TRAVEL SPEED EFFECTS OF 70 MPH SPEED LIMIT CHANGE

Hiba Nassereddine

A thesis submitted in partial fulfillment of the requirements for the degree
of:

Master of Science

From the University of Wisconsin –

Madison Graduate School

Department of Civil and Environmental Engineering

December 2017

EXECUTIVE SUMMARY

Posted speed limit (PSL) on most of the Interstate highway system in Wisconsin was increased from 65 to 70 mph during the week of June 16, 2015. Segments in the Milwaukee area as well as I-535 in Superior were excluded from this increase.

This research aimed at evaluating the impact of the change in speed on Wisconsin's Interstate system after the maximum PSL increased. The first objective was to determine the impacts of the increased maximum PSL on operating speed across the state on multiple segments identified in all counties with an Interstate highway. The second objective was to assess the safety effect of increasing the maximum PSL.

This research's primary data source was the National Performance Management Research Data Set (NPMRDS), which is provided by the Federal Highway Administration (FHWA) for use in performance monitoring and management, and the data are provided by HERE. NPMRDS provides speed data on several hundred Interstate segments in Wisconsin every five minutes. For validation, the NPMRDS speeds were compared with a second data source: Wisconsin TransPortal data. WisTransPortal Volume, Speed, and Occupancy (VSPOC) Application provides online tools to retrieve and analyze traffic detector data throughout the state of Wisconsin. General Detector Data Retrieval module was used to extract data corresponding to the investigated areas. For this research, the analysis timeframe was 2014 to 2016. One-week time periods in every month from March 2014 to May 2015 were collected for the before period. One-week time periods in every month from July 2015 to June 2016 were collected for the after period.

Previous studies found that an increase in posted speed limit is associated with an increase in average operating speeds. This increase in operating speed is usually less than the posted speed limit increase. Based on previous research, the 5 mph increase in Wisconsin was expected to increase the average operating speeds approximately 1-3 mph. The findings of this research were consistent with the literature; the mean operating speed statewide increased between 0.8 and 2.8 mph for all vehicles in the research sample for segments with PSL change while that of segments without a PSL change (Milwaukee area) increased on average by 0.8 mph. A standard deviation of 5.25 and 5.82 mph was found for segments with and without PSL change respectively.

Upon analyzing the data for this research, two external effects were immediately evident, the first of which was changes in operating speed that occurred in cyclic seasonal pattern. This effect was controlled for in the analysis by comparing isochronal 11-month periods before and after the change in posted speed limit. The second external effect was the effect of work zones that existed in several segments. The presence of work zones caused operating speeds to rise or fall in ways not related to the change in posted speed limit. These work zones were controlled for by identifying segments with higher magnitude shifts in speed that were not related to posted speed limit change during the timeframe of the analysis.

Safety impact of raising the maximum PSL was investigated with a before and after study using crash frequency instead of crash rates due to missing traffic volumes for most segments. Crash data were collected from 2005 to 2017, covering 10.5 years (Jan 2005 – May 2015) prior to increasing the maximum PSL and 2.25 years (July 2015 – Sep 2017) after the increase of the maximum PSL. According to the analysis, approximately 57% of the segments did not show any difference in the average number of monthly crashes between the before and after period, which implies that increasing the PSL did not negatively impact safety. As for the remaining 43% of segments, the analysis showed a statistically significant difference between both before and after periods. The before and after analysis does not establish a cause and effect relationship between an increase in the PSL and the increase in the average number of crashes.

Acknowledgments

I would like to thank everyone who supported me throughout this research. Specifically, I would like to thank my advisor Dr. David Noyce for his invaluable support and advice throughout this project. I would like to thank Dr. David Noyce, Dr. Sue Ahn, and Dr. Steven Parker for being members of my thesis defense committee. I would also like to acknowledge the assistance and supervision of Peter Rafferty. A special thank you to my beloved family back home whose love and support are my motivation and the reason I stand here today. I must express my profound gratitude to my fiancé-to-be for supporting me spiritually throughout writing this thesis. Finally, a shout out to my sister Hala for providing me with unfailing support and continuous encouragement throughout my years of study.

TABLE OF CONTENT

1.	INTRODUCTION	1
1.1	Statement of the problem	3
1.2	Objectives.....	3
1.3	Organization	4
2.	LITERATURE REVIEW	5
2.1	Historical Overview on the Changes in Speed Limit.....	5
2.2	Effect of Speed Limit Changes on Operating speed	6
2.3	Effect of Speed Limit Changes on Traffic Safety	9
2.4	Findings from Other Midwest States	12
3.	METHODOLOGY	15
3.1	Data Description.....	15
3.1.1	National Performance Management Research Data Set (NPMRDS)	16
3.1.2	Volume, Speed, and Occupancy (VSPOC) Application Data	20
3.1.3	MV4000 Crash Data	22
3.1.4	Data Timeframe Period.....	26
3.2	Statistical Tests.....	28
3.2.1	Statistical Approaches to Measuring Error	28
3.2.2	NPMRDS Speed Analysis	30
3.2.3	Non-Parametric Test: Mann-Whitney U Test.....	32
3.2.4	Statistical Hypothesis Test: F-test.....	34
4.	DATA ANALYSIS.....	36
4.1	Impact of Posted Speed Limit Increase on Traveling Speed	36

4.1.1	VSPOC and NPMRDS Comparisons	36
4.1.2	NPMRDS Speed Analysis	40
4.1.3	Non-Parametric Test: Mann-Whitney U Test (MWW test)	45
4.1.4	Statistical Hypothesis Test: F-test.....	48
4.2	Impact of Posted Speed Limit Increase on Safety.....	49
5.	CONCLUSION.....	54
5.1	Future Research/Work.....	56
6.	REFERENCE.....	58
	APPENDICES	61
	Appendix A I-90	61
	Appendix B I-41	63
	Appendix C I-43	65
	Appendix D I-39/90	68
	Appendix E I-94	70
	Appendix F I-535	73
	Appendix G I-794	75
	Appendix H I-894	77

LIST OF FIGURES

Figure 1: Maximum Posted Speed Limit by State [11]	6
Figure 2: Map of Interstates (shown as green) with Speed Limit Increase	16
Figure 3: Wisconsin Interstate TMCs with Increased PSL from 65 to 70 mph.....	20
Figure 4: VSPOC Data Collection Process.....	21
Figure 5: Example of VSPOC Detectors for the Corresponding TMC	22
Figure 6: Procedure to Retrieve Crash data	23
Figure 7: Highways with 70 mph Speed limits.....	25
Figure 8: Data Collection calendar	27
Figure 9: Good Match Between VSPOC and NPMRDS Speed	37
Figure 10: Bias Between VSPOPC and NPMRDS Speed.....	38
Figure 11: Moderate Match Between VSPOPC and NPMRDS Speed	39
Figure 12: Before/After Speed Plot of All Segments	41
Figure 13: Typical Example of Metrics for a Segment.....	42
Figure 14: Example of Seasonal Variation in Passenger Vehicle Speeds	43
Figure 15: Example Segment with Work Zone Effects	44
Figure 16: Maximum Speed Shift for Each TMC	45
Figure 17: P-value (of Mann–Whitney U Test) for Each TMC’s Speed Change.....	46
Figure 18: Comparison TMCs t-test Results	47
Figure 19: P-value (of t-test) for each TMC’s Speed Change	48
Figure 20: P-value (of F-test) for Each TMC’s Speed Change	49
Figure 21: Monthly average Crashes for the Before and After Speed Limit Increase periods	51

Figure 22: Monthly average Crashes Difference Between Before and After Speed Limit

Increase using 2016 Data52

Figure 23: Monthly average Crashes Difference Between Before and After Speed Limit

Increase using 2017 Data53

LIST OF TABLES

Table 1: Minimum List of Locations Arranged for Evaluation15

Table 2: TMC Segment Tallies by Interstate and County18

Table 3: Segments of interest by Interstate and County25

Table 4: VSPOC and NPMRDS Comparison Statics39

Table 5: Summary Statistics40

Table 6: Summary Statistics for Crash Data.....50

1. INTRODUCTION

An important purpose of speed limits is to improve traffic safety by reducing the risks imposed by the speed choices of drivers. This purpose is achieved in two ways. On one hand, by setting an upper bound, speed limits create a controlling threshold and hence aim to reduce both the probability and severity of crashes. On the other hand, speed limits reduce dispersion in speeds among drivers and thereby reducing potential vehicular conflicts. In addition to this primary reason, speed limits also help improve the efficiency of traffic flow by achieving an orderly flow of traffic [1].

Despite these benefits, establishing an arbitrary value for the speed limit may have a negative impact on traffic flow and safety. Hence, implementing a speed limit is effective only if set within an appropriate range. This range varies from one road to another and is determined based on several factors such as roadway functionality, roadway characteristics, sight distance, and others. As this value shifts from this range, the effectiveness declines. Therefore, in establishing speed limits for a roadway or highway segment, decision makers try to set a reasonable balance between safety (crash risks) and mobility (travel time) [2] [3]. Various aspects of speed are used depending on the application. The following terms are commonly used in speed literature and discussions:

- Design speed: a selected speed used to determine the various geometric design features of a roadway.
- Operating speed: the speed at which vehicles are observed operating during free flow conditions. Free flow speeds are those observed from vehicles whose operations are unconstrained by traffic control devices (e.g., traffic signals) or by other vehicles in the

traffic stream. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed.

- Posted speed: the maximum legal speed a vehicle can operate at for a particular location as displayed on regulatory signs.
- 85th percentile speed: the speed at or below which 85 percent of vehicles travel. [4]

When designing a new road, the characteristics of the facility guide the choice of a design speed. Speed limits are often determined by the driver operating speeds (85th percentile speed – the speed at or below which 85% of all vehicles are observed to travel under free-flowing conditions past a monitored point) which in turn affect the timing of traffic signals. Achieving consistency between design speeds, actual driving speeds, and posted speed limits is also taken into consideration [1].

In 1995, the US Congress decided that setting speed limits on the roads in the United States is no longer the responsibility of the federal government. States were allowed to determine and establish their own maximum speed limits. Many states raised their speed limits at that time [3] [5]. Wisconsin State Legislature passed the 2015 Wisconsin Assembly Bill 27, effective May 21, 2015. This bill increased the maximum allowable highway speed limit from 65 mile per hour (mph) to 70 mph on any freeway, including those that are part of the national system of interstate and defense highways and on any section of an expressway that gives priority to through traffic by using interchanges only [6] [7]. As a result, the Wisconsin Department of Transportation (WisDOT) implemented a 70 mph speed limit on most interstate segments. This speed increase affected approximately 726 miles of interstate the week of June 16, 2015 with the exclusion of segments in the Milwaukee area.

1.1 Statement of the problem

Increasing the posted maximum speed limit intensified the debate on the tradeoff between safety and mobility. This debate started in 1974 with the passage of the Emergency Highway Energy Conservation Act, which prohibited speed limits higher than 55 mph on interstate highways in the US [8]. Following policy changes, various studies were conducted to assess the impacts of increasing the maximum speed limit on traffic crashes and fatalities [9].

While several studies showed that increases in the maximum posted speed limit negatively influence traffic safety by increasing the number and/or rate of fatalities/injuries, numerous studies indicated that higher speed limits had no effect on safety [9]. Other studies even suggested that increasing speed limits reduced traffic fatalities and improved safety [9]. Despite the various studies on the effects of speed limit changes, their impacts on traffic safety are not yet fully comprehended [10]. An interest from the state departments of transportation, media, and public remains needed in order to unfold the impacts of increasing the maximum PSL on traffic safety.

1.2 Objectives

The primary objective of this research is to evaluate the operations and safety on the Wisconsin Interstate Highway system after increasing the posted speed limit (PSL) from 65 to 70 mph on 726 lane miles of roadway. The key objectives of this research are as follows:

- Determine the impact of the increased PSL on operating speeds across the state on each identified segment.
- Provide an overview on the overall change in speeds from all segments.
- Determine the impact of raising the maximum posted speed limits on traffic safety.

1.3 Organization

This research is organized into five chapters, references and an appendix. The current Chapter (Chapter 1) comprises of an introduction to the research along with the hypotheses and objectives of the research. Chapter 2 represents a literature review relevant to this research. Chapter 3 describes the methodology used in the research, as well as the tests used to complete the analysis. Chapter 4 documents the results obtained and provides a detailed analysis of the acquired data. Chapter 5 summarizes the results and presents some concluding remarks. Chapter 6 includes all the references used to complete this research. Lastly, additional figures and tables that served this research are compiled in the Appendices.

2. LITERATURE REVIEW

2.1 Historical Overview on the Changes in Speed Limit

Up until 1974, states had the authority to determine and establish their own speed limits. Limits such as 65 mph and 75 mph were posted on most highways. On January 1, 1974, the United States Congress implemented a National Maximum Speed Limit (NMSL) of 55 mph to reduce fuel consumption as a response to the Arab Oil Embargo. As a result, the flow of traffic slowed down on all major highways and the total amount of travel declined. These declines were accompanied by a decrease in the number of traffic fatalities [11].

NMSL remained in effect for 13 years unaffected by the subsequent decrease in oil prices. However, in the mid-1980s, public officials from several states requested the speed limit law to be revisited and allow for higher speeds to decrease travel time. Consequently, on April 1, 1987, Congress passed the Surface Transportation and Uniform Relocation Assistance Act (STURAA) which allowed states to increase speed limits up to 65 mph on rural Interstate highways. By the end of 1987, several states had adopted the new act [11].

On November 28, 1995, the NMSL was repealed by the National Highway System (NHS) Designation Act. This law returned the authority of setting speed limits to the states on the roadways within their boundaries. A total of 32 states used the authority granted by this law to increase posted speed limits on various roadways by the end of 1996 [11]. Wisconsin increased the maximum posted speed limit from 55 mph to 65 mph by the Wisconsin Act 318 in 1996 and then from 65 mph to 70 mph by the Wisconsin Assembly Bill 27 on several interstates in 2015 [6] [3]. Figure 1 shows the current maximum posted speed limits by state in the United States. Idaho, Montana, Nevada, South Dakota, Utah, and Wyoming have a

Following STURAA in 1987, several studies evaluated the effect of raising the maximum posted speed limit to 65 mph on operating speed. A study conducted by Upchurch examined the rural Interstates in Arizona in 1989, and found that the mean operating speed increased from 59.5 mph to 65.0 mph [13]. A similar study examined the rural and urban Interstates in Virginia. The study looked at a 6-year analysis period – 3 years each of the before and after analysis period. The average operating speed increased by 5.2 mph and 3.1 mph on

rural and urban Interstates, respectively. The study also considered the 85th percentile speed which increased by 6.3 mph and 3.5 mph on rural and urban Interstates, respectively [14].

A study conducted in Alabama in 1990 found that the 10 mph increase in posted speed limit (from 55 mph to 65 mph) led to an average increase of 2.4 mph. 85th percentile speed increased by 2.2 mph [15]. In 1991, a study examined the impact of increasing posted speed limits on rural Interstates in 11 states. Speed data between 1986 and 1988 were analyzed to determine the effect of increasing the speed limit from 55 mph to 65 mph on some speed aspects: average operating speed, speed variance, and 85th percentile speed. The analysis showed a 4 mph increase in the average speed, a 5 mph increase in the 85th percentile speed, and a 12 percent increase in speed variance. The study also found that the percentage of vehicles exceeding 70 mph increased from 6 to 19 percent. The study also looked at the adjacent roads with a 55-mph posted speed limit. A small increase of 0.8 mph was observed on these roads, suggesting a nominal effect from the increase in posted speed limit on other sections [16].

In 1996, WisDOT (Wisconsin Department of Transportation) looked at the implications of increasing the speed limit from 55 mph to 65 mph. The study emphasized physical and design considerations, noting that freeways are designed for 70 mph. At that time, the 85th percentile freeway speed was predicted to increase by 3 mph (from 72 mph to 75 mph) if the posted speed limit was increased further from 65 mph to 70 mph [17]. As additional data became available, a follow-up report prepared by WisDOT in 1998 showed that the average operating speeds increased by 4.5-4.6 mph on freeways when PSL increased from 55 to 65 mph [18].

In 1998, McCarthy evaluated the impact of raising the speed limits from 55 mph to 65 mph on highways. On non-limited access roads, average speed and speed variance had small changes with respect to the increased speed. On higher-speed limited access roads, the average and the 85th percentile speeds increased by about 4 mph, while the speed variance increased by less than 1 mph [19].

In 2002, a study by the Washington State Department of Transportation (WSDOT) used 10 years of speed data. The 5 years period before the PSL change (1982-1987) had an average rural Interstate speed of 58.5 mph. This average increased to 64.0 mph in the next 5 years (1987-1992) following the posted speed limit increase. The 85th percentile speeds were also investigated in the study, and the analysis showed that they increased from 64.0 mph to 70.6 mph over the same period. The speed limit increase did not affect the speed variance as it increased steadily over the investigated period. Another study in Washington State in 2006 showed that an increase of 10 mph in the posted speed limit (from 65 mph to 75 mph) led to a 3.4 mph increase in average vehicle speed [20].

A recent study in Texas evaluated the impact of increasing the posted speed limit from 70 to 75 mph. The study collected 2 months before (starting November 2012) and 2 months after (starting March 2013) speed data. The average speed increased from 69.9 mph to 71.6 mph, the 85th percentile speed increased from 74.5 mph to 76.6 mph. The standard deviation increased from 4.9 to 5.3 mph. The percentage of people exceeding the posted speed limit increased from 12.1 to 26.1 percent [21].

In 2013, the effect of increasing the posted speed limit in Utah from 75 to 80 mph was investigated on rural Interstates. Speed data were collected for three consecutive years (2008, 2009, and 2010). The study showed that the average speed for passenger cars and trucks decreased between 2008 and 2009 by 2.4 and 7.3 percent, respectively. As for the period between 2008 and 2010, the average speed for passenger cars increased by 0.2 percent, while that of trucks decreased by 3.7 percent. Passenger cars and trucks on adjacent segments – where posted speed limits did not increase – were traveling 1.9 and 1.6 percent faster than expected [22].

In general, the previous studies indicated a consistent effect of raising the posted speed limit. Studies showed that in general, the average driving speeds increased by less than the amount by which the posted speed limit increased. Every 1 mph change in PSL corresponded to a ~0.4 mph (± 0.2 mph) change in average speeds for all vehicles in uncongested conditions, which is due to drivers selecting their operating speed based on their perception of a safe speed which is based on weather, geometric characteristics of the highway, and traffic conditions rather than the posted speed limit [23].

2.3 Effect of Speed Limit Changes on Traffic Safety

Following STURAA in 1987, several studies evaluated the effect of raising speed limits to 65 mph on crash frequency and severity. One of the earliest studies conducted by the Arizona DOT in 1989 looked at highway traffic crashes resulting in injury or a fatality for the period between January 1982 and December 1988. The study used the interrupted time-series method to evaluate the change in injury and fatality crash rates after the posted speed limit increased from 55 mph to 65 mph in May 1987. Highways that did not experience a change in the posted

speed limit were included in the study as a control group. The results showed a 36 percent monthly increase in crash related fatality and injuries, and an increase of 1,100 injuries and fatalities in a year and a half after the speed limit increase [24].

A study in New Mexico compared fatal crashes on rural Interstates before (1982 – 1987) and after (April 1987 – April 1988) the posted speed limit increase from 55 to 65 mph. Crash trends for the before period were used to estimate the expected fatal crash rate using linear regression, and the expected values were then compared with the rate of the collected fatal crashes of the after period. Although the rate of the collected fatal crashes decreased over the study period, the percentage of fatal crashes on rural highways as a percentage of all other road types increased by as much as 3.9 percent when compared to the average proportion of fatal crashes in the 5 previous years. Single-vehicle crashes were accountable for the majority of fatal crashes on rural highways after the speed limit increase. The study concluded that higher speed limits justified the result because of consistent demographic characteristics, alcohol involvement, and seat belt use in the period of the study [25].

Friedman et al. looked at annual crash counts for all 50 states that increased the speed limit on their rural Interstates between 1995 and 2005. They also looked at annual crash counts for states that raised the speed limit on their urban Interstates, and urban and rural non-Interstate highways during the same period. This study used Poisson mixed-effects regression to evaluate the effect of speed limit increase on safety, and it showed that increasing the speed limit resulted in an increase by 3.2 percent of fatalities on all road types. Injuries increased by 11.9 percent on rural interstates and by 5.6 percent on urban Interstates [26].

In a recent study, Farmer examined the effects of increasing speed limits on safety in the United States for the period from 1993 through 2013. Using a Poisson regression model, traffic fatality rates for 41 states were modeled as a function of time, annual state unemployment rate, percentage of the driving population aged 25 or younger, percentage of the driving population aged 65 and older, state seat belt usage, per capita alcohol consumption, and the maximum posted speed limit on any roadway segment in the state. This model predicted that each 5 mph increase in the posted speed limit leads to an increase in interstate highways fatality rate by 8 percent [27].

Lave and Elias evaluated the influences of increasing speed limit to 65 mph for several states. In this study, the authors argued that previous studies only looked at local effects which are specific to the segment under study rather than considering the global effects. Changing speed limits has consequences for other road segments in the state. For example, there might be a shift of traffic from rural roads to the higher speed rural interstates, which would make rural roads safer. The study looked at fatality rates instead of fatality frequency as a better estimate for before and after speed limit change periods. It was found that the statewide fatality rates decreased by 3.4 percent [28]. Other researchers believe that statewide data is a too-wide measure, and that drivers might rarely choose rural freeways because of the geography of the state [1].

Overall, studies have shown that increasing the posted speed limit on rural Interstates and highways with similar design features resulted in increased injury and fatal crashes. The validity of results throughout the studies is likely the result of the use of different analysis

methods, data collection sources, sample size, and other confounding factors such as weather, alcohol impairment, use of seat belt, and presence of law enforcement [23].

2.4 Findings from Other Midwest States

Michigan

On August 1, 1996, the speed limit on segments of Michigan freeways were increased from 65 to 70 mph. Michigan Department of Transportation (MDOT), in conjunction with the Department of Civil and Environmental Engineering at Michigan State University, conducted a study to examine the effects of this increase. The analysis compared test segments where the speed limit was increased to 70 mph with the control segments where speed limits remained the same. The collected data showed that increasing the speed limit on some segments had an increase in the 50th (the speed at which half of the observed vehicles are below and half of the observed vehicles are above) and 85th percentile of 1.0 mph and 0.5 mph respectively [29].

Indiana

On July 1, 2005, the Interstate speed limit was raised to 70 mph. Purdue University conducted a study to analyze the effects of this increase, but did not report on operating speed changes. The study used multinomial models to investigate the impact of increasing the posted speed limit on accident severity. The results indicated that the increase in the posted speed limit had no statistically significant effect on accident injury severity [8].

Iowa

On July 1, 2005, the speed limit was increased to 70 mph on most rural Interstates. Iowa State University, in conjunction with the Iowa Department of Transportation, evaluated

the effects of the speed increase. The study showed that the 85th percentile speeds increased by 2 mph but the number of drivers exceeding the speed limit by 10 mph decreased from 20% to about 8%. Crash data were investigated from 1991 to 2007. The study showed an increase in crash severity categories. Increases were less pronounced in some severity levels when compared to long term trends [30].

Illinois

On January 1, 2014, the Interstate speed limit was increased from 65 to 70 mph on approximately 87% of Interstate highways and 98% of rural Interstates under Illinois Department of Transportation's jurisdiction. There have not yet been studies regarding the effect of this speed limit increase [31].

Minnesota

In 1997, the speed limit was increased from 65 to 70 mph on rural Interstates. In 2005, the Minnesota Department of Transportation conducted a study to evaluate the impacts of PSL increase. University of Minnesota compared operating speed data obtained during the Minnesota Speed Management Program (MSMP) with historical data. Speed data showed a 42.9% decrease in the number of drivers traveling at least 10 mph above the speed limit. Crash data were analyzed and the results showed a reduction in the number of fatal crashes after the implementation of MSMP [32].

Ohio

On July 1, 2013, the Interstate speed limit was increased from 65 to 70 mph. Ohio Department of Transportation (ODOT) conducted a study to investigate the effects of the speed

limit increase. It was found that on Interstate segments where speed limit increased, the 85th percentile speed increased by 1 mph. Before the increase, the 85th percentile speed was slightly above 65 mph, and after the increase it remained below 70 mph [33].

3. METHODOLOGY

3.1 Data Description

Travel time and operating speed data were extracted on interstate segments, in each direction.

Table 1 shows the counties and interstates where the speed data is collected, and Figure 2 shows the interstates which this research will focus on (highlighted in green).

Table 1: Minimum List of Locations Arranged for Evaluation

Interstate	I-94	I-90	I-39	I-41	I-43
County	St. Croix	La Cross	Marathon	Brown	Brown
	Dunn	Monroe	Portage	Outagamie	Manitowoc
	Eau Claire		Waushara	Winnebago	Sheboygan
	Jackson		Marquette	Fond du Lac	Ozaukee
	Monroe		Columbia	Dodge	Waukesha
	Juneau		Dane	Washington	Walworth
	Sauk		Rock	Waukesha	Rock
	Columbia				
	Dane				
	Jefferson				
	Waukesha				
	Milwaukee				
	Racine				
	Kenosha

Figure 2: Map of Interstates (shown as green) with Speed Limit Increase

3.1.1 National Performance Management Research Data Set (NPMRDS)

Federal Highway Administration (FHWA) provides the NPMRDS for use in performance monitoring and management and is available to State Departments of Transportation and Metropolitan Planning Organizations (MPOs). The data are provided by HERE (formerly NAVTEQ and Nokia), and consist of the following [34]:

- Average travel times;
- Five-minute bins, referred to as epochs;
- National Highway System (NHS) coverage, including all interstates and US highways;
- By traffic message channel (TMC) links;
- By passenger, freight (5+ axle, class 7-8 per ATRI), and combined;
- With GIS shapefiles;

- From October 2011 to present, updated monthly; and
- On a state by state basis, with a usage agreement required.

NPMRDS has been available since 2013. In early 2014, there was a significant jump in data quality. Therefore, for this research, data prior to March 2014 were not considered. This analysis used the following NPMRDS versions: 2014Q1 (Mar - Oct '14), 2014Q3 (Nov '14 - Jun '15), 2015Q3 (Jul - Oct '15), and 2015Q4 (Nov '15 – Jul '16). FHWA refers to NPMRDS as a suitable sound data source and requires their use for performance measures as per the Moving Ahead for Progress in the 21st Century (MAP-21) Act [34].

For Wisconsin Interstates, 674 segments (TMCs) were available. Before carrying forward with the analysis, quality and consistency checks for each TMC were done.

- For a TMC to be used, it must exist in all four NPMRDS versions from March 2014 to June 2016. There were 58 TMCs missing from one or more version, leaving 616 segments for further consideration.
- Because NPMRDS segment lengths sometimes change from one NPMRDS version to another – which affect travel time data – all segments were checked for such changes in all four versions. If the standard deviation of the distance was greater than 0.01 mile, that segment was omitted from the analysis, which led to the removal of 21 TMCs, leaving 595 segments for further consideration.
- A typical segment length for Wisconsin Interstates ranges between 0.9 and 3.5 miles. Very short segments have fewer observations and show relatively greater variance. Segments of lengths less than 0.1 mile were removed. There were 16 such TMCs, leaving 579 segments for analysis.

The identified 579 TMCs include samples within all counties identified in Table 1, along with additional selections from other Interstates and counties. Of these 579 segments, 455 segments had an increase in the PSL, while the remaining 124 did not. The speed limit for the 124 segments – primarily in Milwaukee County – is posted at 50 or 55 mph, and these segments are used for comparison and serve as control segments. Table 2 shows TMC segments classified by Interstate and county.

Table 2: TMC Segment Tallies by Interstate and County

I-39 (includes I-39/90; excludes concurrent section with I-94)

County	NB	SB	EB	WB	Total
Columbia	5	5			10
Dane	5	6			11
Marathon	5	6			11
Marquette	4	4			8
Portage	11	10			21
Rock	7	7			14
Waushara	3	4			7
Total	40	42			82

I-41 (previously US 41)

County	NB	SB	EB	WB	Total
Brown	4	6			10
Dodge	3	4			7
Fond du Lac	7	8			15
Milwaukee	10	10			20
Outagamie	10	10			20
Washington	9	9			18
Waukesha	3	3			6
Winnebago	12	11			23
Total	59	61			119

I-43 (includes I-43/894)

County	NB	SB	EB	WB	Total
Brown	7	7			14
Manitowoc	7	8			15
Milwaukee	15	15	6	6	42
Ozaukee	9	9			18
Rock	3	3			7
Sheboygan	8	7			15
Walworth	8	9			17
Waukesha	5	5			10
Total	62	63	6	6	137

Table 2 continued: TMC Segment Tallies by Interstate and County

I-90

County	NB	SB	EB	WB	Total
La Crosse			6	7	13
Monroe			4	4	8
Total			10	11	21

I-94 (includes I-39/90/94 and I-43/94)

County	NB	SB	EB	WB	Total
Columbia	3	4	1	2	10
Dane	6	5	4	3	18
Dunn			2	1	3
Eau Claire			4	5	9
Jackson			5	4	9
Jefferson			5	6	11
Juneau			5	5	10
Kenosha	5	4			9
Milwaukee	13	14	11	9	47
Monroe			7	7	14
Racine	6	6			12
Sauk			4	4	8
St Croix			9	7	16
Waukesha			13	13	26
Total	33	33	70	66	202

Other 3-Digit Interstates

County	NB	SB	EB	WB	Total
I-535 Douglas	1	1			2
I-794 Milwaukee			2	4	6
I-894 Milwaukee	5	5			10
Total	6	6	2	4	18

The 455 segments which had the increased PSL on five Interstate highways (I-39, I-41, I-43, I-90, and I-94) are shown in Figure 3. These TMCs are used to evaluate the effects of changes in the speed limit on operating speed and its variations.

Figure 3: Wisconsin Interstate TMCs with Increased PSL from 65 to 70 mph

3.1.2 Volume, Speed, and Occupancy (VSPOC) Application Data

For validation, the NPMRDS speeds are compared with selected agency-collected loop and microwave detector data. The WisTransPortal Volume, Speed, and Occupancy (VSPOC) Application¹ provides online tools to retrieve and analyze traffic detector data throughout the state of Wisconsin. General Detector Data Retrieval module was used to pull data corresponding to the investigated areas. After selecting the location (region, corridor, and location), the Detector IDs that fell within the limits of the TMC road segment were selected for investigation. Only Detector IDs located along the main road were selected; those associated with on/off ramps were omitted since drivers slow down to make these maneuvers,

¹ <http://transportal.cee.wisc.edu/applications/vspoc.html>

yielding to data which is not reflective of mainline travel. In addition, Detector IDs within one mile of ramps were also avoided since drivers would still be adjusting speed.

From the 579 TMC segments there are 294 that have available detectors in VSPOC. Data were retrieved for 43 segments of these 294. These segments included I-39, I-39/I-90, I-43/I-94 and I-43/I-894 and will be used to compare VSPOC and NPMRDS data. Once the Detector IDs for the roadway segment were identified, five-minute detector data for speed were collected by averaging over the selected detectors. Figure 4 provides a graphical overview of this data collection process.

Figure 4: VSPOC Data Collection Process

Figure 5 shows an example of the selected VSPOC detectors that falls within the limits of the corresponding TMC.

Figure 5: Example of VSPOC Detectors for the Corresponding TMC

3.1.3 MV4000 Crash Data

Wisconsin DOT's motor vehicle accident report is referred to as MV4000. WisTransPortal is the primary source for accessing the crash data archive of all reported crashes in Wisconsin from 1994 to the present. The crash data are available by accessing the

Crash Data Retrieval Facility. Figure 6 shows the procedure a WisTransPortal user needs to go through to retrieve the crash data.

Date Range
(Starting and Ending Year/Month)

Crash Location Area
(Region, County & Municipality)

Include/Exclude Deer Crashes

Filter by Crash Location Type
(Intersection, Non-Intersection...)

Filter by Crash Flag
(Alcohol, Drug use...)

Retrieve Data

Filter by Crash Flag
(Alcohol, Drug use...)

Retrieve Data
Reset Form
Advanced Query
Exit

Note on 2016 Final and 2017 Preliminary Data: Last Modified: Thursday 21 September 2017
 Final 2016 MV4000 crash data. The WisTransPortal is current with the 8/17/2017 DMV Final RP extract of 2016 crash data. This extract includes the final RP coding of 2016 highway crashes.
 Preliminary 2017 DT4000 crash data. The new DT4000 form elements and attributes have been translated back to match MV4000 definitions. The WisTransPortal is updated on a daily basis from the DT4000 extracts.
 RP Coding Status: RP coding of 2017 highway crashes is underway.
☐ Check to Include Preliminary Data with your query.

1. Select a Date Range:
 Starting Year: [2005 ▼] Month: [JAN ▼]
 Ending Year: [2018 ▼] Month: [DEC ▼]
 Restrict Date Range to Selected Months: [Clear Selected](#) | [Help](#)
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

2. Select a Crash Location Area: [Clear Selected](#) | [Help](#)
 Region: [SELECT ALL ▼] County: [ROCK ▼] Municipality: [SELECT ALL ▼]
 [NE ▼] [SAUK ▼] [ABBOTSFORD (C), MARATHON ▼]
 [NW ▼] [SHAWANO ▼] [ALBANY (T), PORTAGE ▼]
 [SE ▼] [VERNON ▼] [ALBION (T), DANE ▼]
 [SW ▼] [VILAS ▼] [ALMOND (T), PORTAGE ▼]
 [WILKESHAIRE ▼] [ALMOND (V), PORTAGE ▼]
 [WOOD ▼] [AMHERST (T), PORTAGE ▼]
 [AMHERST (V), PORTAGE ▼]

3. Include / Exclude Deer Crashes:
☐ Check to exclude Deer crashes.

4. Filter by Crash Location Type: [Help](#)
☒ INTERSECTION
☐ NON-INTERSECTION
☐ PARKING LOT
☐ PRIVATE PROPERTY

5. Filter by Crash Severity:
☐ FATAL
☐ INJURY
☐ INCAPACITATING (A)
☐ NON-INCAPACITATING (B)
☐ POSSIBLE (C)
☐ PROPERTY DAMAGE

6. Filter by Crash Flags:
☐ ALCLAG (Alcohol) ☐ DRUGFLAG (Drug Use)
☐ AUTOF (Passenger Car) ☐ GOVPROP (Government Property)
☐ BIKEFLAG (Bicycle) ☐ NITRUM (Hit and Run)
☐ BUSFLAG (School Bus) ☐ MOPFLAG (Moped)
☐ CITFLAG (Citation) ☐ PEDFLAG (Pedestrian)
☐ CHVFLAG (Commercial Vehicle) ☐ TRKFLAG (Truck)
☐ CONZONE (Construction Zone) ☐ TRLRFLAG (Trailer in Tow)
☐ CYCLFLAG (Motorcycle)

Logical operator to combine crash flags: ☒ OR ☐ AND

Retrieve Data
Reset Form
Advanced Query
Exit

The Total Number of Records for this Query is 245883.

Refine Location
Summarize Data
Show WISLR Map
Show RP Map
New Query
Exit

☒ View additional crash detail
 ☒ View the crash report
 ☒ Crash report is not available
 ☒ Crash report is restricted

First
Previous
Next
Last
Rows Per Page: [20 ▼]
Order By: [LOCATION ▼]
Column List: [GENERAL PURPOSE ▼] [Customize](#)

#	DOCTNMBR	ACCDDATE	NTFYHOUR	REGION	COUNTY	MUNICIPALITY	MUNITYPE	ONHWYRP	ONHWYDIR	ONHWY	ONSTRATHWY	ATSTR
1	1935C4VH	05/19/2006	05W	COLUMBIA	ARLINGTON	T	039	N	039		CS	
2	2C7VN1XM	10/19/2014	05W	COLUMBIA	ARLINGTON	T	039	N	039			SMOKEY H
3	3C7T72MC	07/17/2006	11SW	COLUMBIA	ARLINGTON	T	039	N	039		I	
4	4C7TBS2D	01/09/2012	18SW	COLUMBIA	ARLINGTON	T	039	N	039		DM	
5	5C81W2R8	12/29/2011	17SW	COLUMBIA	ARLINGTON	T	039	N	039			MP 123

Figure 6: Procedure to Retrieve Crash data

After following the procedure shown in Figure 6, an initial crash data table is generated. Clicking on the “Refine Location” box, allows the user to select a location of interest and reduce the number of crash reports to include only those in the investigated area.

Crash data were collected on the segments listed in Table 2. Figure 7 shows the location of the segments of interest on the map, while Table 3 summarizes them by Interstate and county. Data were collected from 2005 to 2017, covering periods of 10.5 years (Jan 2005 – May 2015) prior to PSL increase and 2.25 years (July 2015 – Sep 2017) after the PSL increase. Since the data for 2017 are not official yet, the preliminary data were used instead. Because of that and due to some missing data, two different phases for the analysis were conducted. Phase 1 included data for 2016 only, while phase 2 also included data of 2017.

Figure 7: Highways with 70 mph Speed limits

Table 3: Segments of interest by Interstate and County

Interstate	I-94 (includes I-39/90/94)	I-90	I-39 (includes I-39/90)	I-41	I-43 (includes I-43/894)	I-535	I-794	I-894
County	Columbia	La Cross	Columbia	Brown	Brown	Douglas	Milwaukee	Milwaukee
	Dane	Monroe	Dane	Dodge	Manitowoc			
	Dunn		Marathon	Fond du Lac	Milwaukee			
	Eau Claire		Marquette	Milwaukee	Ozaukee			
	Jackson		Portage	Outagamie	Rock			
	Jefferson		Rock	Washington	Sheboygan			
	Juneau		Waushara	Waukesha	Walworth			
	Kenosha			Winnebago	Waukesha			
	Milwaukee							
	Monroe							
	Racine							
	Sauk							
	St. Croix							
	Waukesha							

3.1.4 Data Timeframe Period

Maximum posted speed limit was increased on Wisconsin interstates the week of June 16, 2015. The before period data were collected for one-week time periods in every month from March 2014 to May 2015. The after period data were collected for one-week time periods in every month from July 2015 to June 2016. Figure 8 shows the calendar for the data collection period, holidays and Sundays are indicated in red, and the weeks for which data were collected are highlighted in yellow. Weeks that had holidays were avoided when collecting data as these days do not depict a normal travel day.

Figure 8: Data Collection calendar

3.2 Statistical Tests

3.2.1 Statistical Approaches to Measuring Error

Mean Absolute Error (MAE) [35]

The mean absolute error (MAE) gives a measure of the magnitude of error between two data sets without considering their direction. It's the average over the sample data set of the absolute differences between the observations of two data sets. However, the MAE does not indicate whether the estimates tend to be over-estimates or under-estimates. The MAE is defined as follows:

$$MAE = \frac{1}{T} \sum_{i=1}^t abs(Travel\ Speed_i^A - Travel\ Speed_i^B)$$

where t is the number of observations.

Root Mean Square Error (RMSE) [35]

RMSE gives a measure of the average magnitude of error between two data sets. It is the square root of the average of the squared differences between two data set observations. Because squaring is a non-linear operation it weights outlier observations more heavily and gives a better indication of whether a data set contains outlier observations. RMSE is defined as:

$$RMSE = \sqrt{\frac{1}{T} \sum_{i=1}^t (Travel\ Speed_i^A - Travel\ Speed_i^B)^2}$$

Correlation Coefficient, ρ

The correlation coefficient, ρ , is the quantitative measure of correlation between datasets. $\rho = 1$ is total positive correlation, 0 is no correlation, and -1 is total negative correlation.

$$\rho = \left(\frac{1}{\sigma_A * \sigma_B * T} \right) \sum (Travel\ Speed_t^A - \overline{Travel\ Speed_t^A})(Travel\ Speed_t^B - \overline{Travel\ Speed_t^B})$$

where σ_A and σ_B are the standard deviations for each series.

Theil's Inequality Coefficient, U – Travel Time Difference [36]

Theil's inequality coefficient is used to analyze the difference between two travel time sets. The value of U will always fall between 0 and 1. If $U = 0$, all travel times are equal, a perfect match. If $U = 1$, the differences are especially notable.

$$U = \frac{\sqrt{\frac{1}{T} \sum_{i=1}^T (Travel\ Speed_t^A - Travel\ Speed_t^B)^2}}{\sqrt{\frac{1}{T} \sum_{i=1}^T (Travel\ Speed_t^A)^2 + \frac{1}{T} \sum_{i=1}^T (Travel\ Speed_t^B)^2}}$$

One useful property of the Theil inequality coefficient is that it can be decomposed into three components: bias, variance, and covariance proportions of U .

Bias Proportion, U^M [36]

The bias proportion, U^M , is an indication of systematic error and it measures the extent to which the average values of the two travel time series deviate from each other. Whatever the value of the inequality coefficient U is, it is best for U^M to be close to zero. A large value of U^M (above 0.2) would mean that a systematic bias is present.

$$U^M = \frac{(\overline{Travel\ Speed_t^A} - \overline{Travel\ Speed_t^B})^2}{(\frac{1}{T}) \sum (Travel\ Speed_t^A - Travel\ Speed_t^B)^2}$$

Variance Proportion, U^S [36]

The variance proportion, U^S , indicates the ability of the travel time estimation to replicate the degree of variability in the variable of interest. If U^S is large, it means that one of the series has fluctuated considerably while the other series shows little fluctuation.

$$U^S = \frac{(\sigma_A - \sigma_B)^2}{(\frac{1}{T}) \sum (Travel\ Speed_t^A - Travel\ Speed_t^B)^2}$$

Covariance Proportion, U^C [36]

The covariance proportion, U^C , measures unsystematic error. It represents the remaining error after deviations from average values have been accounted for. Since it is unreasonable to expect sources to be perfectly correlated with each other, this component of error is less worrisome than the previous two. The ideal distribution of inequality over the three sources is $U^M = U^S = 0$ and $U^C = 1$.

$$U^C = \frac{2(1 - \rho) \sigma_A \sigma_B}{(\frac{1}{T}) \sum (Travel\ Speed_t^A - Travel\ Speed_t^B)^2}$$

3.2.2 NPMRDS Speed Analysis

Travel time data were collected for the 579 TMCs. Speed is then calculated as follows:

$$Speed\ (mph) = \frac{TMC\ distance\ (miles)}{travel\ time\ (seconds) / 3600\ (seconds/hour)}$$

NPMRDS contains some irregular travel times corresponding to very low speeds and representing a very small fraction of the total number of observations. Hence, speeds less than 1 mph were excluded.

Usually the 85th percentile of speed is assumed to be the highest safe speed for a roadway section. This value is used in evaluating or recommending posted speed limits. It is usually obtained from a spot speed study where a person in the field would collect speeds of free-flowing vehicles with a handheld radar. NPMRDS provides five-minute average travel times. Since this data is aggregated and there is no access to any other values such as a certain percentile, a measure of dispersion, or a vehicle count, the 85th percentile speed is not identified and is replaced by the 80th percentile speed. For each segment, the following statistics were calculated for all days from March 2014 to June 2016:

- 20th percentile speed (speed value below which 20% of the observations may be found)
- 50th percentile (median) speed
- 80th percentile speed (speed value below which 80% of the observations may be found)
- Interquartile range (IQR, the difference between the third and first quartiles)
- Average speed
- Standard deviation

An additional parameter – the 20th percentile speed – for speed distribution was calculated. The following two examples illustrate the usefulness of this parameter: first, if both the 80th and 20th percentile speed increase, which implies a systematic increase in speed; and

second, if the 80th increases, the median is unchanged, and the 20th decreases, which implies increased dispersion.

3.2.3 Non-Parametric Test: Mann-Whitney U Test

A t-test is one of the most frequently used test in statistics. It is used to determine whether the mean of a population significantly differs from a specific value or from the mean of another population. In general, a t-test is ideal to use when each population in the dataset is normally distributed. If the data is not normally distributed, the Mann–Whitney–Wilcoxon (MWW) – a non-parametric statistical hypothesis test – is used. In fact, when the data is normally distributed, the MWW test has an 86% of the power of the t-test. However, when the data is not normally distributed, the MWW test has a much larger power, sometimes up to infinity. Because normality assumption is not needed for the MWW test, it is more conservative to interpret its results, and, therefore, the test is less likely to draw the wrong conclusions. [37].

Mann–Whitney–Wilcoxon test is a nonparametric test of the null hypothesis that probability distributions are the same for two independent populations. In 1945, Wilcoxon proposed this test for two samples of equal sizes and in 1947, Mann and Whitney updated the test to handle unequal sample sizes as well as small samples. The MWW test is most useful for testing the equality of two population means and is an alternative to the two independent samples t-test when the assumption of normal population distributions is not satisfied [38]. The null and alternative hypotheses for testing the differences between two mean speed measures, μ_1 and μ_2 for the Mann–Whitney U Test are:

- Null Hypothesis (H_0): The two sample distributions are drawn from the same population, or $H_0: \mu_1 - \mu_2 = 0$
- Alternative Hypothesis (H_a): The two sample distributions are drawn from two different populations, or $H_0: \mu_1 - \mu_2 \neq 0$.

To obtain the test statistic, the two samples are combined, and all the observations are ranked from smallest to largest (ties are assigned the average rank of the tied observations). The smallest observation is indexed with 1 and the largest observation with n . The U statistic is defined as follows:

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

where:

- R_1 = sum of the ranks from sample 1;
- n_1 = sample size of population 1;
- n_2 = sample size of population 2.

The U statistic is a measure of the difference between the ranks of two samples. Based on the assumption that only mean differences exist between two populations, a large or small value of the test statistic provides evidence of a difference in the location of the two populations. For large samples, the distribution of the U statistic is approximated by the normal distribution. The convergence to the normal distribution is rapid, such that for $n_1 \geq 10$ and $n_2 \geq 10$ there is a satisfactory normal approximation. The mean of U is given by:

$$E(U) = \frac{n_1 n_2}{2}$$

The standard deviation of U is given by:

$$\sigma_U = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}} - R_1$$

and the large sample test statistic is given by:

$$Z^* = \frac{U - E(U)}{\sigma_U}$$

The p-value associated with the Mann–Whitney U test is an indicator of the statistical significance of the posted speed limit increase in mean speed. A low p-value (i.e., less than or equal to 0.05) indicates a high probability that the difference in the posted speed limit influenced the mean speeds between two data collection periods. The Z^* -statistic and p-value were computed for each TMC at the 95 percent confidence level [38].

3.2.4 Statistical Hypothesis Test: F-test

The two-sided F-test was used to determine if the differences in speed variance measures were statistically significant. Statistically significant changes in speed variance indicate that the observed speeds are different in the two-time periods being compared [38]. In this research, the null and alternative hypotheses for testing the differences in two variance speed measures, σ_1^2 and σ_2^2 , are:

- Null Hypothesis (H_0): No change in speed variance as a result of the 65 to 70 mph posted speed limit increase, or $H_0: \sigma_1^2 - \sigma_2^2 = 0$
- Alternative Hypothesis (H_a): A change in speed variance as a result of the 65 to 70 mph posted speed limit increase, or $H_a: \sigma_1^2 - \sigma_2^2 \neq 0$.

For each TMC, an F-statistic was calculated between two data collection periods, before vs. after the increase in maximum PSL. The F-statistic is given by:

$$F_{(n_1-1, n_2-1)} = \frac{s_1^2}{s_2^2}$$

where:

- s_1, s_2 = standard deviation of the samples for the before and after periods;
- n_1, n_2 = sample size of before and after periods.

The p-value associated with the F-statistic is an indicator of the statistical significance of the posted speed limit increase on mean speed. A low p-value (i.e., less than or equal to 0.05) indicates a high probability that the difference in the posted speed limit influenced the speed variance between two data collection periods. F-statistic and p-value were computed for each TMC at the 95 percent confidence level.

4. DATA ANALYSIS

4.1 Impact of Posted Speed Limit Increase on Traveling Speed

4.1.1 VSPOC and NPMRDS Comparisons

First, VSPOC speeds are compared to NPMRDS for validity. Previous experience comparing travel times or speeds from various data collection methods indicate that probe sources are closely representative of ground truth given sufficient traffic volumes and sampling. Furthermore, GPS-probe sources are more internally consistent since they are not subject to differences in field hardware setup, poor calibration, or undocumented recalibration. Comparing the two data sets had a purpose of validating this understanding and checking for spatial discrepancies.

TMCs which had both NPMRDS data and VSPOC detectors available were used to compare NPMRDS and VSPOC data. Three trends were identified after calculating the error statistics and the Theil proportions:

a. Good Match

Figure 9 shows an example of a good match between VSPOC and NPMRDS speed data. In this specific example, slower speeds often relate to Sunday afternoon congestion. This fit can also be found by noting the low value of U . U^M (bias) is also low indicating that both series do not deviate much from each other.

MAE	RMSE	U	U^M	U^S	U^C	SUM
0.5260	3.9316	0.0306	0.0179	0.0138	0.9377	1.0000

VSPOC and NPMRDS Speed Comparison
Dane Co, I-39/90 SB, TMC 107P04686 (08/2015)

Figure 9: Good Match Between VSPOC and NPMRDS Speed

b. With Bias

Figure 10 shows an example of a clear bias in the distribution between VSPOC and NPMRDS speed data. Although U remains relatively low, MAE is higher, and U^M is quite high, indicating that both series deviate from each other to a significant extent, hence a notable bias is present. This bias might be due to loop miscalibration, which is common and can have severe effects. In this case, observing the close agreement between data sources at the same location in the opposite direction suggests equipment calibration issues.

MAE	RMSE	U	U^M	U^S	U^C	SUM
7.3980	8.4424	0.0621	0.7679	0.0037	0.1664	1.0000

Figure 10: Bias Between VSPOC and NPMRDS Speed

c. Moderate Match

Figure 11 shows an example of these data on a day with a major crash and lane closures, hence the slow speed values. It also shows some bias between VSPOC and NPMRDS speed data. VSPOC speeds trend slightly higher than those of NPMRDS, but the statistics indicate that they are in moderately close agreement.

MAE	RMSE	U	U ^M	U ^S	U ^C	SUM
4.2622	10.6866	0.0850	0.1591	0.1294	0.6266	1.0000

Figure 11: Moderate Match Between VSPOC and NPMRDS Speed

Table 4 summarizes the range for each statistic conducted to compare VSPOC and NPMRDS data. U and U^M are the two most important statistics since they predict validity between both data sources.

Table 4: VSPOC and NPMRDS Comparison Statics

	Min	Median	Max
MAE	0.38	4.80	34.94
RMSE	8.11	16.35	48.76
U	0.060	0.133	0.448
U^M	< 0.001	0.076	0.811
U^S	< 0.001	0.267	0.638
U^C	0.019	0.489	0.839

$N = 43$

A good match between VSPOC and NPMRDS data was found for 79.7% of the segments with a bias proportion U^M less than 0.2, which was also noted with the low U (less than 0.2) for 72.1% of the segments. Since VSPOC coverage alone is much more limited, this research

proceeds with utilizing the widespread NPMRDS data, but with the understanding of its differences and limitations.

4.1.2 NPMRDS Speed Analysis

For the 455 TMCs with increased PSL, a summary of statistics for the period of March 2014 to June 2016 is shown in Table 5.

Table 5: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Distance (miles)	3.27	2.53	0.10	13.66
20 th Percentile Speed (mph)	60.66	2.73	32.44	67.62
50 th Percentile Speed (mph)	63.60	2.17	45.06	77.52
80 th Percentile Speed (mph)	67.09	2.54	54.48	77.89
Interquartile Range (mph)	4.99	1.73	0	24.96
Average Speed (mph)	63.63	2.47	44.88	71.10
Standard Deviation (mph)	5.20	1.38	2.14	15.81

Figure 12 shows a scatterplot of the 579 TMCs under study. An increase of 5 mph in the PSL did not lead to an increase of 5 mph in the average traveling speed. The largest change in speed magnitudes is attributed to work zones effects rather than the increased PSL. Segments with increased PSL had a change in the of 1-3 mph range, while the remaining segments (Milwaukee area) had slight increase in the 0-1 mph range.

Figure 12: Before/After Speed Plot of All Segments

For segments with PSL change, the mean speed increased between 0.8 and 2.8 mph for all vehicles in the study sample, while that of TMCs without a PSL change (Milwaukee area) increased on average by 0.8 mph. For segments with PSL change, the average standard deviation was 5.25 mph, while that of TMCs without a PSL change was 5.82 mph. The Metrics for a typical segment are shown month by month in Figure 13. A small increase in most metrics is evident after the increase of PSL, indicated by the gray vertical bar.

Figure 13: Typical Example of Metrics for a Segment

Some segments showed a seasonal cyclical pattern in speed distributions. A cumulative distribution function (CDF) was plotted to depict this variation. Figure 14 shows an example of seasonal variation which shows slower speeds in winter and higher speeds in summer. To control for the seasonal effects (along with weather effect), the analysis was conducted for the same 11-month period before (July 2014 – May 2015) and after (July 2015 – May 2016) the increase of the PSL.

Figure 14: Example of Seasonal Variation in Passenger Vehicle Speeds

In addition to seasonal variation, the effects of work zones were identified for some segments. Figure 15 shows an example of a segment with work zone effects.

Figure 15: Example Segment with Work Zone Effects

Some segments were clearly affected by work zones while others were not. This research did not verify locations of work zones through the lane closure records, and hence did not look at their effect on operating speed. Instead, an additional parameter was calculated: the shift from the monthly median speed observations. For each segment, the maximum shift in median speed over the months of data observed is identified. Figure 16 shows the maximum shift of speed for all 579 TMCs, of which 22.8% had a shift greater than 2.5 mph. For the comparison TMCs, 25.8% had a shift greater than 2.5 mph, while 22.0% of the TMCs with increased PSL had a shift greater than 2.5 mph. This 2.5 mph threshold is carried forward in subsequent plots.

Figure 16: Maximum Speed Shift for Each TMC

4.1.3 Non-Parametric Test: Mann-Whitney U Test (MWW test)

Figure 17 shows the p-values obtained from the MWW test conducted for each TMC at the two periods: before and after increasing the PSL.

Figure 17: P-value (of Mann–Whitney U Test) for Each TMC’s Speed Change

Figure 18 shows the p-values obtained from the MWW test conducted for the comparison TMCs at the two periods: before and after increasing the PSL. For a very small number of TMCs (10 of the 124 TMCs), the null hypothesis is retained ($p\text{-value} > 0.05$), which means there is not enough evidence from the current sample of speeds to indicate that the mean speed differs between the before and after periods. For the rest of the TMCs, the null hypothesis is rejected ($p\text{-value} < 0.05$). Segments with greater values of shift are the more likely work zone effects, particularly the large negative changes in speed.

Figure 18: Comparison TMCs MWW test Results

Figure 19 shows the p-values obtained from the MWW test conducted for the 455 TMCs with an increase in the PSL between the two 11-month periods. For a very small number of TMCs (9 of the 455 TMCs), the null hypothesis is retained ($p\text{-value} > 0.05$), which means there is insufficient evidence from the current sample of speeds to indicate that the speed mean differs between the before and after periods. For the rest of the TMCs, the null hypothesis is rejected ($p\text{-value} < 0.05$), which means there is sufficient evidence from the sample to indicate that the speeds differ, and that a speed comparison is statistically significant at the 95 percent confidence level. This difference is reasonably attributed to the increase in posted speed limit from 65 to 70 mph when comparing the before and after periods, which could mean that drivers are adapting to the new posted speed. For segments with increased posted speed limit from 65 to 70 mph, the mean speed increased between 0.8 and 2.8 mph for all vehicles in the study

sample. For the comparison area (Milwaukee area), the mean speed increased on average by 0.8 mph.

Figure 19: P-value (of t-test) for each TMC's Speed Change

21% of TMCs with statistically significant mean difference had a maximum shift greater than 2.5 mph. Most TMCs with maximum shift greater than 2.5 mph had a noticeable work zone effect. Hence, the statistically significant mean difference may either be attributed to the work zone effects or to the increase in the posted speed limit.

4.1.4 Statistical Hypothesis Test: F-test

Figure 20 shows the p-values obtained from the F-test conducted for each TMC at the two periods: before and after increasing the PSL. For a very small number of TMCs, the null hypothesis is retained ($p\text{-value} > 0.05$), which means there is not enough evidence from the current sample of speeds to indicate that the variance speed differs between the before and

after periods. for the rest of the TMCs, the null hypothesis is rejected ($p\text{-value} < 0.05$), which means there is enough evidence from the sample to indicate that the variance speed differs, and a speed comparison is statistically significant at the 95 % confidence level.

Figure 20: P-value (of F-test) for Each TMC's Speed Change

4.2 Impact of Posted Speed Limit Increase on Safety

One method to investigate the effects of increasing speed on safety impacts is a before and after study using crash rates (the combination of crash frequency and traffic volumes). Several segments had missing volume data in VSPOC or no data at all, which did not allow the computation of crash rates. For this reason, safety impact of raising the speed limit was investigated with a before and after study using crash frequency. Appendix 7.1 to 7.8 show the data used to analyze the crash data for the before and after period.

Each section in the appendix also shows a box plot that summarizes the data for each segment. For each segment identified in Table 3, a summary of statistics for the before and after periods is shown in Table 6.

Table 6: Summary Statistics for Crash Data

Segment (year included)	Sample size (Before)	Monthly Average Crashes (Before)	Sample Size (After)	Monthly Average Crashes (After)	Mann Whitney U test	p-value	Statistically Significant Difference?
I-39/90 (2016)	125	86.032	18	116.7222	423	1.95E-05	yes
I-39-90 (2017)	125	86.032	27	112.6667	704	2.14E-06	yes
I-41 (2016)	125	105.944	18	94.55556	1093	0.84794026	no
I-41 (2017)	125	105.944	27	100.037	1492	0.347103098	no
I-43 (2016)	125	51.624	18	58.11111	729.5	0.016176986	yes
I-43 (2017)	125	51.624	27	56	1150	0.009606415	yes
I-43M (2016)	125	58.424	18	60.72222	866	0.115546903	no
I-43M (2017)	125	58.424	27	58.14815	1479	0.315836515	no
I-535 (2016)	125	1.568	18	1.833333	1001	0.435899086	no
I-535 (2017)	125	1.568	27	1.814815	1426	0.192794446	no
I-794 (2016)	125	0.448	18	0.833333	819	0.028648972	yes
I-794 (2017)	125	0.448	27	0.851852	1148.5	0.002630548	yes
I-894 (2016)	125	22.312	18	0.222222	2239	1.16E-11	yes
I-90 (2016)	125	15.136	18	10.77778	1313	0.25311944	no
I-90 (2017)	125	15.136	27	11.07407	1870	0.379539648	no
I-94 (2016)	125	105.168	18	107.1667	854	0.099661318	no
I-94 (2017)	125	105.168	27	101.9259	1395	0.159172482	no
I-94M (2016)	125	7.592	7	1.571429	819	0.000101565	yes

Figure 21 shows the difference in the average crashes for the before and after periods. Segments with small differences in the number of monthly average crashes are those that have no statistically significant difference between the before and after periods.

Figure 21: Monthly average Crashes for the Before and After Speed Limit Increase periods

Figure 22 shows the p-values obtained from the MWW test conducted for the monthly crash data at the two periods: before and after increasing the PSL, using 2016 data for the after period. For 50% of the segments, the null hypothesis is retained ($p\text{-value} > 0.05$), which means there is not enough evidence from the current sample of crash data to indicate that the number of crashes differ between the before and after periods. For the other half of the segments, the null hypothesis is rejected ($p\text{-value} < 0.05$).

Figure 22: Monthly average Crashes Difference Between Before and After Speed Limit Increase using 2016 Data

Figure 23 shows the p-values obtained from the MWW test conducted for the monthly crash data at the two periods: before and after increasing the PSL, using the preliminary 2017 data in addition to 2016 data. For 62.5 % of the segments, the null hypothesis is retained (p-value > 0.05), which means there is not enough evidence from the current sample of crash data to indicate that the number of crashes differ between the before and after periods. for the remaining 37.5% of segments, the null hypothesis is rejected (p-value < 0.05).

Figure 23: Monthly average Crashes Difference Between Before and After Speed Limit Increase using 2017 Data

5. CONCLUSION

During the week of June 16, 2015, the posted speed limit on most of the Interstate system in Wisconsin was increased from 65 to 70 mph. Segments in the Milwaukee area (I-794, I-984, I-94 and I-43) as well as I-535 were excluded from this increase.

For segments with PSL change, the mean speed of all vehicles in the study sample increased between 0.8 and 2.8 mph, while that of TMCs without a PSL change (Milwaukee area) increased on average by 0.8 mph. These values are consistent with the literature review in chapter 2.

Generally, the NPMRDS were valid compared to the VSPOC data. They were more consistent along interstates. Where a bias was present, it could likely be attributable to detector calibration. Seasonal effects were present in many segments. Seasonal trends were mitigated by using isochronal 11-month periods before and after the PSL. More pronounced work zone effects existed in several segments. Probable work zones were flagged by using a 2.5 or 5.0 mph threshold in the month to month median speed shift observed in the data, and indicated on graphics as such.

For TMCs with and without a PSL change, the Mann-Whitney U Test was conducted. Most TMCs for both cases had a p-value less than 0.05, meaning that enough evidence exists from the sample to indicate that the speeds differ, and that a speed comparison is statistically significant at the 95 percent confidence level. 21% of TMCs with statistically significant mean difference had a maximum median shift greater than 2.5 mph. These TMCs had a noticeable

work zone effect. Hence, the statistically significant mean difference may be attributed to the work zone effect or to the increase in the posted speed limit.

For most TMCs, the F-test results showed a p-value less than 0.05, which means that there is enough evidence from the sample to indicate that the variance speed differs, and that a speed comparison is statistically significant at the 95 percent confidence level.

Using data up until 2016 resulted in a small sample size for the after period (12 data points). For segments with and without a PSL change (Milwaukee area), the Mann-Whitney U Test was conducted. For both cases, 50% of the segments had a p-value less than 0.05, meaning that enough evidence exists from the sample to indicate that the average number of monthly crashes differs between the before and after periods, and that a crash comparison is statistically significant at the 95 percent confidence level.

Using data up until 2017 also resulted in a relatively small sample size for the after period (27 data points). Conducting the Mann-Whitney U Test for segments with and without a PSL change indicated that 43% of the segments had a p-value less than 0.05, meaning that enough evidence exists from the sample to indicate that the average number of monthly crashes differs between the before and after periods, and that a crash comparison is statistically significant at the 95 percent confidence level. As for the remaining 57% of the segments, the Mann-Whitney U Test did not show any difference in the average number of monthly crashes. Only one segment in the Milwaukee area had data for 2017, and it showed no statistically significant difference between the before and after periods. Using the before and after analysis does not establish a cause and effect relationship between increasing the PSL and the increase in the average number of crashes. Hence, it is not clear whether the increase in the average

monthly crashes was due to increasing the PSL or due to other factors such as weather, alcohol, distraction or others.

5.1 Future Research/Work

To isolate trends seen in NPMRDS, such as general shifts over time, or annual or seasonal cyclical patterns, a subset of locations with additional data collection should be used. Moreover, additional characteristic trends in the speed data should be identified to isolate any confounding effects.

As discussed previously, several segments had work zones effects. Connecting speed data to work zone data from the Wisconsin Lane Closure System (WisLCS) will greatly increase the control for work zone effects, while establishing effects of work zones and their posted speeds.

Geographic transition areas around PSL changes should be further investigated, which may require more spatially granular data than what is available in NPMRDS.

Increasing the sample size for the after period resulted in increasing the percentage of segments that showed no statistically significant difference in the average number of monthly crashes between the before and after periods. This result emphasizes the fact that increasing the sample size results in increasing the power of the statistical test. Hence, to have a better depth in the analysis, further investigation should be carried out for the crash analysis in time. Analysis can also be done using other methodologies such as the negative binomial model, Bayesian approach, or other. Segments that showed a statistically significant difference in the average number of monthly crashes should be further investigated to better attribute the difference to the increase in posted speed limit or to other factors such as weather, alcohol or

others. Crash severity analysis should also be carried out to check whether there was a statistically significant increase in fatalities or crash severities.

6. REFERENCE

- [1] National Research Council (U.S.), Ed., *Managing speed: review of current practice for setting and enforcing speed limits*. Washington, D.C: Transportation Research Board, National Research Council, National Academy Press, 1998.
- [2] National Research Council (U.S.), Ed., *Managing speed: review of current practice for setting and enforcing speed limits*. Washington, D.C: Transportation Research Board, National Research Council, National Academy Press, 1998.
- [3] A. Dutta and D. A. Noyce, "Impacts of Raising Speed Limits on Traffic Safety." [Online]. Available: http://www.topslab.wisc.edu/workgroups/TSC/Speed_Limit_Lit_Review-Updated_071405.pdf. [Accessed: 24-Aug-2017].
- [4] "Speed Concepts: Informational Guide - Safety | Federal Highway Administration." [Online]. Available: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa10001/. [Accessed: 05-Dec-2017].
- [5] W. C. Taylor, "THE IMPACT OF RAISING THE SPEED LIMIT ON FREEWAYS IN MICHIGAN.," 2000.
- [6] "Wisconsin Legislature: AB27: Bill Text." [Online]. Available: http://docs.legis.wisconsin.gov/2015/related/proposals/ab27/_19. [Accessed: 24-Aug-2017].
- [7] "Wisconsin Legislature: 2015 Wisconsin Act 19." [Online]. Available: <https://docs.legis.wisconsin.gov/2015/related/acts/19>. [Accessed: 24-Aug-2017].
- [8] N. V. Malyshkina and F. L. Mannering, "Analysis of the Effect of Speed Limit Increases on Accident-Injury Severities," *arXiv preprint arXiv:0806.1354*, 2008.
- [9] M. DETROIT, W. TRIM, and O. AKRON, "Evaluating the Impacts of Speed Limit Policy Alternatives," 2014.
- [10] K. Kockelman, J. Bottom, Y. Kweon, J. Ma, and X. Wang, *Safety impacts and other implications of raised speed limits on high-speed roads*. Transportation Research Board, 2006.
- [11] Y. M. Najjar, R. W. Stokes, E. R. Russell, H. E. Ali, and X. C. Zhang, "Impact of new speed limits on Kansas highways," Kansas Department of Transportation Topeka, KS, 2000.
- [12] Insurance Institute for Highway Safety, "Map of maximum posted speed limits on rural interstates." [Online]. Available: <http://www.iihs.org/iihs/topics/laws/speedlimits/mapmaxspeedonruralinterstates?topicName=Speed#map>. [Accessed: 07-Sep-2017].
- [13] J. Upchurch, "Arizona's experience with the 65-mph speed limit," *Transportation Research Record*, vol. 1244, pp. 1–6, 1989.
- [14] J. D. Jernigan, *Impact of the 65 Mph Speed Limit on Virginia's Rural Interstate Highways, 1989-1992*. Virginia Transportation Research Council, 1994.
- [15] D. B. Brown, S. Maghsoodloo, and M. E. McArdle, "The safety impact of the 65 mph speed limit: a case study using Alabama accident records," *Journal of Safety Research*, vol. 21, no. 4, pp. 125–139, 1990.
- [16] D. J. Mace and R. Heckard, "Effect of the 65 MPH Speed Limit on Travel Speeds and Related Crashes. Final Report," 1991.

- [17] Wisconsin Department of Transportation (WisDOT), “Speed limits in Wisconsin after repeal of the national maximum speed limit,” Jan. 1996.
- [18] Wisconsin Department of Transportation (WisDOT), “Report on raising speed limits in Wisconsin from 55 mph to 65 mph.”
- [19] P. McCarthy, “Effect of speed limits on speed distributions and highway safety: a survey of recent literature,” *Transport Reviews*, vol. 21, no. 1, pp. 31–50, 2001.
- [20] E. M. Ossiander and P. Cummings, “Freeway speed limits and traffic fatalities in Washington State,” *Accident Analysis & Prevention*, vol. 34, no. 1, pp. 13–18, 2002.
- [21] N. Alemazkoor and H. Hawkins, “Examining Impacts of Increasing Speed Limit on Speed Distribution: Case Study,” in *Transportation Research Board 93rd Annual Meeting*, 2014.
- [22] W. Hu and A. T. McCartt, “Raising the Speed Limit from 75 to 80 mph on Utah Rural Interstate: Effects on Vehicle Speeds,” in *Transportation Research Board 93rd Annual Meeting*, 2014.
- [23] E. T. Donnell and B. Hamadeh, “70 mph Study,” Pennsylvania Transportation Institute.
- [24] T. Epperlein, “The impact of the 65 mph speed limit in Arizona,” *Arizona: Arizona Statistical Analysis Center*, 1989.
- [25] M. M. Gallaher *et al.*, “Effects of the 65-mph speed limit on rural interstate fatalities in New Mexico,” *Jama*, vol. 262, no. 16, pp. 2243–2245, 1989.
- [26] L. S. Friedman, D. Hedeker, and E. D. Richter, “Long-term effects of repealing the national maximum speed limit in the United States,” *American Journal of Public Health*, vol. 99, no. 9, pp. 1626–1631, 2009.
- [27] C. M. Farmer, “Relationship of traffic fatality rates to maximum state speed limits,” *Traffic injury prevention*, vol. 18, no. 4, pp. 375–380, 2017.
- [28] C. Lave and P. Elias, “Did the 65 mph speed limit save lives?,” *Accident Analysis & Prevention*, vol. 26, no. 1, pp. 49–62, 1994.
- [29] S. Binkowski, T. Maleck, W. Taylor, and T. Czewski, “Evaluation of Michigan 70-mph speed limit,” *Transportation Research Record: Journal of the Transportation Research Board*, no. 1640, pp. 37–46, 1998.
- [30] R. R. Souleyrette, T. B. Stout, and A. Carriquiry, “Evaluation of Iowa’s 70 Mph Speed Limit: 2.5 Year Update,” Center for Transportation Research and Education, Iowa State University, 2009.
- [31] P. Quinn and A. L. Schneider, “New Law: See Which Highways Will Have a 70 MPH Speed Limit on Jan. 1,” 30-Dec-2013. [Online]. Available: <https://patch.com/illinois/stcharles-il/new-law-see-which-highways-will-have-a-70-mph-speed-limit-stcharles-il>. [Accessed: 07-Sep-2017].
- [32] K. Harder and J. Bloomfield, “Evaluating the Effectiveness of the Minnesota Speed Management Program,” 2007.
- [33] G. Manning and C. Grossman, “Joint Legislative Task Force on Department of Transportation Issues,” Dec. 2015.
- [34] “Traffic Operations and Safety Laboratory - ITS.” [Online]. Available: <http://www.topslab.wisc.edu/its/topms/data/>. [Accessed: 25-Aug-2017].
- [35] “MAE and RMSE — Which Metric is Better?,” *Human in a Machine World*, 23-Mar-2016. .

- [36] J. D. Sterman, “Appropriate summary statistics for evaluating the historical fit of system dynamics models,” *Dynamica*, vol. 10, no. 2, pp. 51–66, 1984.
- [37] E. L. Lehmann and H. D’abrera, *Nonparametrics: statistical methods based on ranks*. Holden-Day, 1975.
- [38] S. P. Washington, M. G. Karlaftis, and F. Mannering, *Statistical and econometric methods for transportation data analysis*. CRC press, 2010.

APPENDICES

Appendix A I-90

Crash data for I-90 collected by month:

I-90	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	24	17	23	63	30	36	59	30	20	32	37	11	24
Feb	22	35	22	44	8	29	14	12	23	27	15	13	7
Mar	22	27	16	17	27	7	14	5	12	18	11	15	11
Apr	3	11	10	7	5	10	17	9	14	6	6	7	15
May	9	12	10	9	4	0	7	4	2	9	2	7	9
Jun	10	6	4	5	9	8	8	8	17	9		6	11
Jul	18	8	7	9	3	18	13	12	7	17	5	10	13
Aug	11	8	7	2	9	9	9	3	13	8	3	6	8
Sep	8	6	11	9	3	9	6	8	5	12	4	12	7
Oct	9	5	3	3	6	5	6	3	12	6	4	5	
Nov	44	8	6	27	7	7	12	11	24	26	17	18	
Dec	18	7	71	68	41	32	27	30	45	7	25	26	

Box plot for I-90 data:

Appendix B I-41

Crash data for I-41 collected by month:

I-41	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	203	94	163	326	198	88	218	144	158	255	213	101	162
Feb	165	125	128	305	160	153	213	110	158	162	101	89	117
Mar	121	96	103	98	113	49	122	56	116	137	79	137	155
Apr	43	64	110	79	63	71	99	49	77	83	67	64	69
May	73	74	80	76	69	49	58	48	60	73	59	92	78
Jun	104	63	70	61	62	73	74	62	63	64		91	115
Jul	89	79	77	73	86	98	66	53	69	77	40	93	103
Aug	84	73	84	94	72	64	60	64	69	81	52	105	119
Sep	76	72	63	61	66	71	59	64	73	72	74	80	81
Oct	92	52	81	64	91	83	66	84	73	82	64	97	
Nov	178	88	105	116	75	72	84	56	107	167	75	92	
Dec	156	126	278	414	224	228	103	159	286	114	128	228	

Box plot for I-41 data:

Appendix C I-43

Crash data for I-43 collected by month:

I-43	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	83	52	83	136	113	32	115	71	64	168	75	81	69
Feb	66	51	82	192	94	79	114	47	95	115	51	60	49
Mar	72	48	67	57	59	12	64	54	62	53	44	75	76
Apr	22	35	51	30	29	26	35	23	37	52	26	47	29
May	32	38	38	33	27	20	35	29	33	34	31	46	44
Jun	42	39	33	34	31	26	25	26	23	34		35	50
Jul	43	43	32	32	37	54	25	24	33	26	50	54	49
Aug	37	37	35	23	28	43	34	36	33	33	56	57	54
Sep	45	41	48	26	30	35	48	22	33	33	33	53	46
Oct	38	35	40	44	37	37	28	31	24	36	46	43	
Nov	87	54	51	59	31	36	40	26	64	65	54	53	
Dec	94	49	159	184	114	64	48	69	107	54	71	132	

Milwaukee Area:

I-43 M	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	96	48	116	110	110	26	128	57	88	81	122	56	39
Feb	64	64	81	80	84	48	80	17	75	76	101	63	40
Mar	35	28	55	84	39	43	23	15	45	50	52	58	68
Apr	38	39	58	33	35	62	65	35	44	50	34	53	48
May	53	54	43	41	43	54	42	36	48	44	53	63	68
Jun	58	46	44	48	31	66	49	33	45	53		63	66
Jul	49	51	43	45	31	57	48	48	45	45	52	52	52
Aug	47	36	71	59	46	38	44	72	50	51	54	50	55
Sep	69	63	52	49	56	51	50	56	39	53	67	59	41
Oct	54	56	68	50	64	63	54	77	49	68	63	56	
Nov	61	57	70	80	55	61	56	44	67	61	64	48	
Dec	87	82	105	156	66	95	43	78	100	64	80	92	

Box plot for I-43 data:

Appendix D I-39/90

Crash data for I-39/90 collected by month:

I-39/90	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	224	63	127	309	162	72	179	132	114	209	192	96	115
Feb	112	93	162	329	83	96	141	72	107	149	112	102	70
Mar	85	87	119	80	82	42	67	42	84	87	81	159	86
Apr	36	55	59	43	33	41	74	49	61	38	52	105	73
May	51	72	52	47	42	60	47	52	54	65	85	85	112
Jun	57	51	63	57	53	51	57	69	55	65		97	131
Jul	88	79	73	69	70	85	80	71	88	82	110	131	150
Aug	67	61	85	54	64	62	68	69	93	85	107	146	122
Sep	54	62	68	42	54	48	62	61	60	80	88	126	82
Oct	66	69	56	51	50	40	40	62	57	50	84	115	
Nov	132	62	68	67	42	67	66	50	72	112	92	109	
Dec	154	79	272	219	164	145	86	134	223	74	136	213	

Box plot for I-39/90 data:

Appendix E I-94

Crash data for I-94 collected by month:

I-94	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	216	110	162	211	163	115	246	132	128	182	201	97	104
Feb	141	125	179	278	90	127	175	92	142	195	87	119	63
Mar	171	137	116	135	78	63	96	54	121	84	59	118	101
Apr	61	61	97	78	56	53	68	39	96	84	57	91	87
May	65	78	75	71	77	30	45	80	85	68	96	70	101
Jun	88	80	102	73	80	85	49	72	90	78		104	83
Jul	104	110	117	92	69	111	89	74	79	116	92	98	98
Aug	90	105	101	68	70	75	78	74	66	96	121	93	110
Sep	99	79	84	59	68	72	79	73	68	62	73	90	76
Oct	79	87	84	79	84	77	58	89	71	64	94	89	
Nov	157	81	82	128	54	97	73	73	120	162	113	109	
Dec	197	103	309	327	157	198	118	154	256	73	130	228	

Milwaukee Area:

I-94 M	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	12	6	10	6	22	4	13	13	11	14	17		
Feb	13	11	9	14	6	19	16	1	6	11	15		
Mar	6	12	7	8	10	5	3	5	10	8	4		
Apr	10	10	4	5	7	6	7	1	4	3	2		
May	5	8	5	4	6	7	5	4	6	8	0		
Jun	8	12	6	12	5	5	4	8	5	4			
Jul	12	7	5	4	6	8	10	4	9	2	0	1	
Aug	7	4	12	2	8	4	7	8	6	4	4		
Sep	5	11	9	3	5	9	7	1	3	4	1		
Oct	5	4	6	10	5	5	6	4	4	6	1		
Nov	11	3	10	12	6	6	3	1	5	5	0		
Dec	12	20	27	16	13	9	6	8	18	4	4		

Box plot for I-94 data:

Appendix F I-535

Crash data for I-535 collected by month:

I-535	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	9	0	2	0	5	2	5	5	8	12	8	3	4
Feb	0	3	2	2	0	2	0	1	0	2	1	0	1
Mar	1	1	3	1	2	2	1	1	0	3	2	0	2
Apr	0	0	0	1	1	0	0	1	1	2	2	0	1
May	0	0	1	3	1	0	0	1	0	1	1	1	0
Jun	0	2	0	0	0	0	0	0	0	0		2	2
Jul	3	0	1	1	3	0	3	0	1	1	1	1	3
Aug	1	0	3	0	4	0	2	0	1	3	2	2	1
Sep	1	0	1	1	0	1	1	0	2	1	3	0	2
Oct	0	1	0	0	1	1	1	0	3	2	1	0	
Nov	1	0	2	0	2	1	3	2	1	5	6	1	
Dec	0	2	9	7	1	2	1	2	5	2	3	7	

Box plot for I-535 data:

Appendix G I-794

Crash data for I-794 collected by month:

I-794	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	3	1	0	0	2	0	0	0	0	1	0	1	1
Feb	1	0	1	0	0	0	1	0	0	0	1	1	0
Mar	2	1	0	1	0	0	2	0	0	0	1	1	1
Apr	0	0	0	0	0	0	0	0	0	2	0	1	1
May	1	1	1	0	0	0	0	0	0	1	0	0	1
Jun	0	1	0	0	0	0	0	3	0	0		1	1
Jul	1	1	0	0	0	3	0	0	1	0	0	1	2
Aug	0	1	0	0	0	2	0	1	0	0	1	0	1
Sep	1	2	0	0	0	0	0	3	0	0	0	0	0
Oct	1	0	0	0	0	0	1	0	0	0	0	1	
Nov	1	1	0	0	0	0	0	1	1	0	0	3	
Dec	1	0	2	0	0	1	1	0	0	1	1	3	

Box plot for I-794 data:

Appendix H I-894

Crash data for I-894 collected by month:

I-894	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan	37	26	36	40	39	15	26	16	18	55	15		
Feb	25	23	26	27	26	26	30	5	23	29	14		
Mar	18	20	25	25	13	19	17	11	10	14	10	1	
Apr	14	35	29	21	16	16	16	10	17	17	4		
May	19	20	12	12	15	24	16	16	24	21			
Jun	30	22	18	19	10	17	18	31	23	20			
Jul	28	18	28	22	14	25	17	20	15	19			
Aug	27	27	23	26	24	24	28	21	19	26			
Sep	27	18	25	16	12	27	16	18	30	20			
Oct	21	36	31	18	24	36	21	19	24	22	1		
Nov	32	32	28	17	23	23	26	25	32	20		1	
Dec	31	39	35	21	26	35	21	25	24	21	1		

Box plot for I-894 data: