 Crash Data Analysis

4.1 Introduction

Determining raising the speed limit on selected Michigan freeway segments had any impacts on crash frequency and severity was also one of the primary goals of this project. MDOT selected and provided study sites where the speed limit changed. Also, MDOT provided freeway segments which had no change in the speed limit for the period covered in the analysis. Table 4-1 provides the list of eight freeway test sites that were used for the analysis presented in this chapter. The test sites can be categorized into three groups based on speed change margin. The first group consists of sites that had a change in speed limit from 55 mph to 65 mph. These were US-2 and I-75/Telegraph Road connector. The second group of sites had speed limit changed from 55 mph to 70 mph, which are I-69 and M-53 freeway segments. The last group which had more number of sites compared to the first and second group, consists of sites that had a speed limit changed from 65 mph to 70 mph. It includes freeway sections of I-75, M-59 and I-696. Most of the sites were in urban areas, except US-2 as shown in Figure 4-1. The test sites had the speed limit changed between 2005 and 2010. Maps of the sites used in this study are shown in Appendix 8.1.

Table 4-1 Selected freeway segments with the speed limit

Site/Corridor	Boundary	Speed change(mph)	Year of implementation	Land use
US-2	Mather Road to US-41	55-65	2010	Rural
M-53	27 Mile Road to 34 Mile Road	55-70	2007	Urban
M-59	Opdyke to Mound Road	65-70	2007	Urban
I-69	Centre Rd to Hammerburg Road	55-70	2005	Urban
I-75	Adams Road to I-94	65-70	2007	Urban
I-75/Telegraph Rd	I-75 to Telegraph Road	55-65	2005	Urban
I-696	I-94 to Telegraph Road	65-70	2007	Urban
I-75	Outer Dr. to Pennsylvania Road	65-70	2007	Urban

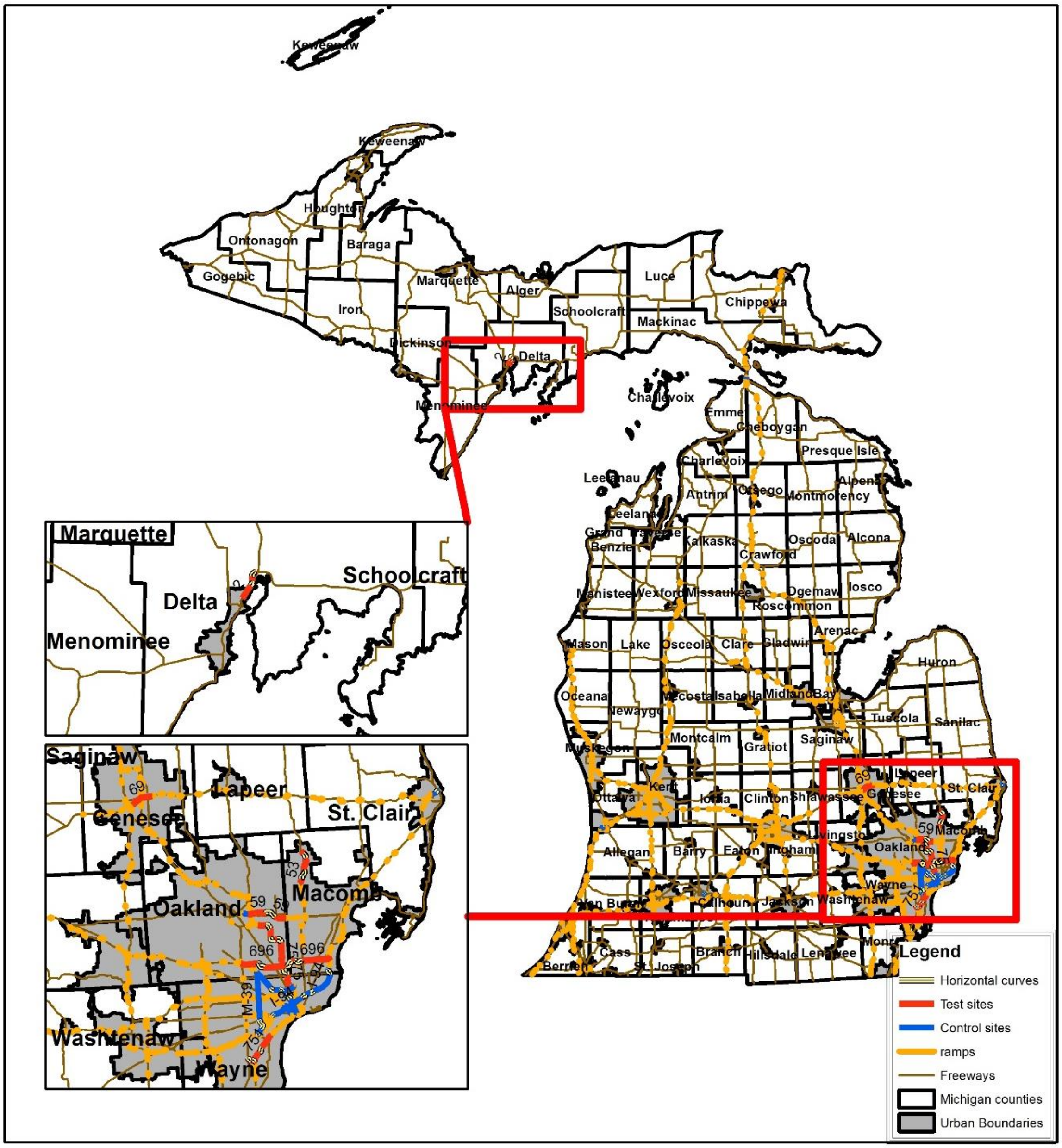

Figure 4-1 Spatial distribution of the test sites and control sites

4.2 Crash analysis methods

Site by site crash data analyses, followed by crash analysis for all sites, were performed. The analyses included generating crash trends over years divided into before and after period to discern any changes in crash trend after raising the speed limit. Crash trends for test sites, control sites and all Michigan freeways were plotted together for comparison purposes. This helped to assess if the trends observed in the test sites in the before and after periods were different compared to the general crash trends on control sites and all other Michigan freeways. A speed limit may have likely impacted the crash frequency and severity over years if the following observations were noted.

- There was a change in slope in the after period compared to the before period.
- The slope in the after period for the test site was different from the slope observed for control sites and all other freeways.

Subsequent analysis covered the determination of annual average crashes for crash frequency, crash severity and road departure crashes before and after raising the speed limit. Vehicle-miles-travelled (VMT) before and after changing the speed limit was also computed for test sites, control sites and all freeways. The percentage change in crash rates based on different crash categories were computed. The crash rate categories included fatality, fatal crashes, severe crashes (KAB), road departure crashes and total crashes.

The final analysis involved modeling of crash data to quantify the impact of raising the speed limit on crash frequency and severity while controlling for exposure and other confounding factors. The mixed-effects negative binomial model was used for this purpose. Selection of this model was mainly influenced by its ability to include fixed effects and random effects in the model simultaneously. The model utilized panel data structure and therefore was possible to control for the effect of time and other time variant factors such Average Annual Daily Traffic (AADT). Controlling for time effect enabled the elimination of potential regression-to the mean bias, which is the natural tendency of crashes to incline toward its average value over time, regardless of intervention by any factor. Other details about the model specification and estimation procedures are discussed later in this chapter.

4.2.1 Crash trends before and after changing the speed limit

Figure 4-2 shows the trend of total crashes from 2000 to 2015 for study test sites and all freeways in Michigan. The crash trend was split into three phases based on the year of speed limit change: before period, during implementation and after period. The test sites included in Figure 4-2 were those that had the speed limit increase in 2005 through 2007 so as to allow adequate observation of crash trends in the before and after periods. Seven out of eight test sites (see Table 4-1) fall under that implementation period and account for 99 percent of all crashes that occurred at test sites considered in this study. The crash trend from all Michigan freeways was observed for comparison purposes. As depicted from Figure 4-2, the crash trend for the test sites had a gentle upward slope (blue line) before the speed limit implementation. The after period had more upward and steeper slope compared to the before period. This suggests that speed limit change could have an association with the observed steeper upward trend in the after period. The crashes for all Michigan freeways were fairly constant with time in the period after speed limit change. A similar trend was observed for the KAB crashes when comparing before and after speed limit change as shown in Figure 4-3.

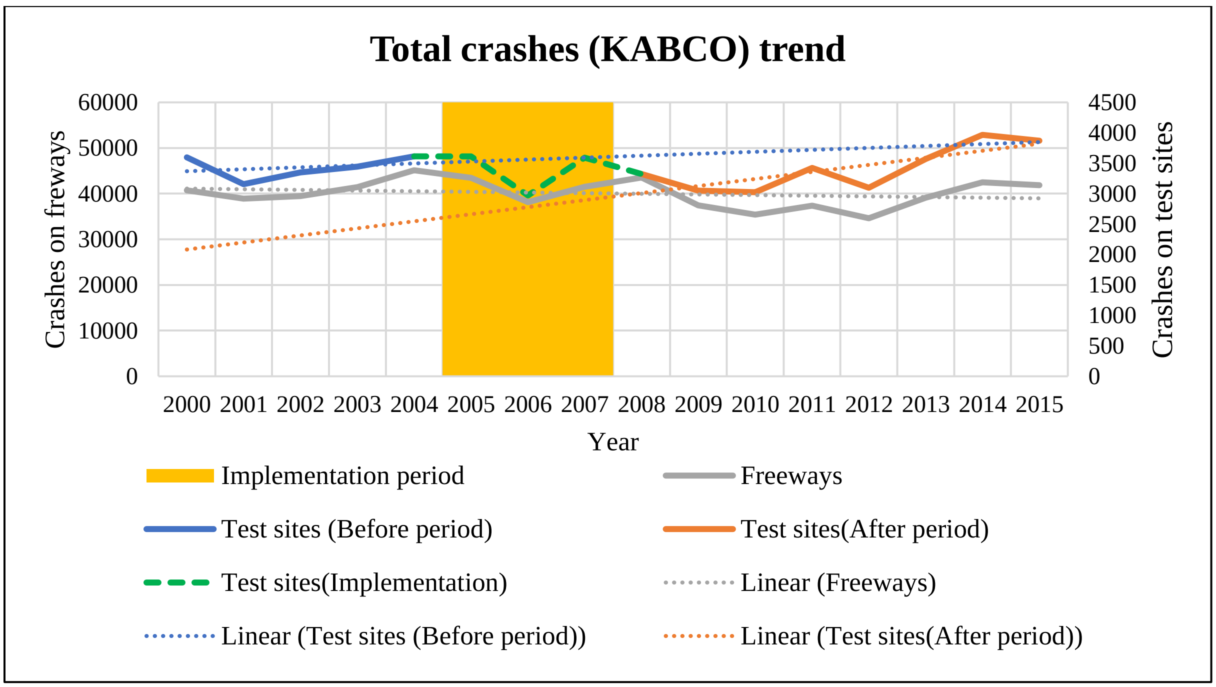

Figure 4-2 Comparison of total crash (KABCO) trend in the before and after speed limit changes

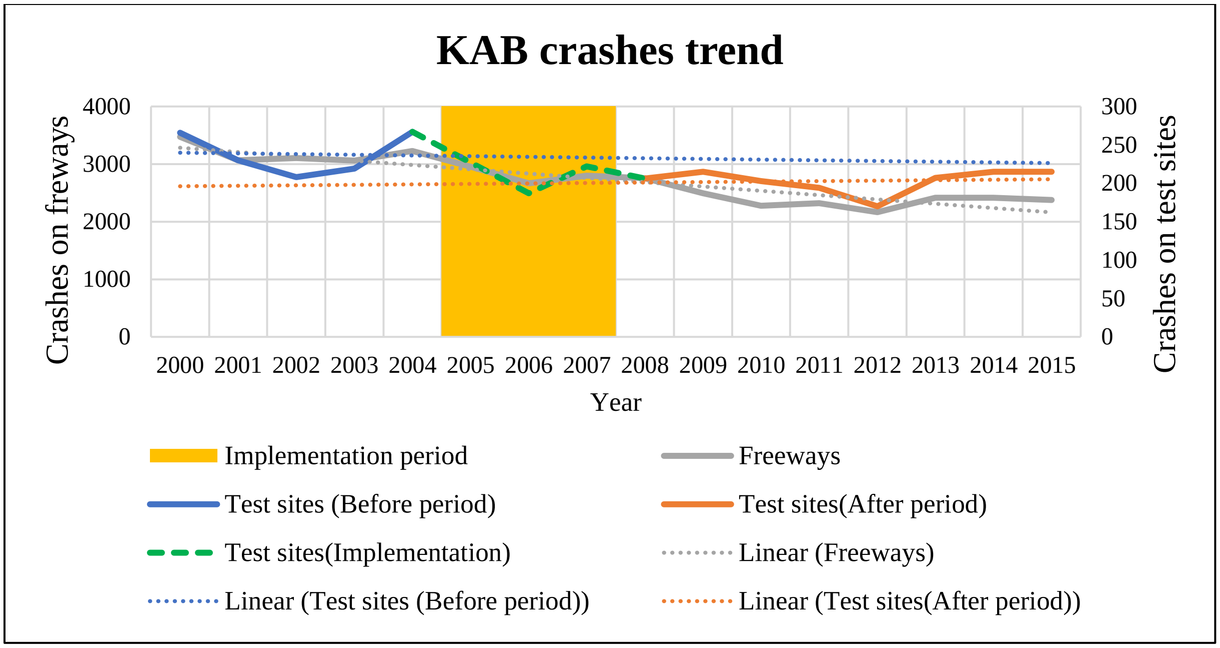

Figure 4-3 Comparison of KAB injury crash trend in the before and after speed limit changes

4.2.2 Before and after study using crash rates

Table 4-2 presents the summary of total number of crashes and VMT before and after changing the speed limit for the test sites, control sites and all freeways in Michigan. As the speed limit change years for the test sites was between year 2005 to 2010, five years before (2000-2004) and five years after (2011-2015) was used in the analysis. The crashes were presented based on fatality, fatal, incapacitating or non-incapacitating (KAB) crashes, total crashes and lane departure crashes. KAB crashes represented all severe form of injuries in the before and after raising the posted speed limit.

The reduction was observed in the number of fatality, fatal crashes, KAB crashes, total crashes and lane departure crashes after raising the speed limit for both test sites, control sites and all freeways as shown in Table 4-2. However, there was a corresponding decrease in vehicle miles travelled after raising the speed limit for both test sites, control sites and freeways. Therefore, before and after study was performed using crash rates. The results indicated a decrease in fatality rate, fatal crash rates and KAB crash rates for both test sites, control sites and all freeways in Michigan. However, observed reduction in the fatality rates, fatal crash rates and KAB crash rates was lower on test sites compared to freeways. The reduction in KAB crashes was also lower for test sites compared to control sites where the speed limit did not change. Total crashes for the test sites increased by 13 percent while a drop in total crashes was observed for control sites and all freeways by 6 percent and 2 percent, respectively. Road departure crashes increased in after period for both test sites, control sites and all freeways - with the highest increase observed at test sites (23 percent).

Table 4-2 Number of crashes before and after changing the speed limits

	Test sites		**Control sites**		**All freeways**	
	Before	*After*	*Before*	*After*	*Before*	*After*
Fatality	41	35	59	52	773	640
Fatal crashes	38	32	55	48	706	581
KAB crashes	1,181	996	1,334	989	15,932	11,692
Total crashes	17,072	17,812	17,812	15,158	20,5709	195,445
Lane departure crashes	3,518	3,987	3,712	3,871	54,529	56,960
VMT (in 100M)	114.56	105.93	100.57	90.79	1,128.82	1,098.99

Table 4-3 Observational before and after study using crash rates (per 100 Million VMT)

Rates	**Test sites**		**Control sites**		**Freeways**		**Percentage change in crash rates**		
	Before	*After*	*Before*	*After*	*Before*	*After*	*Test sites*	*Control sites*	*Freeways*
Fatality rate	0.36	0.33	0.59	0.57	0.69	0.58	-8%	-2%	-15%
Fatal crash rate	0.33	0.30	0.55	0.53	0.63	0.53	-9%	-3%	-16%
KAB crash rates	10.31	9.40	13.27	10.90	14.13	10.64	-9%	-18%	-25%
Total crash rate	149.36	168.37	177.11	167.03	182.17	177.69	13%	-6%	-2%
Lane departure crash rates	30.68	37.65	36.90	42.68	48.27	51.81	23%	16%	7%

Further, the changes in speed standard deviation were compared with the corresponding changes in crash rates (crashes per 100MVMT) for sites that had speed data as shown in Table 4-4. These sites were US-2 (Mather Road to I-41), I-75 (Outer Dr. to Pennsylvania Road) and M-59 (Opdyke to Mound Road). Since crashes were collected for both directions combined at each site, the speed standard deviations for both directions combined were also computed to allow the comparison with crashes. Note that the standard deviations presented earlier in Table **3-1** in Chapter 3 were computed by direction. For US 2, the speed standard deviation in the after period increased by 0.3 mph. The total crash rates increased in the after period for this site by 2 percent. There were no fatalities before and after changing the speed limit for the period covered in the analysis for US-2. For I-75 and M-59 which had a speed change margin of 5 mph (65-70 mph), the standard deviation decreased by 0.8-1 mph in the after period. There was a corresponding decrease in fatality and crash rates. The percentage decrease in fatality rate and crash rate for M-59 was 55 percent and 16 percent, respectively. For I-75, the reduction of fatal crash rate and total crash rate in the after period was 27 percent and 13 percent, respectively. It should be noted that the changes in crash rates presented in Table 4-4 suggest an association between speed variance and crash occurrence. To quantify the actual impact of raising the speed limit, additional considerations such as comparison of test and control sites as well as accounting for other factors, are needed. The next section presents such an analysis which can be used to conclude on the impact of raising speed limits on crashes.

Table 4-4 Site by site comparison of crash rates and speed standard deviations.

Site	Change in fatal crash rate (%)	Change in total crash rate (%)	Change in speed SDEV (mph)
US-2 (Mather road to US-41)	0%	+2%	+0.31
I-75 (Outer Drive to Pennsylvania Road)	-27%	-13%	-1.04
M-59 (Opdyke to Mound Road)	-55%	-16%	-0.79

4.2.3 Modeling crashes using Mixed Effects Negative Binomial Regression

The before and after study using crash rates method controlled only for the exposure by incorporating VMT in the procedure, but other confounding factors were not taken into consideration. A carefully planned modeling approach was developed to be able to quantify the net effect of speed limit changes by taking into account the other confounding factors. The model was specified to offset several prevailing limitations that have been documented in previous studies inherent in count data such as overdispersion of count data (Rodrıguez, 2013; Hilbe, 2014), regression to mean bias (Hauer et al 2002), omitted variable bias (Sessions et al 2006, Cameron & Trivedi, 2005) and intra-cluster correlation of clustered count data (Oliveira et al 2016).

The mixed effects negative binomial model was used in this study, as it is appropriate for offsetting the above-mentioned limitations, if properly specified. The mixed-effects model is a multilevel model with a hierarchical data structure (Faraway, 2006). It consists of two main parts, namely fixed effects and random effects. The fixed effects part of the model allows the estimation of regression coefficients of all time-variant factors. The random effect is introduced in the model to account for intra-cluster correlation and individual specific effects. Intra-cluster correlation arises from the count data that have been observed from the same site (Booth et al, 2003). This was true for our study as crash occurrences were observed by segments within the same freeway corridor over time.

The individual specific effects also referred as individual heterogeneity (Cameron & Trivedi, 2005) includes all unobserved characteristics for each site whose difference contributed to the observed variation in count data across the sites. Accounting for individual heterogeneity indirectly addresses the omitted-variable bias. This occurs when important variables are not included in the model. Thus, the model tends to underestimate or overestimate the effect of one of the factors included in the model as it tries to compensate for the missing or latent variable. The panel data structure used in the mixed-effects model enables to measure the time effect on the observed crash variation. The inclusion of time effect controls the regression-to-the mean bias in the modeling of crash data. The regression-to-the mean phenomenon is described as a tendency of crashes to converge towards the average over time (Hauer et al 2002). It is therefore common in crash data for the high spikes to be followed by low spikes and vice versa, independent of any intervention. The observed decrease or increase in crashes can be mistakenly linked with factors included in the model if regression-to-the mean effect is not accounted for in the model. Controlling for intra-cluster correlation, individual specific effects and time effect in our study, allowed for the net effect of speed limit change to be estimated.

Count data are usually represented with Poisson distribution when the mean and variance are the same. The omission of factors from the models, which were unobserved, causes overdispersion of the data with the observed variability of data exceeding the mean (Booth et al 2003). The over dispersion of the data can be controlled by forming a mixture of Poisson-gamma model, commonly referred as Negative binomial model. The probability mass function of the negative binomial regression can be written as:

$$\Pr(Y_i = y : \alpha, \mu_i) = \frac{\Gamma(y+\alpha)}{\Gamma(\alpha)y!}\left(\frac{\alpha}{\mu_i+\alpha}\right)^{\alpha}\left(\frac{\mu_i}{\mu_i+\alpha}\right)^{y} \quad (1)$$

Where,

Y_i – Count data

α – Overdispersion parameter

$\Gamma(\alpha)$- Gamma function

It can further be shown that through integration and iteration process of Negative binomial probability mass function, the mean of Y_i is μ_i and the variance of Y_i is $\mu_i + \frac{\mu_i^2}{\alpha}$. As α →∞, the negative binomial model converges to Poisson model.

The derivation of mixed-effects negative binomial introduces random effect v_i in the estimation of mean μ_{ij}. Suppose we have a count data Y_{ij} from the i^{th} cluster and j^{th} observation then μ_{ij} can be estimated as

$$\mu_{ij} = \exp(x_{ij}\beta + z_{ij}v_i) \quad (2)$$

Where,

x_{ij} = a vector of fixed effects covariates

β = a unknown vector of fixed effects or regression coefficient of the covariates

z_{ij} = a vector of random effects covariates, which includes random intercepts (individual specific effects) and/or random slopes. For the random intercept model z_{ij} is a scalar with a value of one.

v_i = an unknown vector of random effects, which explains how each cluster, influence the observed variation.

The random effect is assumed to be normally distributed with the mean of zero and variance component, Σ.

The Log-likelihood ratio test was used to test whether the observed variability between sites was adequate to justify the use of the mixed-effects negative binomial model over the standard negative binomial model. The algorithm for computing the log-likelihood ratio test estimates the p-value. The p-value is compared to the critical value at a given level of confidence to reject or accept the null hypothesis which favors the alternative model (Hilbe, 2014). For instance, at the 95 percent confidence level, if p is less than 0.05 then the null hypothesis is rejected, and the mixed-effects negative binomial model is preferred over the standard negative binomial model.

Modeling Results

provides a descriptive summary of the variables used in the modeling process with their average value, standard deviation, minimum and maximum values. These data were collected per segment, for a total of 3,808 segments. Each test site (corridor) had a number of segments from which the data were collected.

Table 4-5 Descriptive summary of the variable used in the model

Variable	Obs	Mean	Std. Dev.	Min	Max
KA total crashes	3,808	0.4	0.7	0	6
KAB total crashes	3,808	1.5	1.8	0	18
KABC total crashes	3,808	5.9	5.7	0	57
KABCO total crashes	3,808	23.9	20.4	0	171
KA road departure crashes	3,808	0.2	0.4	0	3
KAB road departure crashes	3,808	0.6	1	0	7
KABC road departure crashes	3,808	1.8	1.9	0	19
KABCO road departure crashes	3,808	5.5	5	0	59
AADT	3,808	60,326.9	22,119	2,694	111,047
Segment length (miles)	3,808	0.8	0.5	0.059	3.1
Number of lanes	3,808	3.2	0.6	2	5
Speed limit change indicator	3,709	0.2	0.4	0	1
Ramp indicator	3,808	0.9	0.3	0	1
Horizontal curve indicator	3,808	0.2	0.4	0	1

Table 4-6 shows the model results that were obtained after estimating the mixed-effects negative binomial model to quantify the impact of raising the speed limit on total crashes and road departure crashes. The regression coefficients, incident rate ratio (IRR) and p-values are presented for each variable. The increase or decrease in crashes due to changes in one of the independent variables can be obtained by subtracting one from the IRR. The difference obtained shows the impact (in percentage when multiplied by 100) of the variable on crashes considered. The models were developed separately for straight segments, curved segments and overall for all segments combined. Test sites and control sites were combined when estimating each model. Indicator variables were used to indicate if the segment had a change in speed or did not.

For total crashes, the impact of changing speed limit was more pronounced at curved segments with a 24.7 percent increase in crashes. Straight segments had only 5.8 percent increase in total crashes as a result of raising the speed limit. Overall, for all segments there was 8.1 percent increase in total crashes after raising the speed limit.

Other confounding variables were controlled in the model, including the time effect, individual specific random effects and presence or absence of ramp in a given segment. The presence of a ramp increased the likelihood of a crash by a factor of 2.027 at curved freeway segments. This factor was reduced to 0.104 in straight segment, although not significant at the 95% confidence level.

Using the mixed-effects model also helped in capturing the random effects which were presented by the variance component. Random effects captured the intra-cluster correlation of crashes that occurred on the same corridor. Two steps mixed-effects negative binomial model was estimated to capture the intra-cluster correlation of crashes within the segment nested in corridors. The observed variance in total crashes due to random effects was 18.7 percent, 17.2 percent and 19 percent for all segments, straight segments and curved segments, respectively.

For road departure crashes, raising the speed limit had more pronounced effects on curved segments compared to straight segments. There was a 21 percent increase in road departure crashes for curved freeway segments. This was reduced to 13.2 percent in straight segments. Overall there was an increase in road departure crashes by 13.2 percent. This increase was above what was observed for total crashes (8.1 percent) - suggesting that road departure crashes are most likely to be impacted more with increasing the speed limits. The presence of a ramp on the freeway curved segments increased the likelihood of road departure crashes by a factor of 1.94 percent. This was reduced to 0.015 percent, on straight segments, although not significant at the 95 percent confidence level. Overall the effect of ramps on all freeway segments that were analyzed accounted for 16.8 percent increase in road departure crashes. The clustering of crashes on segments nested within the corridors accounted for 18.3 percent, 15.8 percent and 22.8 percent of the variation in crashes for all segments, straight segments and curved segments, respectively. At least 50 percent of variation in crashes was observed at corridor level for all segments. The crash variation was therefore highly dispersed between corridors compared to segments that were nested within corridors.

The KAB crashes were also modeled using the mixed-effects model using freeway corridor (instead of segments) as shown in Table 4-7. Freeway corridors were used due to the low number of KAB crashes by segment. The random effects accounted only for intra-cluster correlation between corridors but not for segments nested within corridors. The model depicts an increase in KAB crashes by 10.2 percent for all corridors as the result of raising the speed limit. The model results can be compared with those from the before-after study using crash rates in Table 4-2 above. The reduction of KAB crash rates observed in the test sites (9 percent) was lower compared to reduction observed in control sites (18 percent). That is why the model estimated a net increase in KAB crashes after accounting for exposure and other confounding factors in both test sites and control sites.

Table 4-6 Mixed Effects Negative Binomial Regression Results

Total crashes									
	All segments			Straight Segments			Curved segments		
Variables	Coef.	IRR	P>z	Coef.	IRR	P>z	Coef.	IRR	P>z
Ln(AADT)	0.511	1.668	0.000	0.491	1.635	0.000	0.615	1.850	0.000
Time t	-0.052	0.950	0.000	-0.056	0.945	0.000	-0.026	0.974	0.051
Square of time t^2	0.003	1.003	0.000	0.003	1.003	0.000	0.001	1.001	0.119*
Speed change indicator	0.078	1.081	0.000	0.056	1.058	0.018	0.221	1.247	0.000
Ramp indicator	0.254	1.289	0.009	0.099	1.104	0.339*	1.107	3.027	0.000
Constant	-2.695	0.068	0.000	-2.298	0.100	0.000	-4.381	0.013	0.002
Length	Fixed			Fixed			Fixed		
Ln(alpha)	-2.761		0.000	-2.754		0.000	-2.866		0.000
Corridor variance	0.166			0.235			0.013		
Corridor-segment variance	0.187			0.172			0.190		
Road departure crashes									
	All segments			Straight Segments			Curved segments		
Variables	Coef.	IRR	P>z	Coef.	IRR	P>z	Coef.	IRR	P>z
Ln(AADT)	0.300	1.350	0.000	0.218	1.244	0.010	0.567	1.764	0.000
Time t	0.007	1.007	0.004	0.007	1.007	0.012	0.009	1.009	0.144*
Speed change indicator	0.124	1.132	0.000	0.124	1.132	0.001	0.191	1.210	0.012
Ramp indicator	0.155	1.168	0.143*	0.015	1.015	0.891*	1.079	2.940	0.000
Constant	-1.932	0.145	0.015	-1.135	0.321	0.197	-5.113	0.006	0.005
Length	Fixed			Fixed			Fixed		
Ln (alpha)	-2.437		0.000	-2.474		0.000	-2.325		0.000
corridor variance	0.501			0.579			0.023		
Corridor-segment variance	0.183			0.158			0.228		

Note * means not significant at 95 percent confidence level.

Table 4-7 Mixed effects model for KAB Crashes

Total crashes (KAB)			Variable	No. of Groups	Observations per Group		
					Min	Ave	Max
			corridor	19	15	15.5	16
Variables	Coef.	IRR	Std. Err.	z	P>z	[95 percent Conf. Interval]	
Ln(AADT)	0.025	2.566	0.188	12.88	0.000	2.223	2.962
Time t	-0.078	0.924	0.014	-5.27	0.000	0.897	0.951
Square of time t^2	0.003	1.003	0.001	4.08	0.000	1.002	1.005
Speed change indicator	0.154	1.102	0.066	1.62	0.104	0.980	1.240
Constant	-0.742	0.000	0.000	-12.21	0.000	0.000	0.000
Length	1.000	1.000	(exposure)				
Ln(alpha)	4.382		0.368	-11.900	0.000	-5.104	-3.660
corridor variance	0.048		0.022			0.020	0.118

The time effects which control for the natural fluctuation of crash over time were accounted for in the model. For total crashes and KAB crashes, the time effect was modeled using a quadratic trend by incorporating time and square of time in the model ($\boldsymbol{\beta t} + \boldsymbol{\alpha t^2}$). For road departure crashes, time effect was modeled using a linear trend($\boldsymbol{\beta t}$). Modeling of time effect by assuming these shapes was based on observation of crash trend over years for each crash category. Figure 4-4 and Figure 4-5 show the effect of time obtained for total crashes, KAB crashes and road departure crashes. Overall, KAB crashes were decreasing at higher rate compared to total crashes. Total crashes on straight segments were decreasing at lower rate compared to crashes on curved segments. Road departure crashes on curved segments were increasing at higher rate compared to straight segments.

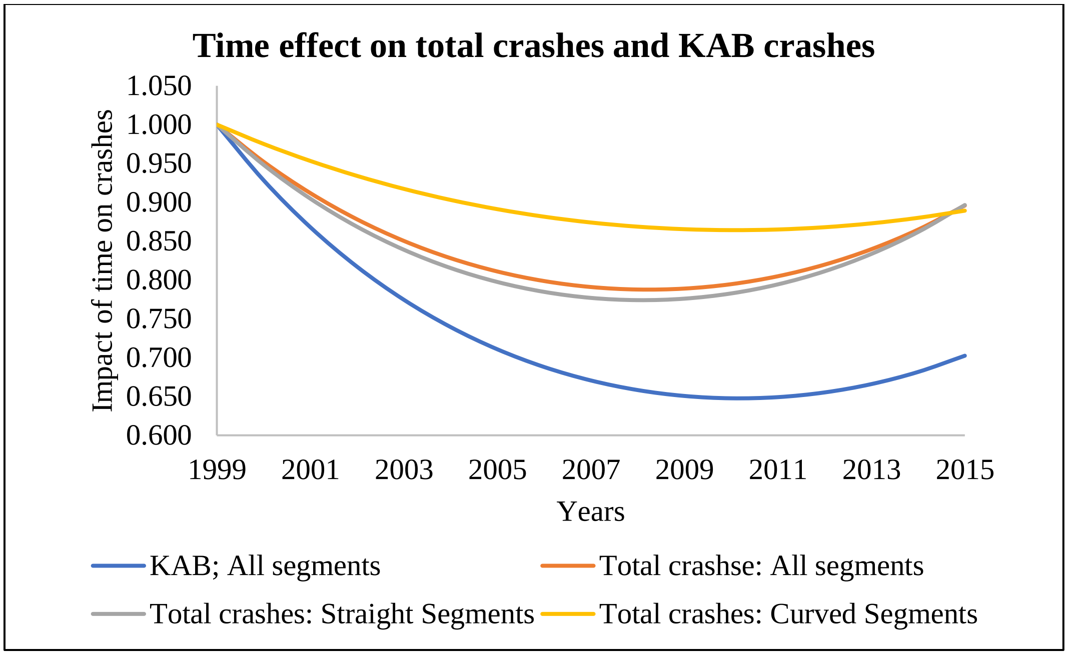

Figure 4-4 Time effect for total crashes

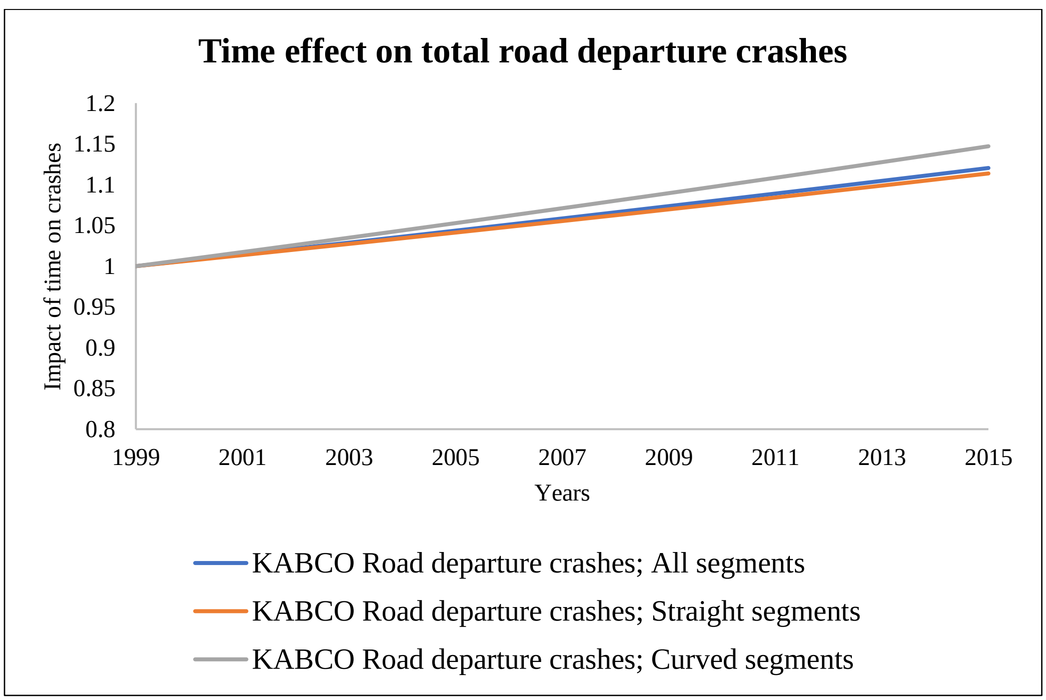

Figure 4-5 Time effect for road departure crashes

4.3 Summary of the impact of speed limit changes on crash frequency and severity

This chapter documented crash data analysis which aimed at quantifying the impact of increasing the speed limit on selected freeways in Michigan. The analysis of crash data comprised of three steps. First, trends of crashes in the before and after periods at test sites and all other freeways were analyzed. Second, a simple before and after analysis using crash rates (crashes per 100 million VMT) was carried out. Third, modeling of crashes using the mixed-effects negative binomial regression was performed. The before and after study using crash rates, controlled for the exposure by incorporating VMT in the procedure, but other confounding factors were not taken into consideration. The use of the mixed-effects negative binomial regression considered the intra-correlation of crash data from freeway corridors and segments nested within the corridors. The time effect and individual specific random effects which contributed to the observed pattern in crashes were also considered in the model. The results obtained using the mixed-effects negative binomial regression can be used to derive Crash Modification factors (CMF) for raising speed limits on urban freeways. The effects of raising speed limit on crashes which was estimated by using the mixed-effects negative binomial model revealed the following;

- Total crashes increased by 8.1 percent (CMF of 1.081). The effect was more pronounced on curved segments which had a 24.7 percent increase (CMF of 1.247) compared to straight segments which had a 5.8 percent increase (CMF of 1.058).
- Overall, road departure crashes increased by 13.2 percent (CMF of 1.132). On curved segments, however, a 21 percent increase (CMF of 1.21) in road departure crashes was estimated.
- Raising the speed limit increased KAB crashes by 10.2 percent (CMF of 1.102).

Other confounding factors were also discussed in this study such as time effect, effect of ramps and site heterogeneity. The time effect exhibited a quadratic and a linear shape for total crashes and road departure crashes, respectively. Significant variation in crashes due to individual heterogeneity was observed between freeway corridors and segments nested within the corridors. The presence of a ramp increased the likelihood of crashes on curved segments compared to straight segments.

The crash results from the model concurred with the findings of the study by Taylor (2000) which showed an increase in fatal (4.5 percent) and total crashes (10.5 percent) after changing the speed limit on rural interstate freeways. It should be noted that the Tylor (2000) study used a simple before and after study to quantify the safety impact of changing the speed limit. Other confounding factors were not taken into consideration. In addition, the Taylor (2000) study focused on rural freeways while this study focused mainly on urban freeways.

5 Economic Analysis

This chapter discusses the costs and benefits associated with raising the speed limit based on the sections of Michigan freeways used in this study. The costs presented in this chapter include the infrastructure cost, crash costs, travel time cost, and fuel consumption cost. The test sites were divided into three groups based on the speed limit change margin when calculating the cost components: 55 to 65 mph test sites, 65 to70 mph test sites and 55 to70 mph test sites. Table 5-1 provides a summary of information for these three groups, including annual vehicle mile travelled (VMT) for passenger cars and trucks estimated for year 2016. The VMT was calculated using the AADT and road length information for each segment. Due to lack of AADT at the time of analysis, the 2016 VMT estimation was based on VMT for year 2015 and a yearly VMT growth factor of 0.2 percent. The yearly change in VMT from the test sites was computed as the average yearly change in VMT from 2000 to 2015.

Table 5-1 Descriptions of test sites based on speed limit changes

Group (Test sites)	Corridor Length (Miles)	2016 VMT (Passenger cars)	2016 VMT (Trucks)
55-65	12.3	22,377,592	2,057,088
55-70	6.3	61,245,569	4,960,643
65-70	81.1	1,881,310,030	125,810,155
Total	99.8	1,964,933,191	132,827,886

5.1 Infrastructure Cost

The segments selected and used in the analysis did not undergo major geometric changes when the speed limits changed. Therefore, the only infrastructure cost related to raising the speed limit could be replacing the existing speed limit signs with a new speed limit. The MDOT's assessment of systemwide replacement of sign estimated a cost of $730 per mile based on 2014 dollar (Savolainen et al, 2014). For the 99.8 miles of test sites considered in this analysis, approximately $72,850 could have been used.

The resulting annual cost (using 2.8 percent discount rate, 10 years of useful life and the initial investment of $72,850) is $8,450.

5.2 Crash Cost

The unit crash costs by severity were obtained from the study conducted by Kostyniuk *et al*, (2011). The unit crash cost for each severity was the sum of the following costs: medical care, lost wages due to accident, loss in public services, property damage and loss in quality of life. The dollar amounts specified in the report were from 2010. A real discount rate of 1.75 percent was used to project the crash cost for year 2016, which was the year of this analysis. The source of the discount rates was the Executive Office of the President, Office of Management and Budget (OMB, 2010). The crash cost in the report for 2010 were given as cost per injury sustained a party involved in an accident or a vehicle damaged. The cost per injury sustained were converted using the 2016 crash data to a cost per crash for analysis purposes.

The Crash Modification Factors (CMF), which were developed from crash analysis section, were used to estimate the cost associated with increasing the speed limit on the test sites. From the crash analysis results presented in Chapter 4, the CMF for KAB crashes and total crashes were 1.081 and 1.102, respectively. This is equivalent to 10.2 percent and 8.1 percent increase in KAB crashes and total crashes, respectively. Table 5-2 provides the cost summary for each injury severity and Table 5-3 provides the estimated crash cost for the test sites as the result of raising the speed limit. The crash cost for each crash severity had to be aggregated into KAB crashes and total crashes in order to apply the CMF for KAB crashes and total crashes. The cost for KAB crashes and total crashes were computed as the weighted average based on unit crash cost by crash severity (2016 dollar) and the number of crashes by severity at the test sites for year 2016 as shown below:

$$Weighted\ unit\ crash\ cost = \frac{\sum_i^n Cost\ per\ crash_i * Crashes_i}{\sum_i^n Crahes_i}$$

Where $Cost\ per\ crash_i$ and $Crashes_i$ are cost per crash and number of crashes at the test sites, respectively, for a given crash injury severity *i*. The change in the number of crashes following the change in the posted speed limit was computed as:

$$Crash\ change = N_{spdlimit\ change} - N_{no\ spdlimit\ change}$$

$$N_{no\ spdlimit\ change} = \frac{N_{speed\ limt\ change}}{CMF}$$

Where $N_{spdlimit\ change}$ is the number of crashes observed on the test sites where the speed limit was raised and $N_{no\ spdlimit\ change}$ is the expected number of crashes if there was no change in the speed limit. The change in crashes for minor and property damage crashes was computed as the difference between the increments in total crashes and KAB crashes.

Table 5-2 Crash cost by severity

Injury severity	Cost per person injured (2010 dollar)	Cost per person injured (2016 dollar)	Cost per crash (2016 dollar)	Crashes on the test sites (2016)
Fatal(K)	$3,611,958	$4,008,198	$4,253,598	5
Serious (A)	$229,646	$254,839	$309,547	34
Moderate (B)	$68,431	$75,938	$94,765	154
Possible Injury (C)	$39,910	$44,288	$61,052	617
Property Damage Only (O)	$3,690	$4,095	$8,217	2670
Average cost (KABCO)	$19,999	$22,193	$41,682	3480

Table 5-3 Computation of crash cost as the result of changing the speed limit

Crash severity	Weighted Cost per crash	Observed crashes (annual)	CMF	Crash increment	Crash cost
Fatal, Incapacitating & Non-incapacitating (KAB)	$240,344	193	1.102	18	$4,293,479
Total crashes (KABCO)	$41,682	3,480	1.081	261	$10,868,947

5.3 Travel Time Savings

The average speed of passenger cars and trucks for a given posted speed limit and the value of time in dollars for passenger cars and trucks were the essential information used to quantify the travel time savings as a result of raising the posted speed limit. The value of time for each vehicle category were obtained from previous MDOT projects (Savolainen et al, 2014 & Gates et al, 2015). The value of time was projected to year 2016 using consumer price indices (CPI) obtained from the U.S Department of Labor, Bureau of Labor Statistics. The price index for 2014 was 236.736 while for 2016 was 240.007. The ratio of CPI for 2016 and CPI for 2014 ($CPI\text{-}U_{2016}/CPI\text{-}U_{2014}$) was multiplied by the value of time based on the 2014 dollar to obtain the value of time in the 2016 dollars, as shown in Table 5-4.

Table 5-4 Projecting value of time in 2016 dollar using consumer price indices.

Parameter	Year 2014 (Gates et al, 2014)	Year 2016
Consumer price index CPI-U	236.74	240.01
Ratio($CPI\text{-}U_{2016}/CPI\text{-}U_{2014}$)	1.014	
Passenger vehicles ($ per veh-hour)	$18.28	$18.53
Trucks ($ per veh-hour)	$32.25	$32.70

The travel time cost was computed using the following formula:

$$Travel\ time\ cost = VMT * \left(\frac{1}{Av.Spd_{before}} - \frac{1}{Av.Spd_{after}}\right) * Time\ value(\$\ per\ vehhour)$$

Whereby

$Av.Spd_{before}$ – Average vehicle speed with no speed limit change.

$Av.Spd_{after}$ – Average vehicle speed with speed limit change.

VMT – Annual vehicle miles travelled for year 2016.

The average speed for passenger cars and trucks were obtained from the field spot speed study, which was conducted at the selected sites with 55 mph, 65 mph and 70 mph speed limits. The results of the average speed from these sites were assumed to apply to all other sites in the analysis that had the same speed limit provided the road geometry were similar. Computations of the travel time savings due to the increase in speed limits at selected segments is shown in

Table 5-5.

Table 5-5 Computation of monetary travel time savings based on average speed and value of time

Vehicle type	Speed limit (before)	Speed limit (after)	Average speed (before)	Average speed (after)	VMT (2016)	Time savings (Hours)	Monetary time savings ($)
Passenger car	55	65	63.3	66.1	22,377,592	14,986	$277,731
	55	70	63.3	74.0	61,245,569	140,684	$2,607,245
	65	70	66.1	74.0	1,881,310,030	3,061,572	$56,738,809
Trucks	55	60	60.8	64.7	132,827,886	129,235	$4,225,424
Travel time savings							$63,849,210

5.4 Fuel Cost

The fuel cost was computed based on the average speed (mph) and the fuel economy, expressed in miles per gallon (mpg). The fuel economy as a function of speed were adopted from the previous MDOT project (Gates, 2015). The fuel economy by vehicle types are updated each year by the U.S. Department of Energy and the U.S. Environmental Protection Agency (EPA). A linear relationship has often been observed between fuel economy and vehicle speed by vehicle type. The following fuel economy guidelines were adopted for this analysis:

- Passenger cars fuel consumption; 31 miles per gallon at 55 mph, decreases by 0.4 mpg for every 1 mph increase in travel speed above 55 mph.
- Truck fuel consumption; 7 miles per gallon at 55 mph, decreases at the rate of 0.1 mpg for every 1 mph increase in travel speed above 55 mph.

The differential fuel cost resulting from the increase in speed limit (shown in Table 5-6) was computed using the formula below. The cost per gallon as of year 2016 was $2.41 for diesel and $2.28 for gasoline.

$$Fuel\ cost = VMT * \left(\frac{1}{fuel\ economy_{after}} - \frac{1}{fuel\ economy_{before}}\right) * Cost\ per\ gallon$$

Whereby

$Fuel\ economy_{before}$ – Fuel economy (mpg) with no speed limit change

$Fuel\ economy_{after}$ – Fuel economy (mpg) with speed limit change

VMT – Annual vehicle miles travelled for year 2016.

Table 5-6 Computation of fuel consumption as the result of increasing speed limit

Vehicle type	Speed limit (before)	Speed limit (after)	Average speed (before)	Average speed (after)	Fuel economy mpg (Before)	Fuel economy mpg (After)	Gallons (After-Before)	Fuel cost
Passenger car	55	65	63.3	66.1	27.7	26.6	34,045	$77,487
	55	70	63.3	74.0	27.7	23.4	406,841	$925,971
	65	70	66.1	74.0	26.6	23.4	9,634,928	$21,929,097
Trucks	55	60	60.8	64.7	6.4	6.0	1,312,182	$3,155,798
Incremental fuel cost								$26,088,353

5.5 Cost Benefit Analysis

Table 5-7 summarizes the annual benefits, dis-benefits and costs associated with changing speed limits on the studied sites.

Table 5-7 Computation of cost benefit ratio.

Benefits	
Travel time savings	$63,849,210
Dis-benefits	
Fuel cost	$26,088,353
Crash costs (total)	$10,868,947
Infrastructure cost	
Sign modification cost	$8,450

The net benefit-cost ratio for the test sites was computed by dividing the sum of fuel cost, crash cost and travel time savings to the infrastructure cost associated with speed limit increase as follows:

$$\text{Net benefit} - \text{cost ratio} = \frac{Benefits(Travel\ time\ savings) - Disbenefits(Crash\ cost, Fuel\ cost)}{Infrastructure\ cost}$$

Also the benefit-disbenefit ratio for the test sites was computed by dividing travel time savings with the sum of fuel cost and crash cost associated with speed limit increase as follows:

$$\text{Benefit} - \text{Disbenefit ratio} = \frac{Benefits(Travel\ time\ savings)}{Disbenefits(Crash\ cost, Fuel\ cost)}$$

The monetary time savings outweighed the sum of the differential fuel cost and the crash cost associated with increasing the speed limit for the segments used in this analysis. The ratio of the benefits to dis-benefits was 1.73 while the ratio of net-benefits to cost was

3,182. It should be noted, again, that the corridors selected in this study did not have geometric changes such as horizontal and vertical curve realignment. Therefore, the results of the cost-benefit analysis in this study provide an indication of possible benefits that might accrue from raising the speed limit on freeway sections that do not require major geometric upgrades.

6 Conclusions and Recommendations

The primary goal of this project was to determine if the change in speed limit on the selected freeway segments in Michigan had impact on crash pattern and motorists' operating speed. This section compiles the summary of all results from crash data analysis, speed data analysis and economic analysis.

6.1 Conclusions

6.1.1 Impacts of raising speed limit on crash frequency and severity

Analysis of crash rates before and after the speed limit change showed a decrease in fatality rates, fatal crash rates, KAB crash rates, total crash rates and road departure crash rates for the test sites. The observed reduction in crashes on the test sites was lower compared to the reduction which was observed on all freeways. The decrease in KAB crash rates at test sites was also lower compared to that at control sites. Total crashes and road departure crashes increased in the after period. Comparison of the change in crash rates and speed standard deviations indicated a positive association - there was a corresponding increase in the crash rate due to increase in the standard deviation, and vice versa.

The effects of raising freeway speed limit on crashes was estimated by applying the mixed effects negative binomial regression model. The model provides the ability to control for other confounding factors such as time effects, specific site heterogeneity and other geometric features. The model results revealed the following:

- Total crashes increased by 8.1 percent as a result of increasing speed limit. The effect was more pronounced on curved segments (24.7 percent) compared to straight segments (5.8 percent).
- Road departure crashes increased by 13.2 percent as a result of increasing speed limit. For curved segments, a 21 percent increase in road departure crashes was estimated.
- Raising the speed limits increased KAB crashes by 10.2 percent.

The crash results from this analysis concurred with a previous study conducted by Tylor (2000) which showed an increase in fatal (4.5 percent) and total crashes (10.5 percent) after changing the speed limit on the rural interstates.

6.1.2 *Impacts of raising speed limit on operational speed*

The analysis compared speed parameters such as the 50th percentile speed, the 85th percentile speed and the standard deviation before and after changing the speed limit. The speed trend and distribution at the test sites and control sites were examined to discern any association between speed limit changes and the changes in patterns of operational speed. The following results were obtained:

- The change in speed limit exhibited an effect on operating speeds when speed trends and speed distributions at test sites before and after changing the speed limit were compared to those of the control sites.
- The summary of speed parameters indicated an increase in the 85th percentile speed by 2.4mph (1.8-4.7 mph) and 4.4mph (3.5-4.2 mph) for test sites that had the speed limit change margin of 5 mph and 10 mph, respectively. At control sites, there was a reduction in the 85th percentile speed in the after period by an average of 0.4 mph (1.6mph to -2.8mph).
- The sites that had an increase in speed standard deviation after increasing the speed limit had an increase in total crash rate and fatal crash rate.

The cross-sectional analysis of speed data collected from I-69 (a test site which had a speed limit changed from 55 mph to 70 mph) and M-8 (a control site with a speed limit of 55 mph) indicated that:

- The differences in the 85th percentile speeds between the test site and the control site were 4.5-8 mph for passenger cars and 1-4.6 mph for trucks.

- Truck drivers had a relatively higher compliance rate with their posted speed limit compared to passenger car drivers for both test site and control site.
- Driver compliance was observed to be higher at the test site compared to the control site. This could be because drivers at the control site (M-8) might expect a higher speed limit since the geometrics were similar to the test site (I-69 with the speed limit of 70 mph).

6.2 Recommendations

When modifying speed limits on freeways, more emphasis should be placed on evaluating the suitability of geometric features particularly horizontal curves. As it has been shown in this study, freeway curved sections were more prone to severe crashes and increased road departure crashes compared to straight freeway sections after raising the speed limit.

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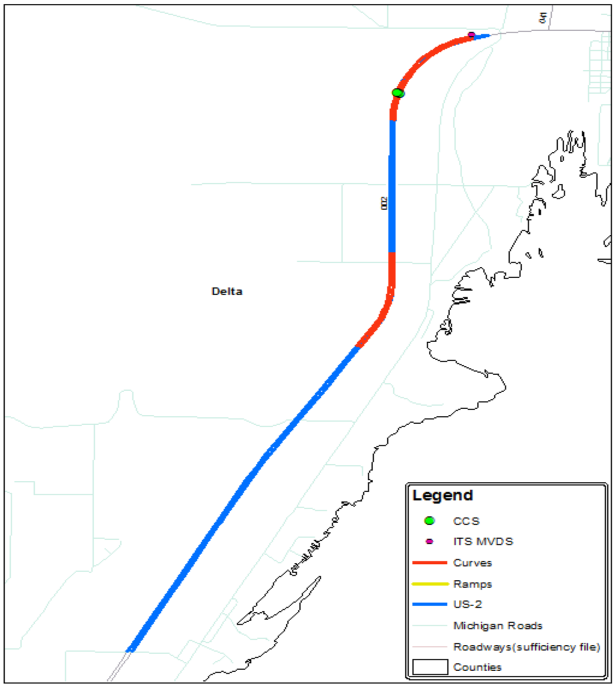
8 Appendices

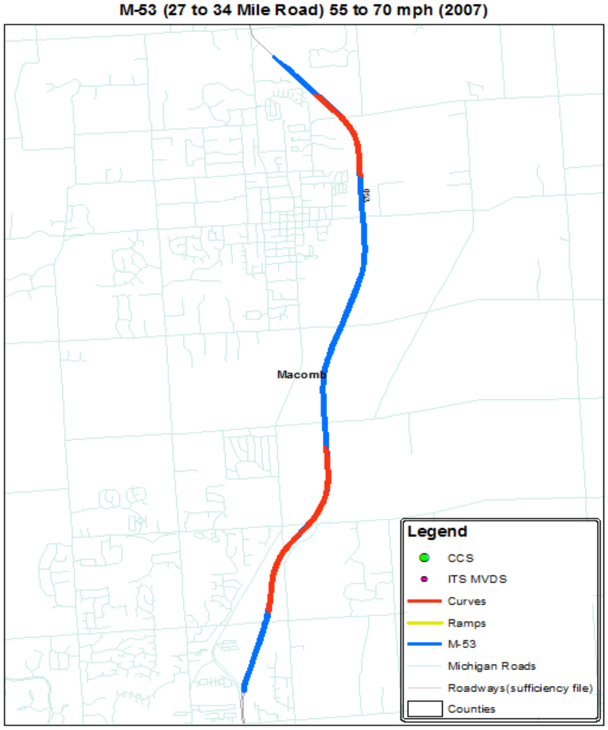
8.1 Test sites used in the study

US-2(Mather road to US-41) 55 to 65mph (2010)

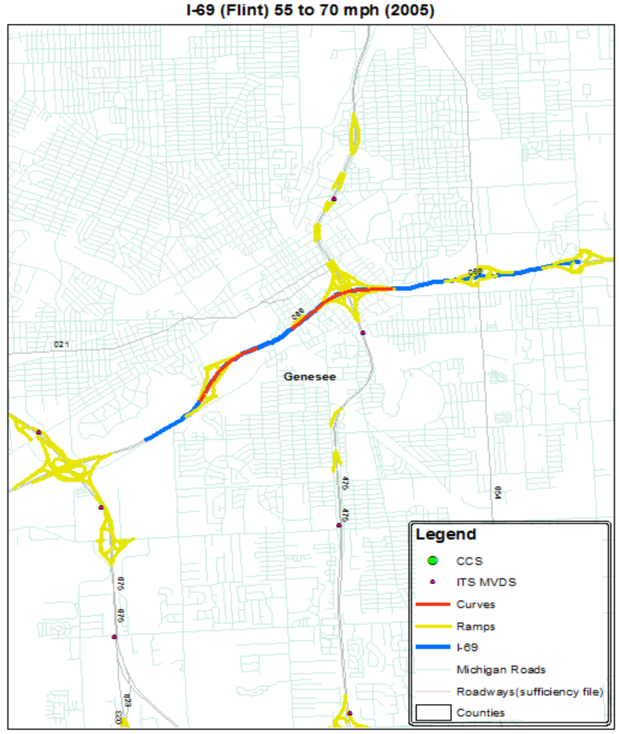


I-75/Telegraph Road 55 to 65 mph(2005)

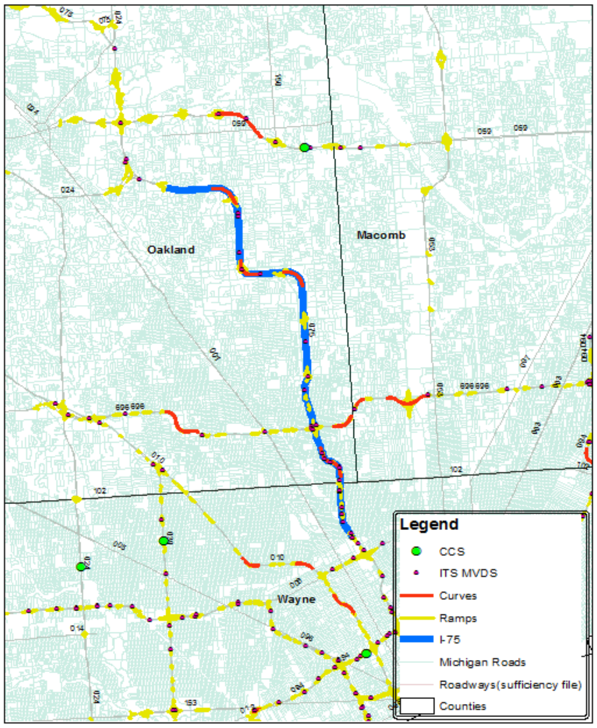
M-53 (27 to 34 Mile Road) 55 to 70 mph (2007)



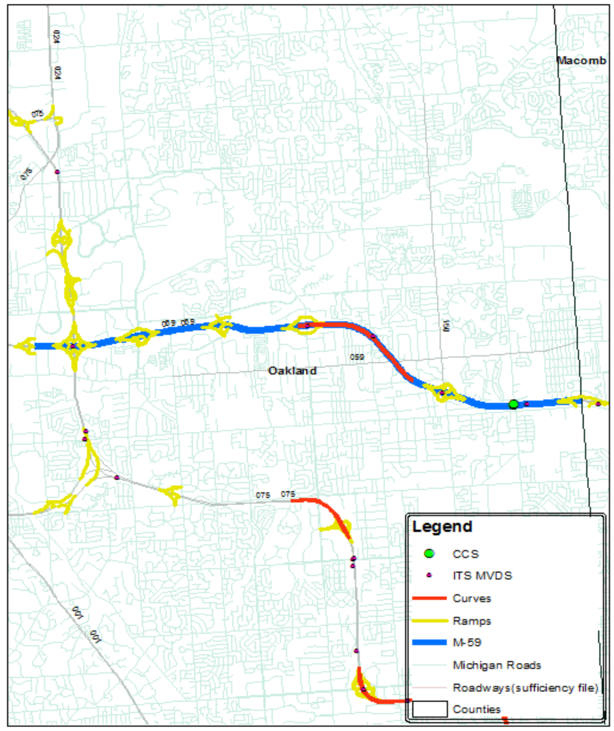
I-69 (Flint) 55 to 70 mph (2005)



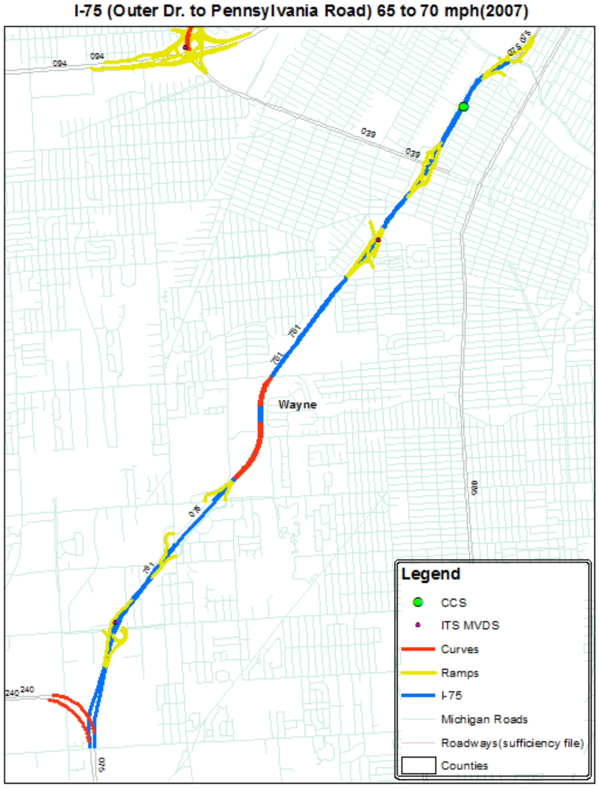
I-75 (Adams Road to I-94) 65 to 70 mph (2007)



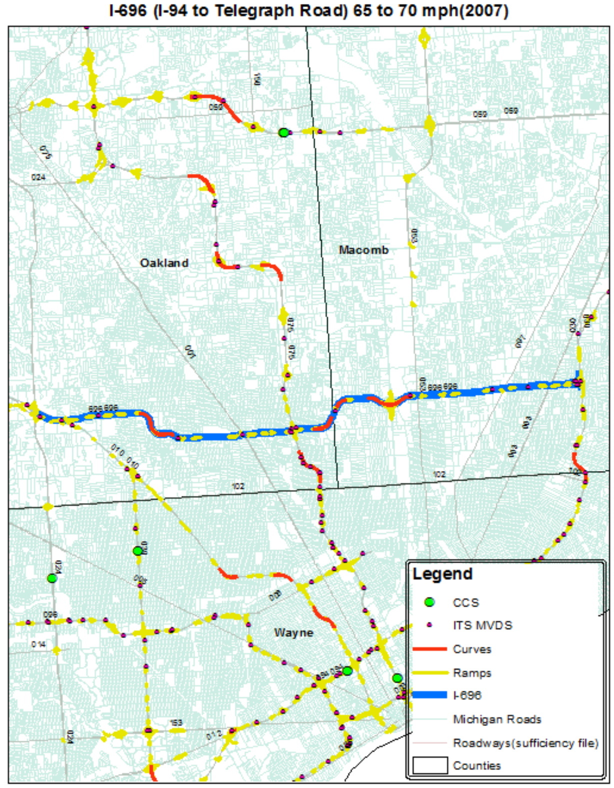
M-59 (Opdyke to Mound Road) 65 to 70 mph-(2007)



I-75 (Outer Dr. to Pennsylvania Road) 65 to 70 mph(2007)



I-696 (I-94 to Telegraph Road) 65 to 70 mph(2007)



8.2 Modeling results

Table 8-1 Model results for total crashes (KABCO) on freeway segments

Total crashes (KABCO)			Variable	No. of Groups	Observations per Group		
					Minimum	Average	Maximum
			corridor	16	30	231.8	960
			segment	238	15	15.6	16
Total crashes	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
Natural log of AADT	0.511	1.668	0.001	9.41	0.000	0.405	0.618
Time	-0.052	0.950	0.077	-9.6	0.000	-0.062	-0.041
Square of time	0.003	1.003	0.090	9.35	0.000	0.002	0.003
Speed change indicator	0.078	1.081	0.005	3.53	0.000	0.034	0.121
Ramp indicator	0.254	1.289	0.000	2.63	0.009	0.065	0.443
Constant	-2.695	0.068	0.022	-4.81	0.000	-3.793	-1.597
Length	1.000	1.000	0.283	(exposure)			
lnalpha	-2.761		0.045	-61.47	0.000	-2.849	-2.673
corridor var	0.166		0.087			0.059	0.464
corridor>segment var	0.187		0.019			0.152	0.229

Table 8-2 Model results for total crashes (KABCO) on straight freeway segments

Total crashes (KABCO) Straight Segments			Variable	No. of Groups	Observations per Group		
					Minimum	Average	Maximum
			corridor	16	15	193.8	768
			segment	199	15	15.6	16
Total crashes	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
AADT in thousands	0.491	1.635	0.060	8.25	0.000	0.375	0.608
Time	-0.056	0.945	0.006	-9.58	0.000	-0.068	-0.045
Square of time	0.003	1.003	0.000	9.47	0.000	0.002	0.004
Speed change indicator	0.056	1.058	0.024	2.36	0.018	0.010	0.103
Constant	-2.298	0.100	0.618	-3.72	0.000	-3.509	-1.087
Length	1.000	1.000	(exposure)				
lnalpha	-2.754		0.048	-56.91	0.000	-2.849	-2.659
corridor var	0.235		0.114			0.090	0.609
corridor>seg var	0.172		0.019			0.138	0.214

Table 8-3 Model results for total crashes (KABCO) for curved freeway segments

Total crashes (KABCO) Curved Segments			Variable	No. of Groups	Observations per Group		
					Minimum	Average	Maximum
			corridor	7	15	87	192
			segment	39	15	15.6	16
Total crashes	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
AADT in thousands	0.615	1.850	0.123	5.01	0.000	0.375	0.856
Time	-0.026	0.974	0.013	-1.95	0.051	-0.053	0.000
Square of time	0.001	1.001	0.001	1.56*	0.119	0.000	0.003
Speed change indicator	0.221	1.247	0.057	3.87	0.000	0.109	0.333
Ramp indicator	1.107	3.027	0.243	4.57	0.000	0.632	1.583
Constant	-4.381	0.013	1.391	-3.15	0.002	-7.107	-1.655
Length	1.000	1.000	(exposure)				
lnalpha	-2.866		0.123	-23.14	0.000	-3.087	-2.604
corridor var	0.013		0.025			0.000	0.612
corridor>seg var	0.190		0.054			0.109	0.331

Table 8-4 Model results for KAB crashes for freeway segments

Total crashes (KAB)			Variable	No. of Groups	Observations per Group		
					Minimum	Average	Maximum
			corridor	16	30	231.8	960
			segment	238	15	15.6	16
Total crashes	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
AADT in thousands	0.015	1.015	0.002	7.43	0.000	0.011	0.018
Length(miles)	1.003	2.726	0.073	13.71	0.000	0.859	1.146
Time	-0.082	0.921	0.013	-6.15	0.000	-0.108	-0.056
Square of time	0.004	1.004	0.001	4.93	0.000	0.002	0.005
Speed change indicator	0.103	1.108	0.055	1.87*	0.061	-0.005	0.210
Ramp indicator	0.391	1.479	0.110	3.55	0.000	0.175	0.607
_cons	-1.894	0.150	0.205	-9.25	0.000	-2.295	-1.492
lnalpha	-2.532		0.202	-12.53	0.000	-2.927	-2.136
corridor var	0.321		0.171			0.113	0.910
corridor>seg var	0.133		0.020			0.100	0.178

Table 8-5 Model results for roadway departure crashes for freeway segments

Road departure crashes (KABCO)			Variable	No. of Groups	Observations per Group		
					Minimum	Average	Maximum
			corridor	16	30	231.8	960
			segment	238	15	15.6	16
Road departure	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
AADT in thousands	0.300	1.350	0.076	3.94	0.000	0.151	0.449
Time	0.007	1.007	0.002	2.9	0.004	0.002	0.012
Speed change indicator	0.124	1.132	0.034	3.61	0.000	0.057	0.191
Constant	-1.932	0.145	0.796	-2.43	0.015	-3.493	-0.372
Length	1.000	1.000	(exposure)				
lnalpha	-2.437		0.074	-32.88	0.000	-2.582	-2.292
corridor var	0.501		0.225			0.208	1.209
corridor>segment var	0.183		0.020			0.147	0.228

Table 8-6 Model results for roadway departure crashes for freeway straight segments

Road departure crashes (KABCO) Straight segments			Variable	No. of Groups	Observations per Group		
					Minimum	Average	Maximum
			corridor	16	15	193.8	768
			segment	199	15	15.6	16
Road departure	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
AADT in thousands	0.218	1.244	0.084	2.59	0.010	0.053	0.383
Time	0.007	1.007	0.003	2.5	0.012	0.001	0.012
Speed change indicator	0.124	1.132	0.037	3.32	0.001	0.051	0.197
Constant	-1.135	0.321	0.880	-1.29	0.197	-2.860	0.590
Length	1.000	1.000	(exposure)				
lnalpha	-2.474		0.085	-28.94	0.000	-2.642	-2.307
corridor var	0.579		0.257			0.243	1.380
corridor>segment var	0.158		0.019			0.125	0.201

Table 8-7 Model results for roadway departure crashes for freeway curved segments

Road departure crashes (KABCO) Curved segments	Variable	No. of Groups	Observations per Group		
			Minimum	Average	Maximum
	corridor	7	15	87	192
	segment	39	15	15.6	16

Road departure	Coef.	IRR	Std. Err.	z	P>z	[95% Conf. Interval]	
lnAADT	0.567	1.764	0.161	3.51	0.000	0.251	0.884
Speed change indicator	0.191	1.210	0.076	2.52	0.012	0.042	0.339
Ramp indicator	1.079	2.940	0.302	3.58	0.000	0.488	1.670
Constant	-5.113	0.006	1.806	-2.83	0.005	-8.652	-1.574
Length	1.000	1.000	(exposure)				
lnalpha	-2.325		0.153	-15.18	0.000	-2.625	-2.025
corridor var	0.023		0.038			0.001	0.560
corridor>segment var	0.228		0.072			0.123	0.423

8.3 Speed Data Analysis

Table 8-8 Quarterly analysis of speed parameters before and after changing the speed limit; US-2

	Before period (2003-2009)				After period (2010-2015)				Change (Before-After period)			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
US2 NB												
85th speed	63.1	63.2	63.7	63.3	68.3	69.6	70.5	70.0	5.3	6.4	6.7	6.7
50th speed	59.0	59.4	59.6	59.3	62.7	64.1	64.8	64.4	3.7	4.7	5.2	5.1
Average speed	60.8	61.5	61.8	61.2	64.5	66.0	66.6	66.2	3.7	4.5	4.8	5.0
Standard dev	6.0	5.4	5.7	5.9	6.9	6.2	6.5	6.3	0.9	0.8	0.7	0.4
US2 SB												
85th speed	63.9	64.3	65.2	64.4	68.9	69.8	70.7	70.3	4.9	5.5	5.5	5.9
50th speed	59.6	59.9	60.0	59.8	63.3	64.3	64.9	64.6	3.7	4.4	4.8	4.8
Average speed	61.6	62.1	62.2	62.1	65.2	66.3	66.8	66.7	3.6	4.3	4.6	4.6
Standard dev	5.9	6.3	7.1	5.6	6.6	6.0	6.4	6.0	0.7	-0.4	-0.7	0.4

Table 8-9 Quarterly analysis of speed parameters before and after changing the speed limit; I-75

	Before period (2003-2007)				After period (2008-2016)				Change (Before-After period)			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
I-75 NB												
85th speed	73.3	73.0	73.1	73.2	75.0	75.1	75.0	75.7	1.7	2.2	2.0	2.5
50th speed	65.2	65.1	65.1	65.2	67.2	67.2	68.1	68.5	2.0	2.1	3.0	3.3
Average speed	65.8	66.3	66.6	66.6	68.7	64.9	66.6	69.9	2.9	-1.4	0.1	3.3
Standard dev	13.4	11.7	10.7	10.6	9.6	18.5	16.3	9.0	-3.8	6.8	5.6	-1.6
I-75 SB												
85th speed	72.3	72.6	72.6	72.7	73.2	74.7	74.8	74.5	0.9	2.1	2.2	1.8
50th speed	63.5	63.6	64.2	64.6	65.6	67.4	67.6	67.1	2.0	3.8	3.4	2.5
Average speed	61.5	59.7	64.3	66.1	66.9	69.0	68.9	68.7	5.4	9.3	4.5	2.6
Standard dev	17.3	20.0	13.9	10.4	10.2	9.1	10.1	9.1	-7.2	-11.0	-3.8	-1.3

Table 8-10 Quarterly analysis of speed parameters before and after changing the speed limit; M-59

	Before period (2003-2007)				After period (2008-2016)				Change (Before-After period)			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
M-59 EB												
85th speed	76.2	76.4	75.9	77.5	77.1	77.5	77.5	77.5	0.9	1.0	1.7	-0.1
50th speed	68.9	69.1	68.6	69.7	70.4	71.1	71.1	70.9	1.5	2.0	2.5	1.2
Average speed	68.8	69.0	68.2	70.0	71.1	72.0	71.4	71.3	2.3	3.0	3.2	1.3
Standard dev	11.4	11.8	12.0	13.2	10.1	9.9	11.7	11.3	-1.3	-1.8	-0.3	-1.9
M-59 WB												
85th speed	72.4	72.8	72.5	76.8	77.5	77.6	78.0	78.1	5.1	4.8	5.5	1.3
50th speed	65.6	66.0	65.7	67.4	70.2	70.5	71.1	71.0	4.6	4.5	5.4	3.7
Average speed	66.1	66.9	66.8	69.0	71.5	70.3	72.1	72.6	5.4	3.4	5.3	3.6
Standard dev	10.8	11.1	10.1	13.9	9.6	14.5	11.3	9.3	-1.2	3.3	1.2	-4.5

Table 8-11 Speed parameters for non-freeway sites with the posted speed limit of 55 mph

Bound	Vehicle type	Speed limit (mph)	Sample size	Mean speed	50 per speed	85 perc speed	SDEV	% above speed limit		
								5 mph	10 mph	15 mph
M123 NB[a]	passenger	55	107	62.1	62.3	65	3.76	79.4%	15.0%	3.7%
	Trucks	55	7	61.8	62.4	62.9	2.18	71.4%	14.3%	0.0%
	All	55	114	62.1	62.3	65	3.68			
M123 SB[a]	Passenger	55	99	61.3	62.1	64.6	4.05	65.7%	13.1%	2.0%
	trucks	55	9	59.0	58.7	61.2	1.57	22.2%	0.0%	0.0%
	All	55	108	61.1	61.3	64.1	3.95			
M231 NB[b]	Passenger	55	371	61.8	61.3	65.7	4.07	66.6%	18.9%	3.2%
	trucks	55	47	60.7	60.2	64.6	3.65	59.6%	8.5%	2.1%
	All	55	418	61.7	61.2	65.6	4.04			
M231 SB[b]	Passenger	55	384	61.7	61.4	66.1	4.27	65.1%	21.1%	3.1%
	trucks	55	72	60.2	60.1	63.1	2.96	54.2%	2.8%	0.0%
	All	55	456	61.5	61.1	65.6	4.12			
M72 EB[c]	passenger	55	290	60.1	59.65	64.1	5.34	46.2%	11.4%	2.8%
	trucks	55	14	59.3	58.75	63.1	3.37	28.6%	7.1%	0.0%
	All	55	304	60.1	59.45	64.1	5.27			
M72 WB[c]	passenger	55	307	58.1	58.2	62.1	4.44	31.6%	5.9%	0.7%
	trucks	55	39	57.3	57.7	60.8	4.38	23.1%	2.6%	0.0%
	All	55	346	58.0	58.2	62	4.43			

Note;

[a] Speed data were collected outside the road shoulder (46.059885, -84.898544) on 06/07/2017 from 11:10 am to 14:30 pm. Weather condition was sunny

[b] Speed data were collected outside the road shoulder (43.019212, -86.091506) on 05/30/2017 from 11:35 am to13:50 pm. Weather condition was sunny

[c] Speed data were collected outside the road shoulder (44.656623, -84.674805) on 06/06/2017 from 11:00 am to 14:30 pm. Weather condition was sunny

8.4 Traffic Counts

8.4.1 Description of locations for field traffic count data

Sites	Coordinates of the location	Description of the location	Data collection dates	Time	Weather condition
M-231 (M-45 to M-104)	43.019212, -86.091506	Outside road shoulder	Tuesday, May 30, 2017	10:34 am-13:50pm	Sunny
M-8(Rosa Park to Joseph Campau St)	42.403418, -83.095621	Woodward Ave Overpass	Wednesday, May 31, 2017	14:13 pm - 16:08 pm	Sunny
I-75 (Outer Dr. to Pennsylvania Road)	42.259376, -83.179698	Cicotte Ave Overpass	Wednesday, May 31, 2017	11:16 am - 13:00 pm	Sunny
I-69 (Flint)	43.000724, -83.701123	Pedestrian trail overpass	Monday, June 05, 2017	12:41 pm - 15:50 pm	Sunny
M-72 (Grayling to Luzerne)	44.656623, -84.674805	Outside road shoulder	Tuesday, June 06, 2017	11:10 am-14:12 pm	Sunny
M-123(Moran to Trout Lake)	46.059885, -84.898544	Outside road shoulder	Wednesday, June 07, 2017	11:00 am-14:30 pm	Sunny
US-2(Mather road to US-41)	45.918533, -86.992994	Outside road shoulder	Thursday, June 08, 2017	11:20 am - 14:45 pm	Sunny

8.4.2 I-69 East and West Bound

East Bound

I69-East Bound						
Time interval	Inner Lane		Middle Lane		Outer Lane	
	Cars	Trucks	Cars	Trucks	Cars	Trucks
12:41:01 - 13:00	141	0	276	17	250	31
13:00 - 13:15	130	1	171	13	189	18
13:15 - 13:30	118	0	234	27	209	22
13:30 - 13:45	120	0	136	11	206	25
13:45 - 14:00	101	0	195	18	212	25
14:00 - 14:15	160	1	185	22	233	24
14:15 - 14:30	157	1	232	24	213	35
14:30 - 14:45	159	0	240	20	229	28
14:45 - 15:00	194	1	269	30	245	22
15:00 -15:15	209	1	211	19	299	23
15:15 - 15:30	225	1	229	20	297	25
15:30 - 15:50:16	241	0	344	31	416	20
Total	1955	6	2722	252	2998	298

West Bound

I69-West Bound						
Time interval	Inner Lane		Middle Lane		Outer Lane	
	Cars	Trucks	Cars	Trucks	Cars	Trucks
12:44:03 - 13:00	134	2	206	29	266	19
13:00 - 13:15	112	1	173	25	236	18
13:15 - 13:30	98	0	197	24	193	27
13:30 - 13:45	126	0	191	29	239	16
13:45 - 14:00	151	0	189	39	288	19
14:00 - 14:15	134	2	195	24	231	44
14:15 - 14:30	132	0	217	25	339	19
14:30 - 14:45	160	0	222	40	365	22
14:45 - 15:00	158	1	205	38	305	22
15:00 -15:15	172	0	233	25	305	18
15:15 - 15:30	147	0	231	31	296	16
15:30 - 15:52:00	287	0	382	51	491	31
Total	1811	6	2641	380	3554	271

8.4.3 I-75 South Bound

South Bound

I-75 South Bound						
Time interval	Inner Lane		Middle Lane		Outer Lane	
	Cars	Trucks	Cars	Trucks	Cars	Trucks
11:16:11 - 11:30	168	0	132	57	87	51
11:30 - 11:45	156	0	134	67	109	67
11:45 - 12:00	148	0	148	65	105	64
12:00 - 12:15	175	0	146	67	114	62
12:15 - 12:30	131	0	156	53	114	64
12:30 - 12:45	162	0	197	33	115	69
12:45 - 13:00:08	161	0	142	69	123	62
Total	1101	0	1055	411	767	439

8.4.4 M-8 East and West Bound

M-8 East Bound								
Time interval	Inner Lane		I-Middle Lane		O-Middle Lane		Outer Lane	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks
14:13:08 - 14:30	169	22	183	15	189	21	252	22
14:30 - 14:45	163	23	203	13	214	22	328	22
14:45 - 15:00	165	25	191	8	192	23	318	23
15:00 - 15:15	169	16	188	17	223	12	338	12
15:15 - 15:30	187	18	189	17	218	13	321	17
15:30 - 15:45	161	10	231	11	224	13	416	17
15:45 - 16:00	171	15	206	17	207	11	369	18
16:00 - 16:08:26	97	4	126	8	124	11	240	10
Total	1282	133	1517	106	1591	126	2582	141
M-8 West Bound								
	Inner Lane		I-Middle Lane		O-Middle Lane		Outer Lane	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks
14:19:48 - 11:30	34	4	75	6	134	15	150	17
14:30 - 14:45	63	1	133	5	211	20	235	27
14:45 - 15:00	64	3	125	9	217	9	230	26
15:00 - 15:15	62	2	139	8	235	23	245	16
15:15 - 15:30	68	2	143	15	261	20	314	23
15:30 - 15:45	88	3	170	8	248	20	283	21
15:45 - 16:00	79	2	172	11	242	19	288	21
16:00 - 16:02:02	12	0	26	0	35	7	47	3
Total	470	17	983	62	1583	133	1792	154

8.4.5 M-72 East and West Bound

East Bound

M-72 East Bound			M-72 East Bound		
Time interval	Cars	Trucks	Time interval	Cars	Trucks
11:10:43 - 11:15	2	2	11:11:40 - 11:15	4	1
11:15 - 11:30	39	5	11:15 - 11:30	20	5
11:30 - 11:45	46	4	11:30 - 11:45	27	3
11:45 - 12:00	47	4	11:45 - 12:00	29	1
12:00 - 12:15	34	2	12:00 - 12:15	42	2
12:15 - 12:30	30	8	12:15 - 12:30	41	6
12:30 - 12:45	41	6	12:30 - 12:45	26	3
12:45 - 13:00	41	6	12:45 - 13:00	37	0
13:00 - 13:15	27	6	13:00 - 13:15	33	10
13:15 - 13:30	23	2	13:15 - 13:30	32	3
13:30 - 13:45	47	6	13:30 - 13:45	34	1
13:45 - 14:00	36	5	13:45 - 14:00	20	1

14:00 - 14:12:25	17	5	14:00 - 14:15:23	36	4
Total	430	61	Total	381	40

8.4.6 M-123 North and South Bound

North Bound

M-123 North Bound			M-123 South Bound		
Time interval	Cars	Trucks	Time interval	Cars	Trucks
10:59:12 - 11:00	0	0	11:01:34 - 11:15	6	0
11:00 - 11:15	8	0	11:15 - 11:30	13	1
11:15 - 11:30	9	2	11:30 - 11:45	10	1
11:30 - 11:45	13	3	11:45 - 12:00	4	1
11:45 - 12:00	13	0	12:00 - 12:15	9	7
12:00 - 12:15	9	2	12:15 - 12:30	4	2
12:15 - 12:30	10	2	12:30 - 12:45	7	0
12:30 - 12:45	12	2	12:45 - 13:00	7	4
12:45 - 13:00	5	1	13:00 - 13:15	14	2
13:00 - 13:15	3	1	13:15 - 13:30	9	0
13:15 - 13:30	10	1	13:30 - 13:45	6	2
13:30 - 13:45	10	0	13:45 - 14:00	6	0
13:45 - 14:00	8	1	14:00 - 14:15	4	4
14:00 - 14:15	8	1	14:15 - 14:25:13	6	0
14:15 - 14:29:12	10	0	Total	99	24
Total	128	16			

8.4.7 M-231 North and South Bound

M-231 North Bound			M-231 South Bound		
Time Interval	Cars	Trucks	Time interval	Cars	Trucks
10:34:24 - 10:45	26	2	10:32:37 - 10:45	46	11
10:45 - 11:00	60	8	10:45 - 11:00	50	10
11:00 - 11:15	45	6	11:00 - 11:15	35	7
11:15 - 11:30	48	6	11:15 - 11:30	34	6
11:30 - 11:45	49	8	11:30 - 11:45	41	12
11:45 - 12:00	47	4	11:45 - 12:00	40	6
12:00 - 12:15	48	9	12:00 - 12:15	49	13
12:15 - 12:30	55	9	12:15 - 12:30	39	8
12:30 - 12:45	53	6	12:30 - 12:45	72	10
12:45 - 13:00	48	8	12:45 - 13:00	44	8
13:00 - 13:15	65	6	13:00 - 13:15	47	9
13:15 - 13:30	61	10	13:15 - 13:30	43	4
13:30 - 13:45	59	9	13:30 - 13:45	49	11
13:45 - 13:51:37	31	3	13:45 - 13:47:52	9	2
Total	564	78	Total	598	117

8.4.8 US-2 North and South Bound

US-2 North Bound					US-2 South Bound				
Time interval	Inner Lane		Outer Lane		Time interval	Inner Lane		Outer Lane	
	Cars	Trucks	Cars	Trucks		Cars	Trucks	Cars	Trucks
11:20:23 - 11:30	13	3	31	11	11:29:46 - 11:30	0	0	0	0
11:30 - 11:45	9	0	50	7	11:30 - 11:45	24	1	58	6
11:45 - 12:00	12	0	59	10	11:45 - 12:00	17	0	79	9
12:00 - 12:15	5	0	57	19	12:00 - 12:15	36	3	60	15
12:15 - 12:30	19	0	72	5	12:15 - 12:30	30	0	69	18
12:30 - 12:45	27	3	78	24	12:30 - 12:45	17	0	64	8
12:45 - 13:00	23	3	55	18	12:45 - 13:00	21	0	64	21
13:00 - 13:15	28	2	78	11	13:00 - 13:15	34	2	73	13
13:15 - 13:30	16	0	75	10	13:15 - 13:30	22	1	66	6
13:30 - 13:45	14	2	77	4	13:30 - 13:45	29	1	60	18
13:45 - 14:00	25	0	62	12	13:45 - 14:00	14	5	59	15
14:00 - 14:15	21	1	62	7	14:00 - 14:15	26	1	68	14
14:15 - 14:30	34	3	74	14	14:15 - 14:30	26	10	50	19
14:30 - 14:45	16	0	56	11	14:30 - 14:42:38	33	3	61	7
14:45 - 14:47:31	4	0	6	1	Total	329	27	831	169
Total	266	17	892	164					

8.5 MDOT speed limit survey questionnaire

1. What state are you from? If not in the U.S., please select "other" and specify.
    - ☐ (List of states)
2. Has your state raised the posted speed limit on any freeways since the repeal of NMSL in 1995?
    - ☐ Yes
    - ☐ No
3. Has your department conducted any studies to evaluate the associated impact of speed limit on traffic safety and operational speeds?
    - ☐ Yes
    - ☐ No
4. Please provide a link for any published reports. For any unpublished report, please send as an attachment to the following email address: valerian.kwigizile@wmich.edu

5. Has your state DOT established formal guidelines/procedures to be followed for changing speed limit on freeways?
    - ☐ Yes
    - ☐ No
6. Please provide a link for any published guidelines. For any written but unpublished guidelines, please send as an attachment to the following email address: valerian.kwigizile@wmich.edu.

7. Which of these aspects influence the decision making process of raising speed limit on freeways? (check all applicable)
    - ☐ Design speed
    - ☐ Engineering studies
    - ☐ Crash history/Safety analysis?
    - ☐ Legal limits
    - ☐ Public opinion
    - ☐ Political influence
    - ☐ Other (Specify) ________________________
8. What lesson(s) have you learned as the result of raising speed limit on your freeways? What would you do differently?

9. Please provide contact information, in case we will need further information:

    First Name: ___________________________________

    Last name: ____________________________________

Title: ______________________________________

Phone: _____________________________________

E-mail: _____________________________________