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Final Report

SPEED LIMIT RECOMMENDATION IN VICINITY OF SIGNALIZED, HIGH-SPEED INTERSECTION

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16. Abstract

We evaluated the traffic operations and safety effects of 5 mph and 10 mph speed limit reductions in the vicinity of high-speed, signalized intersections with advance warning flashers (AWF). Traffic operational effects of the reduced speed limits were analyzed for seven high-speed, signalized intersections with AWF using the Quantile regression model and Seemingly Unrelated Regression Estimation (SURE). Change of speed limit from 60 mph to 55 mph did not lead to any statistically significant reduction in 15th, 50th, or 85th percentile. The reduction from 65 mph to 55 mph hour led to a 4.6 mph reduction in 85th percentile speed; also, the speed dispersion based on inter-percentile range between 15th and 85th percentiles was reduced by 1.8 mph. About the mean and standard deviation of speed estimated by SURE, the only statistically significant impact is from the speed limit reduction of 10 mph from 65 mph, which reduced the mean speed of vehicles by 3.8 mph at the significance level of 95%. In the safety effect study, a crash analysis based on 56 approaches from 28 intersections was performed. The 10 mph speed limit reduction from 65 to 55 mph was found to reduce, on an average, 0.4 crashes per approach per year with 90% percent level of confidence while the 5 mph reductions in the dataset was found to reduce, on an average, 0.6 crashes per approach per year with 95% significance level. Also, the studied approaches with 10 mph reduction were found to have a lower probability of possible injury crashes and a higher probability of property damage crashes with a 90% level of confidence. The 5 mph reductions in this dataset did not show any significant effect on reducing crash severity. It was also found that lower speed limits in vicinity of the signalized intersection reduced the probability of fatal and injury crashes.

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List of Abbreviations

Advance Warning Flashers (AWF)
Average Daily Traffic (ADT)
Dynamic Message Signs (DMS)
Federal Highway Administration (FHWA)
Generalized Least Squares Method (GLS)
Intelligent Transportation Systems (ITS)
Inter-Percentile Range (IPR)
Linear Discriminant Analysis (LDA)
Manual of Uniform Control Devices (MUCTD)
Multinomial Logit Model (MNL)
National Maximum Speed Limit (NMSL)
Nebraska Department of Roads (NDOR)
Negative Binomial (NB)
Ordinary Least Squares Method (OLS)
Property Damage Only (PDO)
Quadratic Discriminant Analysis (QDA)
Seemingly Unrelated Regression Estimation (SURE)
Variable Speed Limit (VSL)
Wide Area Detector (WAD)
Zero-Inflated NB Model (ZINB)
Zero-Inflated Poisson Model (ZIP)

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Disclaimer

Abstract

This report presents the results of Nebraska Department of Roads (NDOR) research project SPR-P1 (11) M307, which evaluated the traffic operations and safety effects of 5 mph and 10 mph speed limit reductions in the vicinity of high-speed, signalized intersections with advance warning flashers (AWF).

The methodology involved two studies: 1) field study of the impact of speed limit reduction at seven high-speed intersections, 2) crash analysis using the 10-year history from 28 high-speed intersections.

In the field study, traffic operational effects of the reduced speed limits were analyzed for seven high-speed, signalized intersections with AWF, using the Quantile regression model and Seemingly Unrelated Regression Estimation (SURE). The Quantile regression models indicated that reduction of speed limit from 60 mph to 55 mph did not lead to any statistically significant reduction in the 15th, 50th, or 85th percentiles. It was found that a speed limit reduction from 65 mph to 55 mph led to a 4.6 mph reduction in 85th percentile speed. Also, the speed dispersion based on an inter-percentile range between 15th and 85th percentiles was reduced by 1.4 mph in the vicinity of the intersection. SURE was used to estimate the mean and standard deviation of grouped average speeds simultaneously. The SURE model was chosen to account for any potential correlations between the mean and standard deviation of speed. It was found that a speed limit reduction of 10 mph, when the upstream speed limit was 65 mph, reduced the mean speed of vehicles by 3.8 mph, or by six percent. This result was statistically significant at the 95% percent level of confidence. It was also found that reducing the speed limit by 5 mph when the speed limit was 60 mph did not produce any statistically significant reduction in mean speed.

In addition, the standard deviation of the speeds downstream of the speed limit sign was not statistically significantly different from the upstream for either 10 mph or 5 mph reductions.

In the second study, a crash analysis based on 56 approaches from 28 intersections was performed to study the safety effects of speed limit reductions. The dataset included four approaches of 10 mph reduction from 65 mph to 55 mph, seven approaches of 5 mph reduction from 60 mph to 55 mph, two approaches of 5 mph reduction from 55 mph to 50 mph, and 43 approaches with no limit reduction (i.e., the control group). The 10 mph speed reduction from 65 to 55 mph was found to reduce, on average, 0.4 crashes per approach per year with a 90% level of confidence. Also, the studied approaches with 10 mph reduction were found to have a lower probability of possible injury crashes and a higher probability of possible damage crashes with a 90% level of confidence. The 5 mph reductions from 60 mph to 55 mph and from 55 mph to 50 mph were found to reduce 0.6 crashes per approach per year at a 95% significance level. It was also found that lower speed limits in the vicinity of signalized intersections reduced the probability of fatal and injury crashes.

The conclusions of this study, however, are limited by the low number of intersections with speed limit reductions. For example, only two intersections with 10 mph reduction were available for the study, where the speed limit was reduced from 65 mph to 55 mph. Based on this dataset, for a highway with speed limit at 65 mph, the reduction to 55 mph at intersections with AWF has been found to reduce mean speed and crash frequency, and alleviate possible crashes in comparison to the intersections with only AWF. It is recommended that future research include other speed limit combinations, such as a 5 mph reduction from 65 mph to 60 mph, and utilize larger datasets to provide better generalizability and transferability of results. A before-and-after study could also provide partially controlled conditions to isolate the impacts of speed limit reduction.

Chapter 1 Introduction

1.1 Background Information

The National Safety Council reports motor vehicle crashes as the leading cause of unintentional injury deaths in the United States. The cost of motor vehicle collisions in 2006 totaled nearly $230.6 billion. Intersection crashes constitute 30% of all vehicle crashes, and they account for an average of 9,000 fatalities and 1.5 million injuries annually. Furthermore, among all intersection and intersection-related crashes in the United States in 2009, signalized intersections accounted for 52.3% (1). The safety concerns involving signalized intersections become critical for rural and suburban highways, since high-speed aggravates the severity of crashes.

The Nebraska Department of Roads (NDOR) is responsible for the operation of a large number of traffic signals on rural and suburban expressways throughout Nebraska. However, there is no documented policy on assigning speed limits on expressways in the vicinity of the traffic signals. The undocumented strategy generally adopted is that on some sections there are speed limit reductions in the vicinity of signalized intersections at highways with speed limit higher than 60 mph. For example, on certain sections of Highway 75 the speed limit decreases from 65 mph to 55 mph in the vicinity of signalized intersections. However, on Highway 34, west of Lincoln, the standard speed limit is 60 mph, with no speed limit reduction at the intersections of NW 48th Street and Highway 79. The effects of speed limit reduction on operation and safety are not adequately studied, and no documented guidelines are available. A compounding issue is that most of the intersections are equipped with advanced warning flashers (AWF) and a dilemma protection algorithm; therefore, there may be less need for speed reductions in these situations.

1.2 Research Objectives

The Manual of Uniform Control Devices (MUCTD) states that "Advance warning signs and other traffic control devices to attract the motorist's attention to a signalized intersection are usually more effective than a reduced speed limit zone" (3). However, the MUTCD is silent regarding recommendations of speed limit reduction in conjunction with AWF. For the past several years NDOR has used AWF at high-speed rural intersections that meet their criteria. The speed limit may or may not be reduced at these intersections, and this decision is made on engineering-based judgments. The current research aims to verify the effectiveness of speed limit reduction at rural, high-speed intersections equipped with the NDOR AWF system. This objective can be broken into two important issues:

1. How does a transitional speed limit influence safety at signalized, high-speed intersections with AWF?

The purpose of a transitional speed limit is to increase road safety. Speed limits can increase road users' safety in two ways: by a limiting function; and by a coordinating function. The limiting function is to set up a maximum speed along the road, which can reduce the chance and severity of collisions. For the coordinating function, a maximum speed limit can reduce the variance of speeds along the road, which can make the speed more uniform and increase road safety (4). For example, suppose the speed limit for the transition zone is reduced at a high-speed intersection, one possible consequence is that it separates drivers into two subsets: those who drive accordingly with lower speeds, and those who choose their own speeds, which are probably higher than the reduced limit. The resulting variance of driving speeds could be a potential trap for highway safety.

2. What is the recommended drop in the speed limit for transitional speed zones?

Given that the use of a transitional zone does result in increased safety for the traveling public, a second issue pertains to the appropriate level of speed limit reduction. Based on previous research, "speed limits should be evidence-led, self-explaining and seek to reinforce people's assessment of what is a safe speed to travel" (2); otherwise, there would be little change in the mean or 85th percentile speed as a result of raising or lowering the posted speed limit on urban and rural non-limited access highways. Thus, an engineering study in accordance with traffic engineering practices should be performed to establish speed zones (3). The analyses conducted in this study included an examination of the current speed distribution of free-flowing vehicles. This study compared the speed distribution of free-flow vehicles approaching intersections with different speed limit reductions to justify the effectiveness of advisory speed zone.

The objectives of this study were to identify the necessity and effectiveness of transitional speed zones on signalized, high-speed intersections with AWF on Nebraska highways, as well as to clarify their influence on safety through crash analysis. The goal would be to develop guidelines for a transitional speed limit policy based on the effects of speed limit reductions on vehicle speeds and safety concerns at signalized, high-speed intersections.

1.3 Organization of the Report

There are six chapters in this report. Chapter 1 contains an introduction of the problem and the objectives of the current project. Chapter 2 provides a summary of the literature review of speed limit studies, and a survey about current practices at signalized, high-speed intersections in neighbor states (KS, IA, MO, SD, WY, CO, and CA). Chapter 3 details the data collection process and the validation of the sensors, while introducing data pre-processing. Chapter 4 presents the analytical results of the speed data and provides conclusions on the efficiency of speed limit reductions used in advisory speed zone. Chapter 5 analyzes the crash data at signalized intersections with different speed limit reductions and discusses the safety issues related to transition speed zone at signalized, high-speed intersections with AWF. Chapter 6 summarizes the findings and provides recommendations in developing guidelines for the application of speed limit reduction at signalized, high-speed intersections with AWF.

Chapter 2 Literature Review

2.1 Standards of Speed Limit

There are two kinds of speed limits: general speed limits and speed limits in altered speed zones. General speed limits should obey the statewide law or even nationwide law. The speed limit in altered speed zones is based on a thorough engineering study, and applied to a specific section of road.

Throughout U.S. history, the government has imposed two statutory national speed limits. The first federal speed limit, established during World War II, was 35 mph. The second national speed limit was known as the National Maximum Speed Limit (NMSL), with a maximum speed of 55 mph. The purpose of these two statutory speed limits was based upon reducing energy consumption, rather than transportation cost (4). NMSL has changed several times throughout the years. In 1974, NMSL was set at a maximum of 55 mph. In 1987, Congress allowed the increase of NMSL to 65 mph on some qualified sections of Interstate highways in rural areas. Finally, in 1995, NMSL was repealed to allow each state and local jurisdictions to set their own speed limits. Subsequently, nearly all states increased their speed limits (5). State statutory limits may restrict the maximum speed limit that can be established on a particular road regardless of what an engineering study might indicate, while altered speed zones should be based on engineering studies. For altered speed zones, the advisory speed plaque, used to supplement any warning sign to indicate the advisory speed for a condition (e.g., horizontal curve), should be determined by an engineering study (3). Different states may have different policies regarding speed limits based on the Manual on Uniform Traffic Control Devices (MUTCD) standards. For example, Michigan has regulatory speed limits categorized as statutory or modified speed limits, in addition to the advisory speed limits to alert drivers of the maximum recommended safe driving speeds through a curve or for other special roadways conditions. Or, for instance, Texas classifies speed limits in two groups: statewide statutory speed limits, and a regulatory speed zone which may include an advisory speed section if needed. Despite the variety of speed limits in different states, performing engineering studies is the most common procedure for establishing all but statutory speed limits. One task of engineering studies is to extract the 85th percentile speed from free flow speed in a specific location. The 85th percentile speed has been demonstrated to be beneficial in lowering the possibility of a crash and to promote driver compliance (21). Arbitrary lowering or raising the speed limit has little impact on driver behavior.

2.1.1 Studies of Driver Compliance

Many previous studies were concerned with the effectiveness of changing the speed limit. In 1997, a study conducted by the Federal Highway Administration (FHWA) regarding the effects of raising and lowering speed limits reported that changing the speed limit has little effect on driver behavior (8). In that study, the speed limit was raised 0-15 mph, while for control locations it was lowered by 5-20 mph. The before-after analysis showed that the differences in mean, standard deviation, and 85th percentile speed were generally less than 2 mph. In 2007, Kentucky enacted a law permitting the increase of the speed limit from 65 mph to 70 mph for specific sections. The before-after analysis found that the speed limit change resulted in only a small change in actual travel speeds. On rural interstates, the 85th percentile speed was 1.3 mph faster for passenger cars, and 0.6 mph for trucks. As for the 85th percentile speed along rural four-lane parkways, cars' speed increased by 2.0 mph, and trucks' speed increased by 1.2 mph (6, 7). Similarly, in 2004 Virginia passed new legislation to raise the statutory maximum speed limit from 55 mph to 65 mph on limited access primary roads. Their before-and-after study concluded that average speed increased only 1.7-4.3 mph for all the test sites. However, speed limit compliance decreased from over 80% to approximately 50%. Also, the variance in traffic speed remained fairly constant (9). The consistent conclusion drawn from these studies is that no matter the speed limit posted, drivers mainly choose their own comfortable speed according to road conditions, and not on the basis of posted speed limit signs.

2.1.2 Studies of Crashes and Safety

One common misconception regarding the speed limit is that "lowering speed limit will increase the road users' safety and reduce the crashes rate, and vice versa" (4). Researchers have indicated that the variance of speeds, rather than the absolute magnitude, poses a threat to safety. As the FHWA publication states, "the potential of being involved in a crash is highest when traveling at a speed much lower or much higher than the majority of motorists" (8). The U-shaped relationship between motorist speeds and the chance of being in a crash invalidates the idea that lowering speed limits would increase safety (12). In general, the lowest risk of being involved in a crash occurs at approximately the 85^{th} percentile speed.

2.2 Advisory Speed for Transition Speed Zone

Special road conditions, such as a high-speed intersection, may favor an advisory speed limit different from, and probably lower than, that of other highway segments. However, prior to the current study, there were few studies to support any standard on how to set advisory speed limits for high-speed intersections, while studies do exist for horizontal curves. In order to avoid obtaining skewed results for the 85^{th} percentile speed, MUTCD requires that speed studies for signalized intersection approaches be undertaken outside the influence area of the traffic control signal, which is generally considered to be approximately 1/2 mile (3). However, this 85^{th} percentile speed does not represent the road condition in the vicinity of signalized intersections. A reduced speed limit specific to the signalized intersection could reduce the crash severity resulted from high speed on highways; however, an arbitrary reduction may result in violating drivers' expectations, and lead to lower compliance. Consequently, the increased variety of driving speeds will increase the probability of crashes. Thus, the establishment of a reduced transitional speed limit in advisory speed zones, such as at high-speed intersection, requires special engineering studies to demonstrate its effectiveness. There are several means to display reduced advisory speeds to alert drivers of the recommended speed for special road condition.

2.2.1 Variable Speed Limit

Variable Speed Limit (VSL) has been applied to improve roadway safety under different conditions such as severe weather, the unexpected change of roadway geometrics, and traffic congestion (13, 14, and 36). VSL provides a changeable posted speed limit as speed zones' characteristics change. Buddenmeyer et al. (13) conducted research concerning VSLs along a section of I-80 in Wyoming. The major goal of this project was to reduce speed variability along the corridor and improve safety under adverse weather conditions. The dataset was collected by Wavetronix SmartSensorHD and included traffic volume, vehicle speed, average speed, 85^{th} percentile speed, average headway and gap, lane occupancy, and vehicle classification. Next, a model was built with the 85^{th} percentile speed as its dependent variable. Results were significant for daytime and nighttime factors, surface status, and drivers' visibility. The final results indicated a speed reduction of 0.47 to 0.75 mph for every mile per hour in posted speed reduction. In addition, Summary et al. (14) conducted research of VSL at intersections in Sweden. The study showed that after the application of VSL, average speed was decreased by as much as 17 km/h (10.56 mph). Also, this Intelligent Transportation Systems (ITS) application received positive survey responses from drivers.

2.2.2 Dynamic Message Sign

Dynamic Message Signs (DMS) can provide drivers direct messages of the detected speeds of approaching vehicles. Monsere et al. (15) studied the advanced curve warning DMS system, which demonstrated strong performance in speed reduction in the speed transition zone. The speed limit dropped to 45 mph prior to the curved section from 65 mph. The DMS system's effectiveness at reducing mean speed was examined in a before-after study, which demonstrated statistically significant results. Moreover, most drivers provided positive responses through an attitude survey.

2.2.3 Speed Limit Sign

Cruzado and Donnell (16) studied the factors affecting drivers' speed along two-lane rural transition zones in Pennsylvania. The transition zone in this study was the low-speed area with a higher density of development, such as a rural village along a highway. Based on 2859 vehicles in 20 test sites, the statistically significant factors impacting the speed difference through the speed transition zone included the posted speed limit reduction, change in paved shoulder width, number of driveways, various advance warning signs, transition zone length, and the presence of horizontal curves. Understanding the significant factors influencing operation speed can help engineers design road sections meeting speeds desired under specific conditions.

Table 2.1 displays a summary the literatures discussed above, and it shows that the change in actual speed is significantly smaller than the change of speed limit. Figure 2.1 illustrates this comparison.

Table 2.1 Summary of previous research

Location	Before (mph)	After (mph)	Speed Limit Change (mph)	Mean Speed Change (mph)	85^{th}_Speed Change (mph)
I-5 SB, Douglas ,OR (15)	65 (PC), 55 (truck)	45	-20 (PC), -10 (truck)	-3	NA
I-5 NB, Douglas, OR (15)	65 (PC), 55 (truck)	45	-20 (PC), -10 (truck)	-2	NA
Rural Interstates, KY (6)	65	70	+5	NA	1.3 (PC) 0.6 (Trucks)
Four-lane parkways, KY (6)	65	70	+5	NA	2.0 (PC) 1.2 (Trucks)
Virginia (9)	55	65	+10	1.7~4.3	NA
Campbell County, KY (8)	55	45	-10	NA	-0.9
Franklin County, KY (8)	55	45	-10	NA	-3.8
Graves County, KY (8)	55	45	-10	NA	-0.8
Boone County, KY (*8*)	35	45	+10	NA	1.4

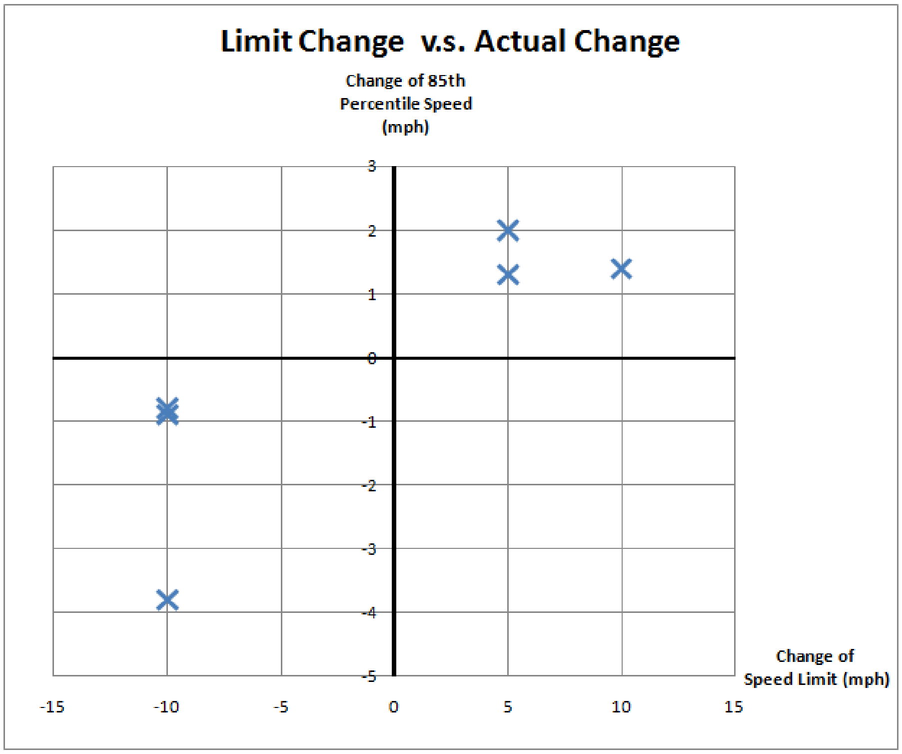


Figure 2.1 Comparison of speed limit change and actual change based on literature review

2.3 Survey of Practices in the Field

A survey for the application of advisory speed zones in several states was conducted. The results are summarized in table 2.2. Most states have a speed break for high-speed intersections, but there is not applicable documented guideline. For example, the Wyoming DOT generally lowers the speed limit to 45 mph at 10-500 feet before the intersection if speed limits on the approaching highway are greater than 45 mph. In Iowa, the decision of speed limit reduction is based on an engineering study including crash analysis and existing traffic volumes. Colorado implements advance warning signs rather than speed limit reduction, which are based on section 2B in MUTCD (3); the section supports the idea that advance warning signs and other traffic control devices used to attract the motorist's attention to a signalized intersection are usually more effective than a reduced speed limit zone. However, advisory speed limit signs are often implemented together with advance warning signs to indicate the advisory speed for a condition. To some extent, advisory speed limit signs fortify advance warning signs. The Missouri DOT typically installs advance warning signs with a dynamic flasher, which are timed with the signal and start to flash if approaching vehicles are expected to arrive at the intersection during a red light. Most other states, however, apply advance warning signs with or without flashing beacons and only install the dynamic flasher at certain locations. Furthermore, advance warning signs, speed limit reduction, and dilemma-zone protection algorithms are also widely applied for isolated high-speed signals.

Texas has one documented guideline that outlines the procedure for establishing speed zones. It advises that advisory zones be posted at intersections where roundabouts which are designed for an operating speed less than the speed of the approaches or intersections with restricted sight distances that require a reduction in speed for safe operation. A flow chart based on this document was developed and is presented in figure 2.2. This procedure enables TxDOT to lower speed limits on roadways by as much as 10 mph (12 mph if the traffic crash rate is above the statewide average) below the 85th percentile speed while considering factors such as pavement width, curves, number of driveways, crash history at a given location, rural, residential or developed areas, and a lack of improved and striped shoulders (21). These procedures were developed as a result of comments received at speed limit town meetings. TxDOT and cities must use these procedures when establishing speed zones on state highways. As shown in Chapter 3, section 2 in (15), TxDOT typically performs a speed study midway between signals—or 0.2 miles from any signal, whichever is less—to ensure an accurate representation of speed patterns. In addition, TxDOT uses advanced warning signs for signalized intersections. These are typically used when there is a crash history at a certain location, or where vertical curves cause limited sight distance. Sometimes these signs will have flashing beacons to increase visibility. The analysis in the current report could help the state of Nebraska to assess the impact of speed limit reduction on operating speeds.

Table 2.2 Survey results pertaining to applications of speed limit reduction

State	Advance Warning Flasher?	Transition Speed Zone?	Documented Guidelines for Transition Speed Zone	Contact	Referred Documents
Kansas	Sometimes	Sometimes	None	Brian D. Gower (gower@ksdot.org)	N/A
Iowa	Sometimes	Never	None	Timothy D. Crouch (tim.crouch@dot.iowa.gov)	N/A
Texas	Sometimes	Sometimes	Yes	Derryk Blasig (Derryk.Blasig@TxDOT.gov)	(21), (22)
California	Sometimes	Never	None	Ahmad Rastegarpour (ahmad_rastegarpour@dot.ca.gov)	N/A
Missouri	Sometimes	Sometimes	None	Jon Nelson (Jonathan.Nelson@modot.mo.gov)	(37)
Colorado	Sometimes	Never	None	K.C. Matthews (K.C.Matthews@dot.state.co.us)	(3)
South Dakota	Sometimes	Never	None	Doug Kinniburgh (Doug.kinniburgh@state.sd.us)	N/A
Wyoming	Sometimes	Sometimes	None	Paul Jones (paul.jones@wyo.gov)	N/A

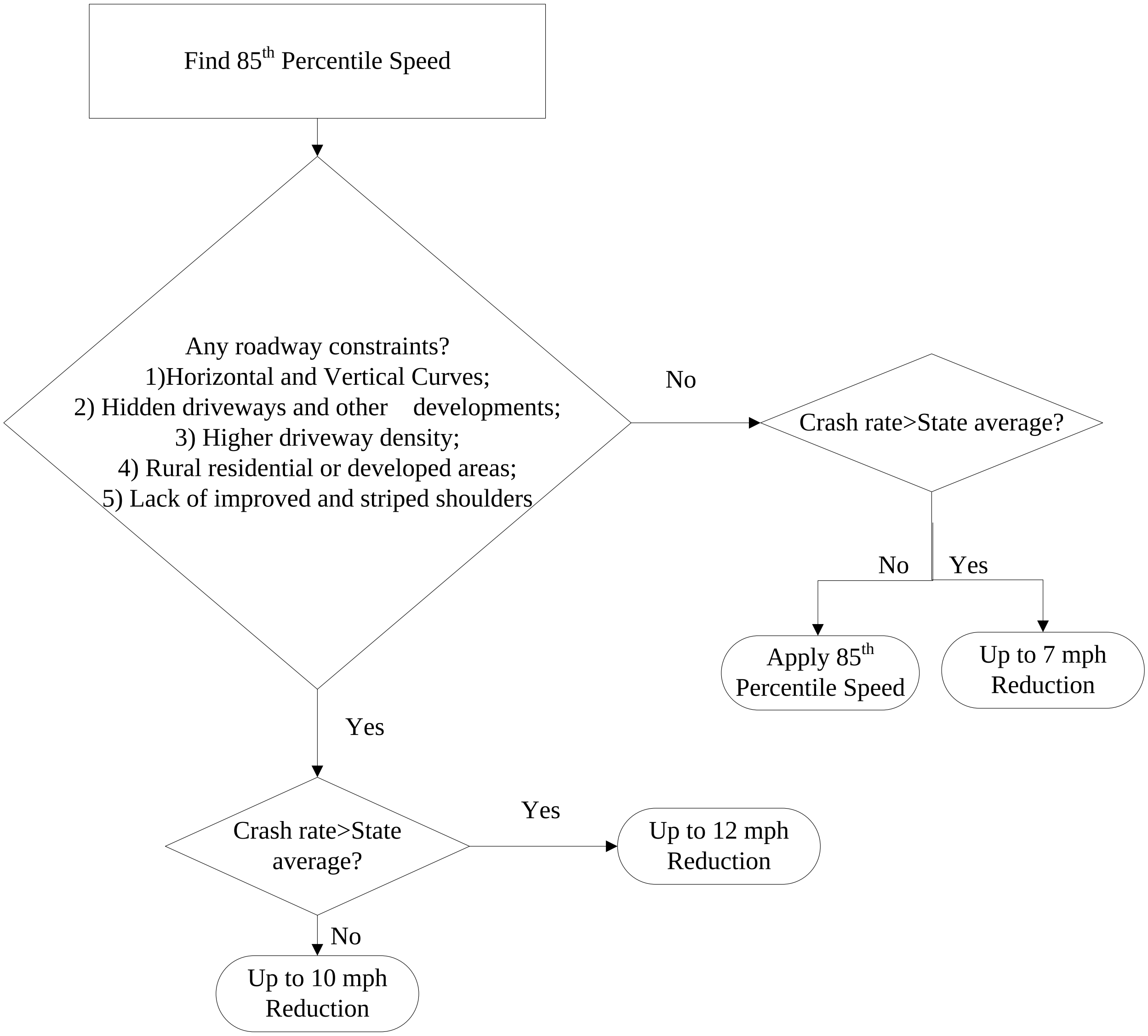


Figure 2.2 Standards to determine speed limits (TxDOT)

Chapter 3 Data Collection and Reduction

3.1 Trailer Setup

A portable trailer, as shown below in figure 3.1a, is utilized in data collection. Data was collected on days having no precipitation and with wind gusts lower than 10 mph. The data collection trailer was equipped with a Wavetronix sensor (WAD) (fig. 3.1b) and a MOBOTIX fisheye camera (fig. 3.1c). The SmartSensor Advance WAD installed on the research pole utilizes digital wave radar technology to track the vehicles upstream of the pole and record their distance, speed, lane, and vehicle length up to a distance of 500 ft. The video was used to identify vehicle types and lane occupation, and also to eliminate false calls.

The signal phase reader (shown in fig. 3.1d) communicates the signal phase status via radio to the portable sensor pole cabinet. There is one Click! 200 in the cabinet to collect data from the detector and send it to the Click! 500; thus, the Click! 500 in the pole cabinet receives data from the signal and Wavetronix detectors.

Time synchronization with the portable system is maintained with reference to the trailer's Click! 500 real-time clock. The phase-reading Click! 500 receives updates from trailer's Click! 500 via the wireless link. When both of these systems are properly synced, drift is less than 70 ms. The entire system has a time resolution accuracy of at least 0.1 sec. The data is pushed from the Click! 500 using the device's serial port and a serial to USB converter that connects to a laptop. MATLAB opens the serial port and saves the data in both .DAT and .txt files.

(a) Mobile data Collection Trailer

(b)Wavetronix SmartSensor Advance Sensor

(c) MOBOTIX Camera Sensor

(d)Safe Track Portable Signal Phase Reader

Figure 3.1 Figures of equipment for data collection

The overall data collection schematic is shown below in figure 3.1; the MOBOTIX camera on the top (A2 in fig. 3.2) can record the live traffic with a field of vision covering up to 180°. Figure 3.3 displays the view from the camera. The data collected by Wavetronix Sensor, as show in figure 3.4, includes date, time, ID, range, and speed.

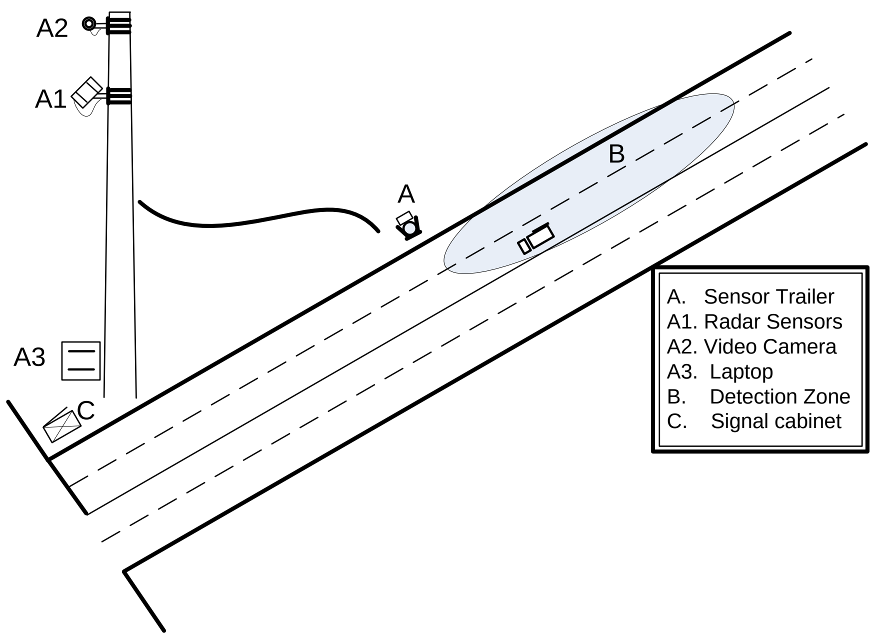


Figure 3.2 Trailer setup of data collection

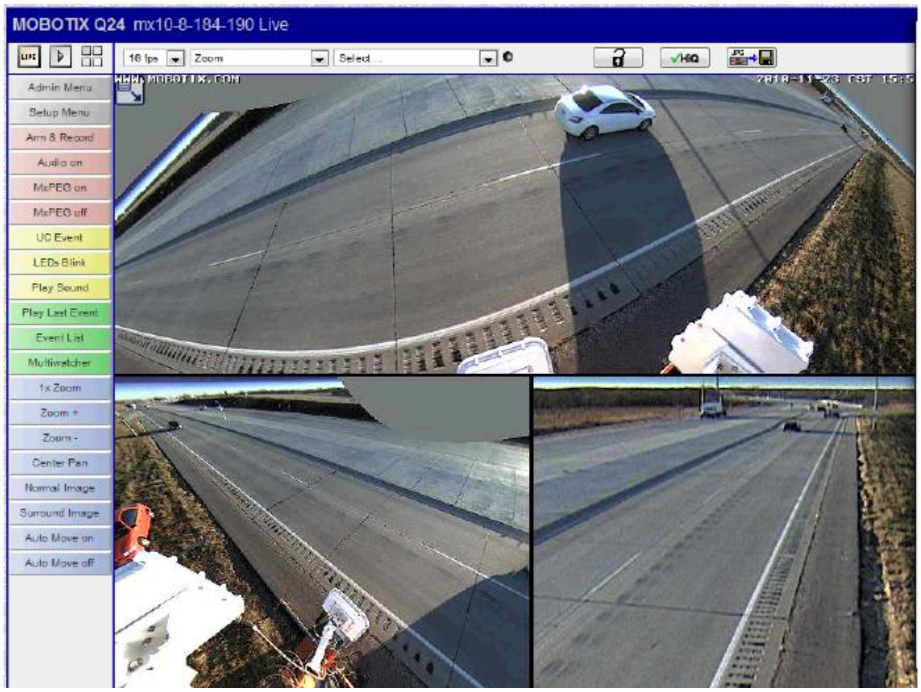


Figure 3.3 Mobile trailer data collection environment

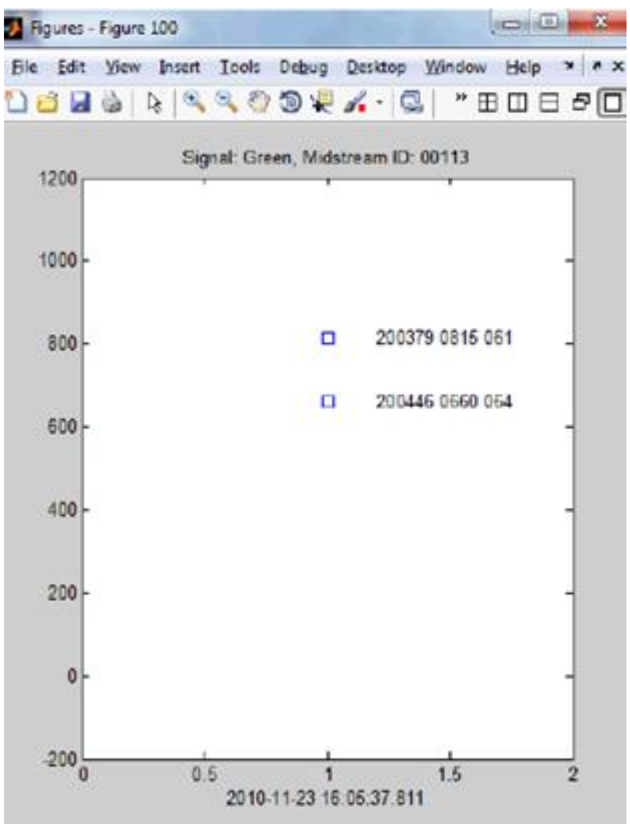
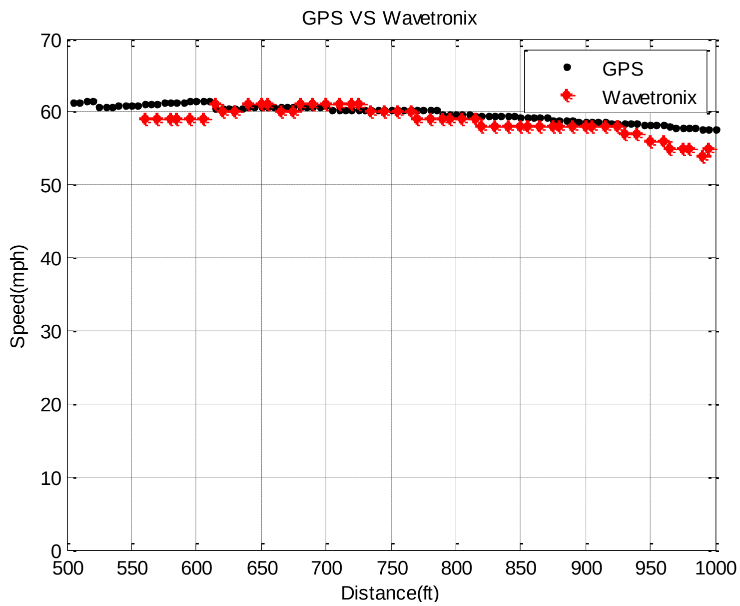


Figure 3.4 Data in MATLAB

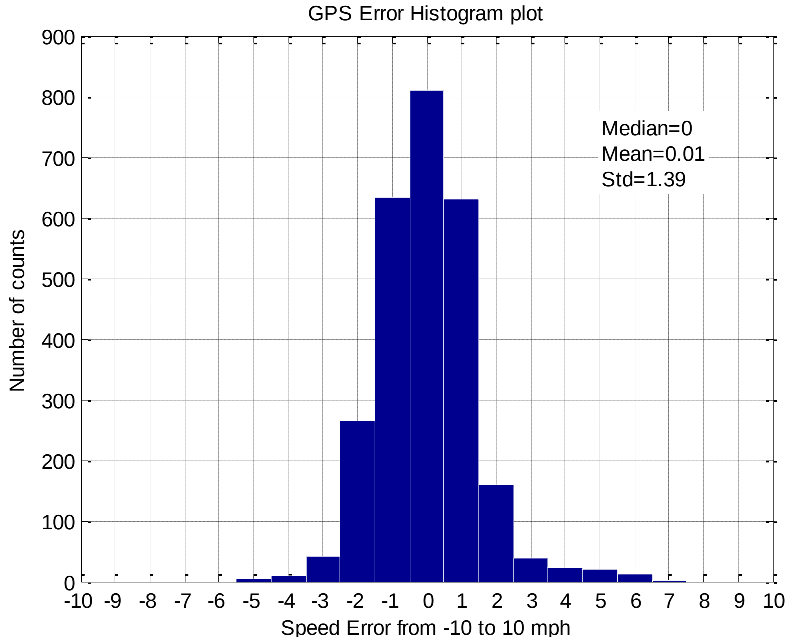
3.2 Sensor Performance Evaluation

GPS was used to validate the accuracy of Wavetronix in this study. Researchers performed 55 test runs with portable GPS to record the speed and distance data. Figure 3.5a shows a comparison of data recorded by GPS and Wavetronix for one test run. The difference between the two trajectories is the error of the Wavetronix, and represents a measurement of accuracy. Figure 3.5b shows the error histogram for all 55 runs. The error is distributed with the mean close to 0.01 mph and the standard deviation at 1.39 mph, which indicates acceptable performance of the Wavetronix sensor.



a) GPS vs. Wavetronix

Figure 3.5 Wavetronix's performance



b) Wavetronix Error Histogram

Figure 3.5 Wavetronix's performance (cont.)

3.3 Site Selection

Based on input provided by the Technical Advisory Committee and the judgment of the authors, seven intersections were selected for analysis. Table 3.1 shows the specific location and speed limit information of each site. In order to study the speed transition zone at high-speed intersections, three intersections (#1, #2, and #3) with no speed limit reduction (i.e., no transition zone) were chosen as a control group. Four other intersections were grouped into two types with speed limit reduced at 5 mph and 10 mph, respectively. More detailed information about the seven intersections is included in appendix A. The data collection at all seven sites was conducted during daylight hours on weekdays, in clear weather conditions.

Table 3.1 Information on study sites

#	Upstream Speed	Downstream Speed	Drop	Site Location	Trailer location	Dist. to Stop Bar (ft)
1	60	60	0	US-34 & N-79 *Lincoln* (Westbound)	Upstream	1,545
					Downstream	495
2	55	55	0	US-77 & Pioneers Blvd. *Lincoln* (Southbound)	Upstream	1,380
					Downstream	535
3	55	55	0	N-133 & N-36 *Omaha* (Northbound)	Upstream	1,025
					Downstream	505
4	60	55	5	US-75 & Platteview Rd. *Bellevue* (Southbound)	Upstream	1,560
					Downstream	520
5	60	55	5	US-81 & S Lincoln Ave. *York* (Southbound)	Upstream	930
					Downstream	500
6	65	55	10	US-77 & Saltillo Rd. *Lincoln* (Northbound)	Upstream	1,150
					Downstream	500
7	65	55	10	US-281 & W. Platte River *Doniphan* (Southbound)	Upstream	2,130
					Downstream	740

Figure 3.7 gives an example of the arrangement of trailers at the US-77 and Saltillo Road test site. It can be seen that the mobile trailer was placed upstream (near the vicinity of the upstream speed limit reduction sign) and downstream (approximately 500 ft in advance to the

stop bar). The objective for placing the upstream detector was to place it as close to the beginning of the speed transition zone (i.e., the speed limit sign showing a lower speed limit for the transition zone) as possible. Note that the beginning of the transition zones for all sites is more than 1,000 ft away from the intersection.

Similarly, the goal for placing the downstream detector is to place it approximately 500 ft from the stop bar. This was done in order to give enough distance for the vehicle to decelerate after seeing the speed limit reduction sign and to avoid any influence of upstream dilemma zone boundaries (5.5 sec). The precise location in the field varied by location of speed limit reduction sign, feasibility of parking the trailer, and line of sight from the cabinet and is shown in column 6 in table 3.1). By using this layout, a consecutive speed pattern along the road could be outlined for a vehicle approaching the intersection.

Figure 3.6 Trailer layout at test site US-77 and Saltillo Rd. (Source: Google Earth)

3.4 Data Collection

The portable trailer instrumented with the Wavetronix sensor (fig 3.1a) was used to track speed and distance data of the oncoming traffic flow 500 ft upstream of the trailer. The top-mounted MOBOTIX camera can record live traffic with a field of vision covering up to 180 degrees, which is used for the ground truth validation and for manually reducing the vehicle type and lane occupation for each detected vehicle. The data from the Wavetronix sensor is logged in .txt files. An example is shown in table 3.2. For signal status, 0 indicates red, 1 indicates yellow and 2 indicates green. The signal status of the intersection can be derived from communication with the traffic cabinet, and is used as a filter to extract free flow data—the vehicles arriving during the green time period. The first and last 10 sec are removed from the whole green period while filtering data for analysis to guarantee the free flow data. Table 3.3 summarizes the data collection date and sample size from Wavetronix Sensor for each intersection.

Table 3.2 Wavetronix raw data sample

Time	Original ID	Range (ft)	Speed (mph)	Signal Status
39030847	200071	440	53	2
39030947	200071	425	57	2
39031047	200071	425	57	2
39031147	200071	415	57	2
39031247	200071	405	58	2

Table 3.3 Data collection information

#	Intersection	Upstream Trailer		Downstream Trailer	
		Date collected	# of Tracked Vehs.	Date collected	# of Tracked Vehs.
1	US-34 & N-79	10/19/2010	539	10/20/2010	464
				10/21/2010	527
				11/23/2010	293
		Total	539	Total	1,284
2	US-77 & Pioneers Blvd.	10/12/2010	876	10/13/2010	1,170
				10/14/2010	1,094
		Total	876	Total	2,264
3	N-133 & N-36	11/2/2010	321	11/11/2010	528
				11/15/2010	300
		Total	321	Total	828
4	US-75 & Platteview Rd.	11/16/2010	1,685	11/18/2010	1,551
				11/19/2010	1,544
		Total	1,685	Total	3,095
5	US-81 & S Lincoln Ave.	12/6/2010	77	6/6/2011	83
		12/8/2010	49	6/8/2011	74
		5/26/2011	75	6/15/2011	125
		6/24/2011	136	6/23/2011	104
		Total	337	Total	386
6	US-77 & Saltillo Rd.	9/28/2010	661	9/29/2010	98
				9/30/2010	558
		Total	661	Total	656
7	US-281 & W. Platte River Dr.	12/2/2010	857	6/7/2011	435
		Total	857	Total	435

3.5 Data Classification

After verifying the accuracy of Wavetronix and the filter reduction for free flow data, the final stage of data reduction is to minimize false calls generated by the sensor.

Under ideal conditions, a car is tracked over time with the same ID number. For classification, all of the data generated by the sensor are grouped by ID; that is, each group represents only one vehicle. Classification analysis is used to classify the good calls from the false call. Several variables could be used to classify groups:

- Diff_Range: Diff_Range is defined as the distance between the range where the vehicle first triggers the sensor and the range where the sensor last detects the vehicle. Since the Wavetronix sensor is able to track a vehicle continuously within 500 ft, a well-detected vehicle should have a Diff_Range around 550 ft That is, a well-detected vehicle would keep the sensor turned on over a relatively long distance within the 500 ft range, while false calls will have a lower Diff_Range. The false call might stay in the same point with the same range value and trigger multiple calls, or, generate a short track. For both cases, the Diff_Range is relatively small compared to that of good calls. Thus, Diff_Range can be an efficient criterion to discriminate between good and false calls.
- Sample points: Ideally, Wavetronix tracks a vehicle every 5 ft after it first hits the detection area. Thus, a false call is highly possible when the vehicle has unreasonably fewer points. The number of points in an ID group could be used as a variable to distinguish groups.
- Mean speed and speed variance: for each vehicle, they have been detected with different speeds at different points in its group as it is passing the detection area. Hence, the mean speed and variance could be calculated for each group.

In the current study, a binary classification system was used where each vehicle ID generated by Wavetronix was classified as belonging to either a false or true ID group. In order to get a clean and valid dataset to analyze speed characteristics, it is necessary to find the most significant variable(s) among those variables listed above that can discriminate the false groups in the collection. The discriminant analysis technique is used for the binary classification (19). Discriminate function analysis includes Linear Discriminant Analysis (LDA) and Quadratic Discriminant Analysis (QDA). A linear classifier is based on the value of a linear combination of the variables, while the quadratic classifier will separate measurements of two classes by a quadric surface. The functions for these two classifiers comprise equations 3.1 and 3.2 (20):

$$\text{Linear classifier} = \mathrm{K} + \mathbf{x} * \mathbf{L} \tag{3.1}$$

$$\text{Quadratic classifier} = \mathrm{K} + \mathbf{x} * \mathbf{L} + \mathbf{x} * \mathbf{Q} * \mathbf{x}^{\mathrm{T}} \tag{3.2}$$

where

K: Constant term of the boundary equation

L: Linear coefficients of the boundary equation.

Q: Quadratic coefficient matrix of the boundary equation.

x: Group characteristic variables.

Based on a training dataset composing 549 groups manually reduced from the US-77 & Saltillo Rd. intersections, classify command in MATLAB was used to select the most significant variable combinations that could divide the data efficiently into two target groups. Different combinations of the four variables (i.e., Diff_Range, sample_points, mean speed, and speed variance) are tested in terms of their ability to accurately classify the groups. Figure 3.6 shows the best classifier from Quadratic Discriminant Analysis based on the combination of Diff_Range and sample points.

The accuracy of this classifier on training set is summarized in table 3.4. It may be seen that the classification accuracy was 98% (538 of 549). True data are well classified, and only two bad samples were classified into the true pool. Based on these results the authors were satisfied with the accuracy of the classification scheme.

Table 3.4 Classifier's accuracy on training set

	Sample Size: 549	Manual	
		False Predicted	True Predicted
Classifier	False Predicted	233 (42.4%)	9 (1.6%)
	True Predicted	2 (0.4%)	305 (55.6%)

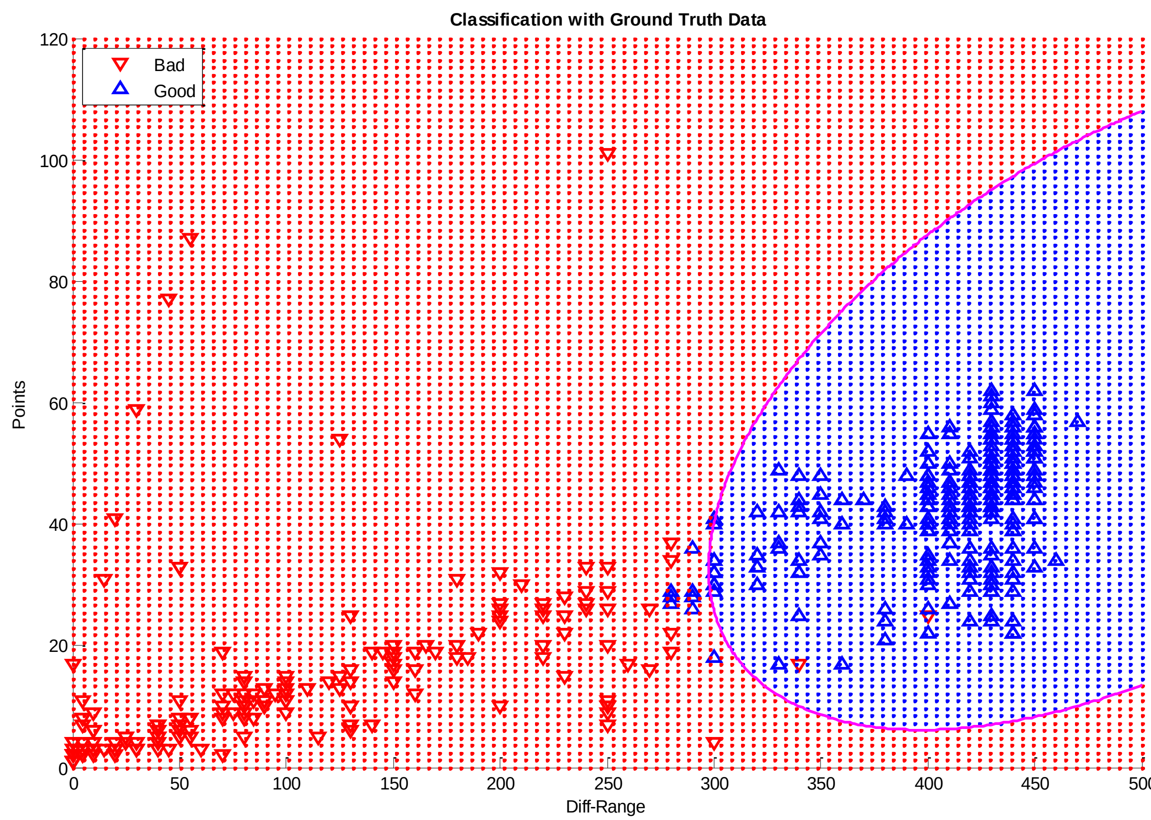


Figure 3.7 Diff_range and sample points with QDA

The classification boundary curve (shown in equation 3.3) based on the combination of the Diff_Range and sample_points are calculated in the format of equation 3.2.

$$f = K + [x_1, x_2] * \mathbf{L} + [x_1, x_2] * \mathbf{Q} * [\mathbf{x}, \mathbf{y}]^T \tag{3.3}$$

$$K = 49.0278, L = \begin{bmatrix} -0.2424 \\ 0.0743 \end{bmatrix}, Q = \begin{bmatrix} 3.1462 \times 10^{-4} & -6.1271 \times 10^{-4} \\ -6.1271 \times 10^{-4} & 0.0044 \end{bmatrix}$$

where

f: The equation of classification curve,

x_1: The distance range,

x_2: The sample points for each ID.

K: Constant term of the boundary equation.

L: Linear coefficients of the boundary equation.

Q: Quadratic coefficient matrix of the boundary equation.

The classification curve so-generated is then used for programmatic elimination of false calls from Wavetronix Data. When f is smaller than zero, the region covered is for true data, as indicated by the data plotted as a triangle located to the right side of the curve in figure 3.6.

The classifier developed from the training set is validated by performing classification for a different dataset which is reduced manually for 15-min periods for each intersection. The results are shown in table 3.5.

Table 3.5 Classifier's accuracy

	Sample Size: 456	Manual	
		Bad Predicted	True Predicted
Classifier	Bad Predicted	238 (52.2%)	4 (0.8%)
	True Predicted	3 (0.7%)	211 (46.3%)

Chapter 4 Speed Data Analysis

4.1 Sample Size

A sample size of 100 samples is commonly used by various state DOTs (17, 23) and academic researchers (16). For a 7 mph standard deviation in speed a sample size of 100 gives a tolerance of approximately 1.3 mph in the mean speed.

In absence of a priori estimate of standard deviation data substantially higher than 100 vehicles were collected at each intersection and a check on error tolerance was later made to verify that mean speed tolerance was lower than 1 mph for each test site locations. The mean speed tolerance for each site is shown in table 4.1. Given the available sample size, speed tolerance (e) under the 95% confident interval is calculated by equation 4.1 and recorded in table 4.1.

$$N = \frac{{z_{0.025}}^2 s^2}{e^2} \rightarrow e = \frac{z_{0.025}\, s}{\sqrt{N}} \tag{4.1}$$

where N is the sample size, e is the tolerance, and s is the standard deviation.

Table 4.1 Sample size and speed tolerance

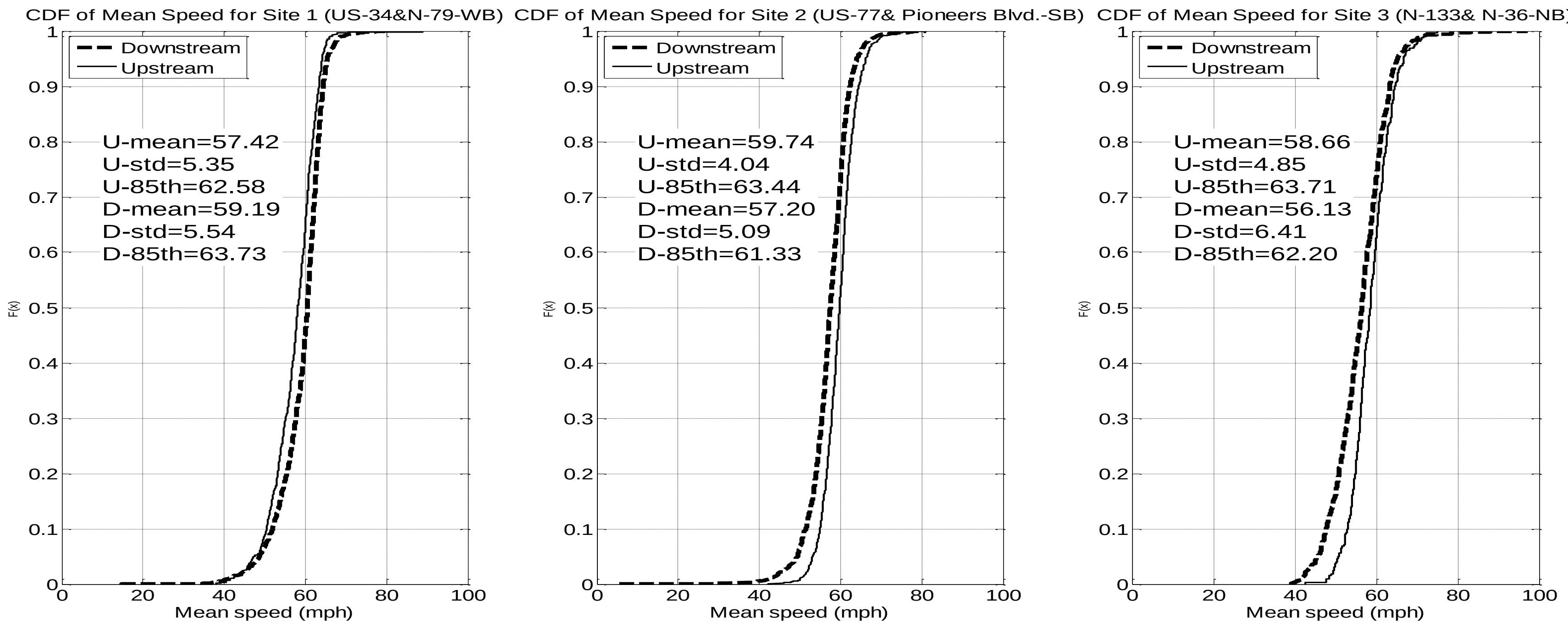
#	Site Name	Standard Deviation		Sample Size		Tolerance (mph)	
		Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
1	US-34 & N-79	5.85	6.20	539	1284	0.49	0.34
2	US-77 & Pioneers Blvd.	4.66	5.93	876	2264	0.31	0.24
3	N-133 & N-36	5.44	6.94	321	828	0.60	0.47
4	US-75 & Platteview Rd.	5.80	5.87	1685	3095	0.28	0.21
5	US-81 & S. Lincoln Ave.	6.94	7.16	337	386	0.74	0.71
6	US-77 & Saltillo Rd.	6.29	8.04	661	656	0.48	0.62
7	US-281 & W. Platte River	6.22	5.45	857	435	0.42	0.51

4.2 Speed Cumulative Distribution Plot

Figure 4.1 plots the cumulative speed distribution for upstream and downstream locations at each test site. The plots are grouped by speed limit drop. For example, figure 4.1a shows plots of three test sites where there was no speed limit reduction at the vicinity of the intersection. The x-axis represents speed in mph and the y-axis represents cumulative percentage. The description of site and approach is provided in the title of each subplot. For example, the left most subplot shows upstream and downstream cumulative speed distribution as measured at the west bound approach of the intersection at US-34 & N-79. The dotted line is the cumulative speed profile for the downstream section and the solid line is the cumulative speed profile for the upstream section. Important cumulative speed distribution statistics are listed as text within the subplot. For US-34 & N-79, the upstream mean speed is 57.4 mph, standard deviation is 5.3 mph and 85th percentile speed is 62.3 mph. For US-34 & N-79 the downstream mean speed is 59.2 mph, standard deviation is 5.5 mph and 85th percentile speed is 63.7 mph. A right shift of dotted line as compared to solid line shows drivers' tendencies to increase speed while going downstream.

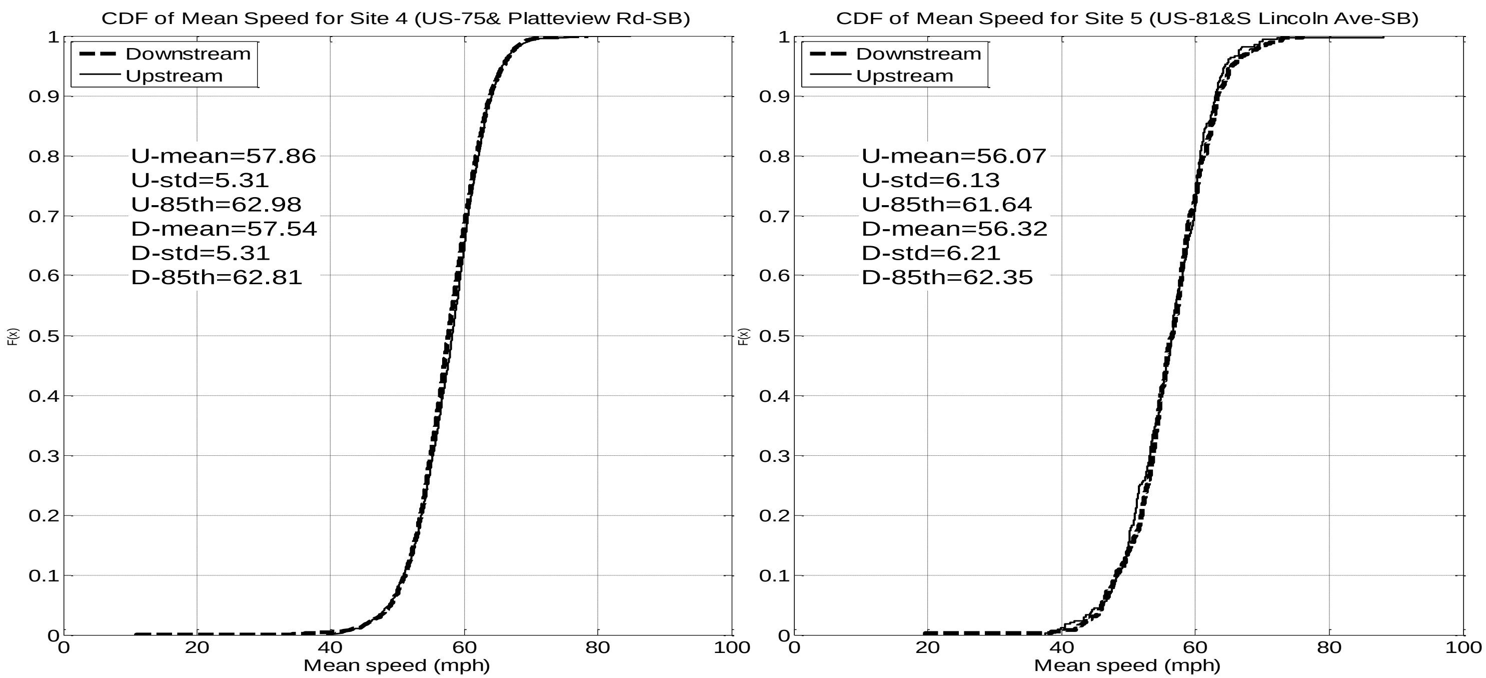
For 0 mph (as shown in fig. 4.1a), the upstream and downstream speed profiles are not distinctly different. In general, the 85th percentile is in the range of 61-64 mph on both upstream and downstream sections. Figure 4.1b shows the cumulative speed profile for two sites where the speed limit was dropped from 60 mph to 55 mph. As can be seen, there is hardly a difference in speed distribution between upstream and downstream sections, and the 85th percentile speed of the vehicles is in the range of 61-63 mph. Figure 4.1c shows the cumulative speed profile for two sites where the speed limit was dropped from 65 to 55 mph. As can be seen, there is a distinguishable reduction of speed between upstream and downstream sections. There was a drop of 3.6 mph in 85th percentile speed from 67.7 mph to 64.1 mph for US-77 & Saltillo. There was a drop of about 5 mph in 85th percentile speed from 67.2 mph to 62.2 mph for US-281 & Platte River.

Table 4.2 tabulates the key statistics discussed above for each site. The changes of the mean speeds and the 85th percentile speeds are less than 3 mph for the control group (without speed limit reduction). For the 5 mph-drop group, the changes are even smaller than those of the control group. This indicates the ineffectiveness of 5 mph reduction to reduce driving speeds at these two sites. For the 10 mph-drop group, the change is larger than the first two groups. The statistical significance of these differences in the mean speed and 85th percentile speed would be tested using quantile regression models (see section 4.3), and more detailed analysis about the impact of reduced signal speed limit on the average and standard deviation of the speeds will be explored by SURE in section 4.4.



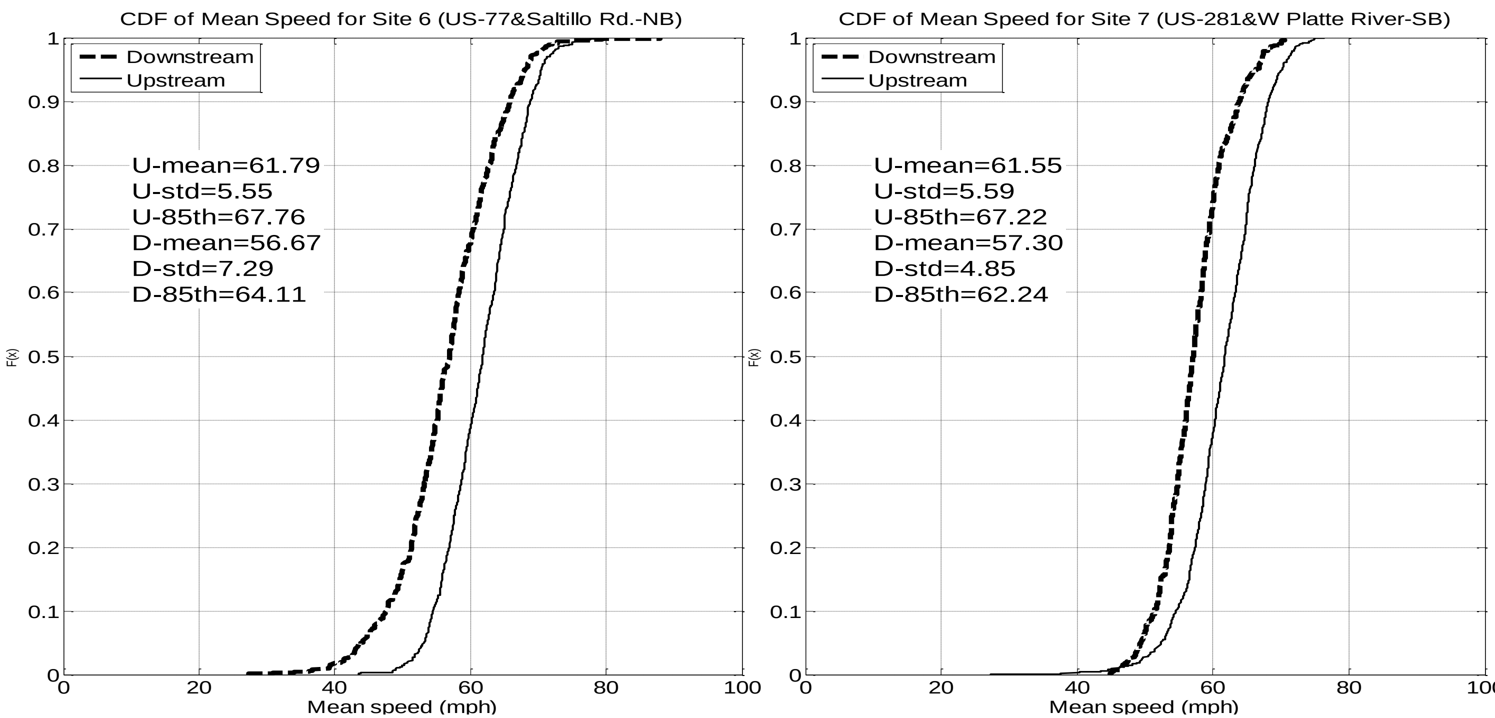
a) Sites for Speed Limit Drop—0 mph

Figure 4.1 CDF plots of speed for each intersection



b) Sites for Speed Limit Drop—5 mph

Figure 4.1 CDF plots of speed for each intersection (continued)



c) Sites for Speed Limit Drop—10 mph

Figure 4.1 CDF plots of speed for each intersection (continued)

Table 4.2 Speed characteristics for each site (mph)

#	Location	Far Speed	Close Speed	Upstream		Downstream		Speed Change (Up-Down)		
				Mean	85th	Mean	85th	Speed Limit	Mean	85th
1	US-34 & N-79	60	60	57.4	62.6	59.2	63.7	0	-1.8	-1.1
2	US-77 & Pioneers	55	55	59.7	63.4	57.2	61.3	0	2.5	2.1
3	N-133 & N-36	55	55	58.6	63.7	56.1	62.2	0	2.5	1.5
4	US-75 & Platteview	60	55	57.8	63.0	57.5	62.8	-5	0.3	0.2
5	US-81 & S. Lincoln	60	55	56.1	61.6	56.3	62.4	-5	-0.3	-0.7
6	US-77 & Saltillo	65	55	61.8	67.8	56.7	64.1	-10	5.1	3.6
7	US-281 & Platte River	65	55	61.6	67.2	57.3	62.2	-10	4.3	5.0

4.3 Quantile Regression Model

Quantile regression is developed to analyze the statistical impact on the 85th percentile speed, median speed and 15th percentile speed. Inter-percentile range (IPR) between 85th percentile speed and 15th percentile speed is calculated as a measure of dispersion using quantile regression.

Table 4.3 summarizes all the results obtained from quantile regression analysis: the value of impact of all the variables on 15th percentile, 50th percentile and 85th percentile. The variables that were not statistically significant at 95% level of confidence have “NA” listed as their impact value.

Table 4.3 Comparison of quantile regression for each intersection group

Limit Reduction	Percentile	Constant	Up_T	Heavy Truck (v2)	Lane_1
0 mph	15	52.8	1.8	NA	NA
	50	59.2	NA	-2.6	NA
	85	63.0	NA	NA	NA
5 mph	15	52.9	NA	NA	NA
	50	58.0	NA	-2.2	NA
	85	64.7	NA	NA	-2.0
10 mph	15	53.5	3.2	NA	-2.1
	50	57.5	4.2	NA	-1.3
	85	63.6	4.6	NA	-2.8

For this research we are most interested in studying the impact of speed limit reduction on upstream and downstream sections. Column "UP_T" in table 4.3 quantifies this impact under different speed limit reduction scenarios. For 0 mph reduction, 15^{th} percentile speed drops by 1.8 mph while traveling from upstream to downstream section, whereas 85^{th} percentile speed is unaffected. The IPR for 0 mph drop is 10.2 mph for downstream sections and 8.4 mph for upstream sections. There is no significant change for 15 or 85 percentile speeds between upstream and downstream sections for 5 mph speed limit reduction. The IPR for 5 mph drop is 11.8 mph for both upstream and downstream speeds. Finally, for 10 mph drop 85^{th} percentile speed reduces from 68.2 mph upstream to 63.5 mph downstream, while 15^{th} percentile speed reduces from 56.7 mph upstream to 53.5 mph downstream. Figure 4.3 plots the distributions of the downstream and upstream mean speed distributions for 10 mph reduction groups based on the coefficients of Up_T in quantile regression models. The IPR decreases from 11.6 mph upstream to 10.1 mph downstream.

From the above analysis it can be seen that for the test sites, reduction of speed limit from 60 mph to 55 mph did not lead to a statistically significant reduction in 85th percentile speeds, but a reduction of speed limit from 65 mph to 55 mph did lead to a 4.6 mph reduction in 85th percentile speed. Also, the speed dispersion was reduced in the vicinity of the intersection.

Based on this analysis, the authors expect to see safety benefits by reducing the speed limit from 65 mph to 55 mph in the vicinity of the intersection. A detailed crash analysis of crash frequency and severity was conducted, of which the results are presented in the next chapter (chapter 5).

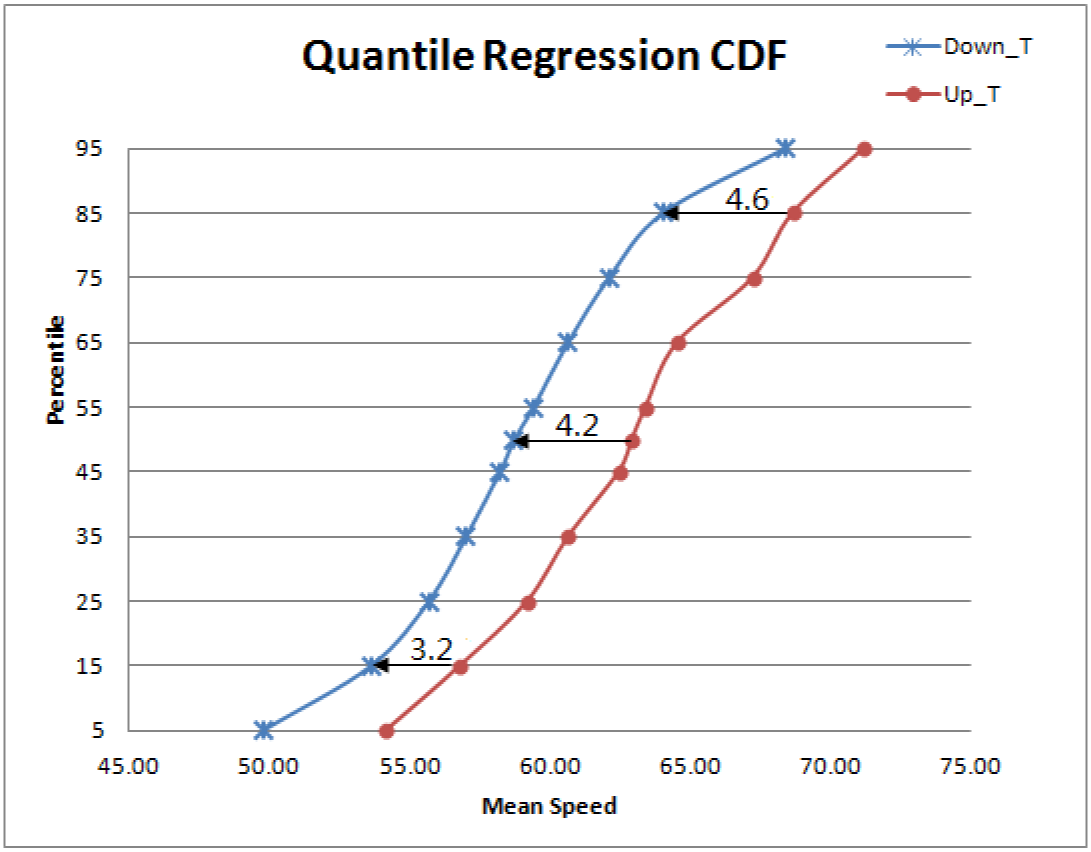


Figure 4.2 CDF of mean speed based on quantile regression for 10 mph reduction

4.4 Seemingly Unrelated Equation Models

The 10 mph reduction of transitional speed limit has shown more impact on reducing driving speed from previous analyses. The seemingly unrelated equation model developed in this section will test the statistical significance of the impact on both the mean and the standard deviation of the average speeds simultaneously, which takes consideration of the indirect interaction between the mean and standard deviation. Besides, the model can account for factors other than speed limit reduction impacting the change in driver speed and speed variance. The analysis of standard deviation will yield a stronger conclusion in terms of the safety impact from speed limit reduction since it’s well established that high variance in traffic flow speeds is potentially unsafe.

4.4.1 Data preparation

Hourly volume.

The distribution of the hourly traffic for all seven intersections in 2010 is shown in figure 4.3, which is derived from available sample count in a specific day for the approach of interest. Since the available counts did not all occur in 2010, growth rates based on available years are developed for each intersection to arrive at its hourly volume in 2010. The calculation of growth rate will be explained in more detail in section 5.1.2. The majority of the speed data in this research was collected between 8:00AM and 5:00PM, which excludes the periods with the most congestion, the morning and afternoon peak hours. Thus, based on the hourly volume distribution in the collection period, the traffic condition is ranked as either LOW (<200 veh/h), MID (200~400 veh/h), or HIGH (>400 veh/h). Traffic engineers generally use hourly volumes of less than 1,000 pcphpl as free flow condition. One should note that most of the speed data was from free flow. Thus, the conclusion from these three ranks is ultimately oriented upon a non-congested traffic flow.

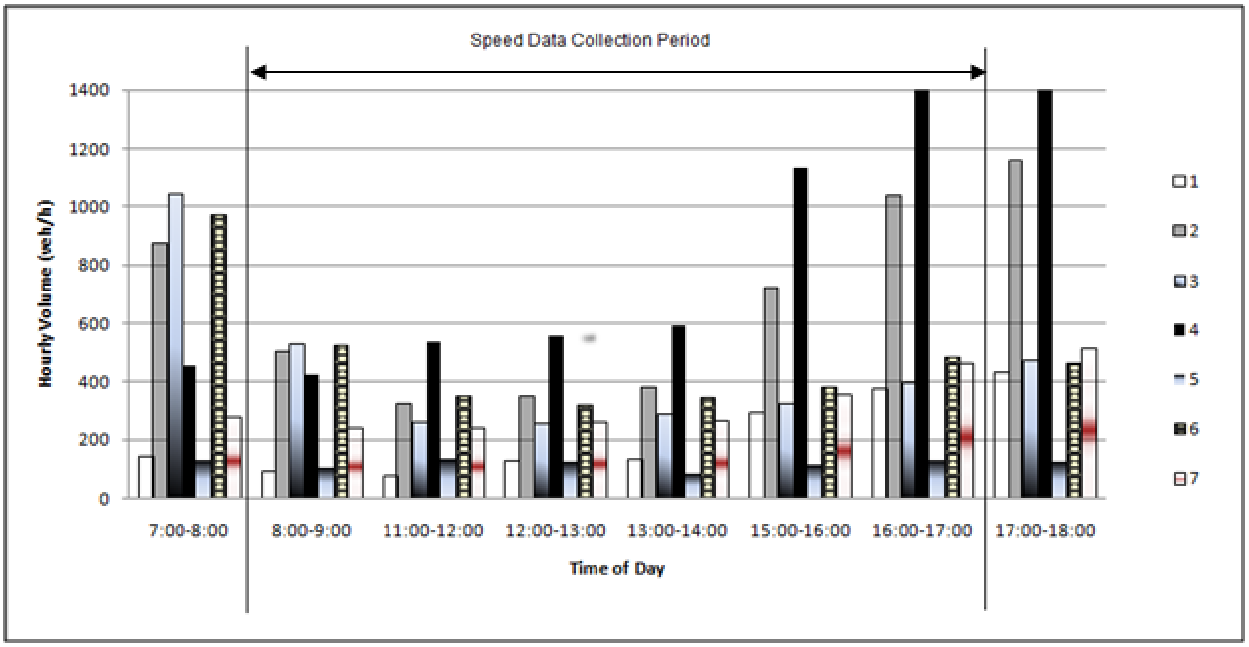


Figure 4.3 Distribution of hourly volume in the seven intersections

Grouping.

As in the quantile analysis, the average speed for each vehicle was calculated by averaging all the spot speeds detected continuously within 500 ft by wide area detector. With the help of the MOBOTIX camera and Wavetronix sensor, the lane occupation and vehicle type are reduced manually for each location. The reduced data includes 1,393 samples with approximately 100 samples for each location (i.e., upstream or downstream) of each intersection. To apply SURE, these average speeds are further grouped based on time of day and hourly traffic volume into groups with a size of approximately 10. The mean and standard deviation of speeds in each group are the dependent variables of SURE models.

4.4.2 Variable Selection and Data Preparation

Table 4.4 lists the explanation of all the variables tested.

Table 4.4 List of variables tested in seemingly unrelated equation model

Variable	Explanation
Dependent Variable	
Mean-Speed	In this study, the speeds of each vehicle were detected continuously. Based on the spots speeds, the average speed for each vehicle is calculated. To develop the SURE model, vehicles are grouped based on time. Each group may include 5 to 11 vehicles. Mean-Speed is the mean of the average speeds for the vehicles in one group.
STD- Speed	The standard deviation of the average speeds for all the vehicles in one group.
Site-Specific Characteristics	
0 mph	Dummy variable of Speed Limit Reduction: The data was collected at three types of intersections in terms of speed limit: 1) the same as the highway speed limit (0 mph reduction); 2) 5 mph lower than the highway speed limit (5 mph reduction); 3) 10 mph lower than the highway speed limit (10 mph reduction).
5 mph	
10 mph	
Site NO.	The ID of intersection: The information of the seven intersections is listed in table 2.1.
Grade	Dummy variables for the grade of the highway close to the intersection: If there is a grade rather than level, Grade=1; if it is an up-grade, Positive G=1; if it's a down-grade, Negative G=1.
Positive G	
Negative G	
Truck%	The percentage of the truck volume at the approach.
Left%	The percentage of the left-turn volume at the approach.
Left Truck%	The percentage of the left-turn truck at the approach.
ADT	The Average Daily Traffic at the approach.
Left-ADT	The Left-turn volume in the ADT.
Group-Specific Characteristics	
Up-T	The location of the detector Trailer: For each intersection, the data was collected separately at two locations: 1) Up-T is around 1000 ft from stop bar; 2) Down-T is close to the signal speed limit sign. (The Trailer locations are listed in table.2.1)
Down-T	
Lane 1	The lane adjacent to the shoulder
Lane 2	The passing lane adjacent to the median
v2 %	The Vehicle Type in the dataset includes: 2- Heavy-Truck, Semi 4- Passenger Car , Pickup Truck, Mini Van, Van, SUV 8- Vehicle towing trailer. v2%, v4%, and v8% are the percentages of each type of vehicle in the sample points aggregated for the group.
v4 %	
v8 %	
Count	The number of vehicles in the group
LOW	These three ranks are based on the hourly traffic volume when the vehicles in the group are detected. If the hourly volume is less than 200 vehicles, LOW=1; if the hourly volume is within the range of 200 to 400 vehicles, MID=1; if the hourly volume is higher than 400 vehicles, HIGH=1.
MID	
HIGH	

(continued)

Table 4.4 (continued)

Location-Specific Characteristics a) Up-T location	
Regular Speed Limit (mph)	The regular speed limit for the highway
U60 U55	Two dummy variables for the regular speed limit: The seven intersections have three types of regular speed limit: 55 mph, 60 mph, and 65 mph. Take 65 mph as the base, U60 is 1 if the regular speed limit is 60 mph and U55 is 1 for 55 mph.
Location-Specific Characteristics b) Down-T location	
Signal Speed Limit (mph)	The speed limit for the transitional zone of the intersection.
D60	The dummy variable for the signal speed limit: The seven intersections have two types of signal speed limit: 55 mph and 60 mph. Take 55 mph as the base, D60 is 1 if the signal speed limit is 60 mph.
Raised-Median	There are two types of the medians for the seven sites; if it's a raised median, Raised-Median=1; if it it's a grass-median, Raised Median=0.
Left-Lane	If there is an exclusive left-turn lane at the intersection, Left-Lane=1
Right-Lane	If there is an exclusive right-turn lane at the intersection, Right-Lane=1
Number of Lanes	At the intersection, the original two-lane on regular highway section may expand to three or four lanes by adding Left and/or Right turn lane.
3-Lane 4-Lane	Dummy variables for the number of lanes; the intersection may have 2, 3, or 4 lanes at the entry of the intersections in the dataset. Take two-lane as the base, 3-Lane is 1 if there are three lanes and 4-Lane is 1 if there are four lanes.

4.4.3 Seemingly Unrelated Regression Estimation (SURE)

Since each group is composed of the average driving speed of different drivers, the means and the standard deviations are not related to each other directly. The SURE model, in this case, could represent the possible connections between them through a disturbance term (38). The form of the model is:

$$MS_i = \beta_i Z + \alpha_i X + \varepsilon_i$$

(4.2)

$$SD_i = \tau_i Z + \omega_i X + \vartheta_i$$

where

MS_i=Mean of the mean speeds in sub-sample i;

SD_i= standard deviation of the mean speeds in sub-sample i;

Z=vector of site-specific characteristics (e.g., limit reduction, signal/regular speed limit, ADT, etc.);

X=vector of group-specific characteristics (e.g., vehicle type percentage, lane occupation, etc.).

i = group ID.

Each group, as shown in the group-specific characteristics, consists of speed values obtained from same lane and detector location with an identical traffic condition rank; however, it is reasonable to assume they are impacted by some unobserved factors. Generalized least squares method (GLS) is applied to estimate the coefficients for both equations jointly. This relaxes the assumptions of the ordinary least squares (OLS). OLS estimates the two equations separately, and will yield inefficient estimations not considering the correlation of the disturbances term resulting from unobserved factors.

OLS will estimate the parameters by:

$$\hat{\beta} = (X^T X)^{-1} X^T Y \tag{4.3}$$

where

$\hat{\beta}$ is a $p \times 1$ column vector and p is the number of coefficients;

X is a $n \times p$ matrix of data and n is the number of observations;

X^T is the transpose of X;

Y is a $n \times 1$ column vector.

GLS, on the other hand, add one term to consider the correlation among the disturbance terms for each equation so that efficient estimation is achieved.

$$\hat{\beta} = (X^T\Omega^{-1}X)^{-1}X^T\Omega^{-1}Y \tag{4.4}$$

where Ω is estimated from initial OLS estimates of individual equations (39).

SURE has been frequently been utilized in research on the effects of speed limit (40) and control measures in work zones (38, 41) and is an important tool for addressing the problem of correlation. However, it is still constrained by the quality of the data.

4.4.4 Results

Table 4.5 presents the final model developed for sites with 10 mph, 5 mph and 0 mph reductions. The final models include only the variables that were found to be statistically significant at a 95% level of confidence. All the SURE models have a global significance, as F-test is statistically significant at 90% level of confidence. A lower R-squared value implies that the independent variables were unable to fully capture the variability of the dependent variables. For mean speed model, Up-T is only significant for 10 mph reduction groups, which demonstrate its impact on reducing travel speeds in the field. However, Up-T doesn't show significance in all the models for standard deviation; that is, even with 10 mph speed limit reduction, the reduction on the IPR in section 4.3 cannot be transferred to the standard deviation of speeds with statistical significance. Detailed conclusions related to each variable are listed in the comments column in table 4.5.

Table 4.5 Comparison of the SURE models for speed limit reduction

a) SURE for 10 mph reduction intersections

Parameter Estimation for Mean-Speed of 10 mph reduction Sites Adjusted R-squared=0.47 Chi-sq[2] (prob)=32.86 (.0000) Number of Observations=44			
Variable	Parameter (Std. Err)	P Value (t stat)	Comments
Constant	58.37 (0.63)	.0000 (91.95)	The mean speed of vehicles travelling through the sensor close to signal speed limit is 58.37 mph on the passing lane of the 10 mph reduction sites (i.e., S6 and S7).
Up-T	3.81 (0.65)	.0000 (5.85)	The mean speed collected by Up-T is 3.81 mph higher than that at Down-T. This demonstrates the significant effect of 10 mph reduction on reducing speed in the field.
Lane 1	-1.96 (0.68)	.0042 (-2.86)	Compared to the passing lane adjacent to the median, vehicles on Lane1 travels with a mean speed 1.96 mph slower.
Parameter Estimation for STD-Speed of 10 mph reduction sites Adjusted R-squared=0.24 Chi-sq[1] (prob)=14.91 (.0001) Number of Observations=44			
Variable	Parameter (Std. Err)	P Value	Comments
Constant	4.16 (0.27)	.0000 (15.58)	The standard deviation of Site #7 (S7) is 4.16 mph. Note: There is no significant difference for the flow at Up-T and the flow close to the signal speed limit.
S6	1.46 (0.38)	.0001 (3.87)	The STD-Speed is significantly higher at Site #6 than Site #7 by 1.46 mph. This may be from the higher grade for #6 close to the intersection. The grade at #6 is 2.99% while the grade at #7 is 0.04%.

b) SURE for 5 mph reduction intersections

Parameter Estimation for Mean-Speed of 5 mph reduction Sites Adjusted R-squared=0.11 Chi-sq[1] (prob)=8.05 (.0046) Number of Observations=43			
Variable	Parameter (Std. Err)	P Value (t stat)	Comments
Constant	58.39 (0.43)	.0000 (136.45)	The mean speed of vehicles travelling on the passing lane of 5 mph reduction sites (i.e., S4 and S5) is 58.39 mph, which does not vary significantly from site to site. Note: There was no significant difference for the flow at Up-T and the flow close to the signal speed limit. This shows a weak impact of 5 mph reduction at signal speed limit on reducing speeds of operation.
Lane1	-1.42 (0.56)	.0112 (-2.53)	Compared to the passing lane adjacent to the median, vehicles on Lane 1 travel at a 1.42 mph slower mean speed.
Parameter Estimation for STD-Speed of 5 mph reduction Sites Adjusted R-squared=0.06 Chi-sq[1] (prob)=5.73 (.0167) Number of Observations=43			
Variable	Parameter (Std. Err)	P Value	Comments
Constant	5.33 (0.28)	.0000 (19.36)	The standard deviation of the two 5 mph reduction sites on passing lane is 4.16 mph. This value is not significantly different from site to site. Note: There is no significant difference for the flow at Up-T and the flow close to the signal speed limit.
Lane1	-0.71 (0.36)	.0498 (-1.96)	Compared to the passing lane adjacent to the median, vehicles on Lane1 travel with a standard deviation of speed that is 0.71 mph slower.

c) SURE for 0 mph reduction intersections

Parameter Estimation for Mean-Speed of 0 mph reduction Sites Adjusted R-squared=0.04 Chi-sq[1] (prob)=5.84 (.0156) Number of Observations=66			
Variable	Parameter (Std. Err)	P Value	Comments
Constant	58.90 (0.32)	.0000 (183.30)	The mean speed of vehicles travelling on the passing lane of 0 mph reduction sites (i.e., S1, S2, and S3) is 58.90 mph which does not vary significantly from site to site. Note: There is no significant difference for the flow at Up-T and the flow close to the signal speed limit. This is reasonable since there is not reduced speed limit for the transitional zone at the intersection.
Heavy Vehicle	-3.58 (1.42)	.0116 (-2.53)	Compared to passenger car, heavy vehicles travel at a 3.58 mph slower mean speed on average.

Parameter Estimation for STD-Speed of 0 mph reduction Sites Adjusted R-squared=0.09 Chi-sq[2] (prob)=11.46 (.0032) Number of Observations=66			
Variable	Parameter (Std. Err)	P Value	Comments
Constant	5.45 (0.28)	.0000 (19.66)	The standard deviation of the 0 mph reduction sites is 4.16 mph. This value is not significantly different by site or by lane. Note: There is no significant difference for the flow at Up-T and the flow close to the signal speed limit.
LOW	-0.92 (0.42)	.0304 (-2.17)	The negative coefficients for both LOW and HIGH indicate that very low and relatively high traffic conditions accommodate lower variation than in the medium condition.
HIGH	-1.77 (0.56)	.0016 (-3.15)	

4.5 Summary

Table 4.6 summarizes the findings from this chapter in terms of the impact of various speed limit reductions on several speed statistics. “NS” indicates that there is no significant change at 95% level of significance. All of the changes indicated by “increased” or “reduced” are in units of mph. These findings are specified for the speed limit setup as shown in the second row of the table.

For the intersection approaches with 10 mph reduction in regular 65 mph highway speed limits, there is some evidence that speed limit reduction does reduce the mean traveling speed in the vicinity of the intersection; however, although there is a reduction for the IPR of individual speeds, there is no statistical reduction for the standard deviation within grouped speed data. The main limitation of this study is that there are only two approaches with a 10 mph reduction from 65 mph to 55 mph. For 5 mph speed limit reductions (i.e., reductions from 60 mph to 55 mph), there was no statistically significant effect of this change on reducing the mean or standard deviation of the speeds in the two approaches studied in this project. In the future, sites with 5 mph reduction from 65 mph to 60 mph should be included to generate further evidence. A larger sample size would be required to draw conclusions with more confidence. And for a specific site, a before-and-after study is more effective to identify the impact from signal limit reduction on the travel speeds in operation.

Table 4.6 Summary of the impact from speed limit reduction on downstream speed statistics (in mph) compared with upstream at a 95% significant level

Speed Limit Reduction (mph)	10	5	0
Highway/Upstream Speed Limit (mph)-Signal/Downstream Speed Limit (mph) Number of Approaches Studied	65-55 (2 approaches)	60-55 (2 approaches)	60-60 (1 approach); & 55-55 (2 approaches)
Individual Average Speeds (Quantile Regression Model)			
15th Percentile	Reduced by 3.2	NS	Reduced by 1.8
50th Percentile	Reduced by 4.2	NS	NS
85th Percentile	Reduced by 4.6	NS	NS
IPR=85th -15th Percentile	Reduced by 1.4	NS	Reduced by 1.5
Grouped Average Speeds (SURE Model)			
Mean	Reduced by3.8	NS	NS
Standard Deviation	NS	NS	NS

Note: NS-Not Significant at 95% level of significance.

Chapter 5 Crash Analysis

Based on the analysis conducted in last chapter, safety benefits are expected upon reducing the speed limit from 65 mph to 55 mph in the vicinity of signalized high-speed intersections. This chapter presents a detailed crash analysis to better understand the safety impact of speed limit reduction.

A list of 28 intersections was compiled under the guidance of Matt Neemann from NDOR to identify high-speed intersections managed by NDOR. Ten years of detailed crash data (January 2001 to December 2010) was obtained for 28 intersections. The crash data is further reduced for each approach of the main street of each intersection; resulting in56 approaches total approaches. In the 56 approaches, 43 approaches have the constant speed limit without reduced signal speed limit, 9 approaches have a 5 mph speed limit drop, and 4 approaches have a 10 mph speed limit drop. The uneven numbers of approaches for 0 mph reduction and 5 mph reduction come from the main street (N133) of the rest one intersection (N133 & N36), which has one approach (Northbound) with a 0 mph reduction and another approach (Southbound) with a 5 mph reduction. Appendix B shows the detailed information for these 28 intersections. After being separated by approach, the accident dataset is further categorized by year. Thus, there were originally 560 data points (28 intersections * 2 approaches * 10 years) for the accident frequency model. However, two intersections have a history of stop-control prior to implementing signalized control. Excluding these points, there were 536 observations for the accident frequency model. On the other hand, accidents in the ten years at the 56 approaches totaled 635. Thus, there were 635 observations for the accident severity model.

Statistical models were developed to test the impacts of speed limit reduction and downstream speed limits on crash frequency and severity.

5.1 Data Preparation

Speed limit reduction is the main variable of interest to this project. Traffic-related variables such as volume information and flasher time of advance warning flasher are also included.

Average Daily Traffic (ADT):

The ADT for the year with available sample volume counts is derived through TrfEngrCtFactoring Program, which is also used by NDOR Planning Project Development Division. The available sample counts include the date and day-of-week for the volume counts, and raw counts of all vehicles and truck at each approach within the sample counting period (i.e., 7:00 am-9:00 am, 11:00 am-2:00 pm, and 3:00 pm-6:00 pm). TrfEngrCtFactoring Program calculates expansion factors for the combination of road type, month, day-of-week, and the raw counts during the sample counting period and gives the ADT of total vehicle and truck for each approach. Then, the 10-year ADTs are calculated by available ADT and growth rates through a compound interest formula. Growth rates for each intersection are calculated separately depending on the number of years with available ADT at that intersection:

1. If the intersection has ADTs for two or more years, the growth rate is calculated by a compound interest formula in combination with Solver function to obtain optimal results.
2. If the intersection has only one year's ADT, but it's in the same county as some other intersection in case 1, the same growth rate is applied since they share similar sociological characteristics.
3. If no common growth rate for traffic is available, the growth rate of the population from 2001 to 2010 will be used.

4. A similar calculation is used for truck volume and left-turn volume.

Flasher-Dummy.

The flasher-dummy is created to study the impact of the flasher time of AWF in the field. This variable is based on the fact that whether the flasher time is greater than the time required for the drivers at signal speed limit traveling from the flasher to the stop bar, which is calculated by equation 5.1.

$$Required\ Time\ to\ Travel\ from\ Flahser\ to\ stop\ bar = \frac{Distance\ to\ Stop\ Line}{Signal\ Speed\ Limit} \quad (5.1a)$$

$$Flasher\ Dummy = \begin{cases} 1, & if\ Actual\ Flahser\ Time \leq Theory\ Flaher\ Time \\ 0, & if\ Actual\ Flahser\ Time > Theory\ Flaher\ Time \end{cases} \quad (5.1b)$$

5.2 Overview of Crash Data

Figure 5.1 shows the accident frequency and annual rate distribution by accident type and speed limit reduction. The x-axis consists of three speed limit reduction: 0 mph, 5 mph, and 10 mph. The y-axis for the left column is crash frequency in terms of total accident frequency, angle accident frequency, and rear-end accident frequency. The y-axis for the right column is the frequency rate for each type of accident. This annual rate is calculated by the annual frequency at each approach divided by the corresponding ADT for the approach, as seen in equation 5.2. There are 536 observations in all; the 0mph-box includes 406 observations; the 5 mph-box includes 90 points; and the 10mph-box includes 40 points at each plot.

$$Annual\ crash\ rate = \frac{Annual\ crash\ frequency\ at\ appraoch\ i}{ADT\ at\ approach\ i} \quad (5.2)$$

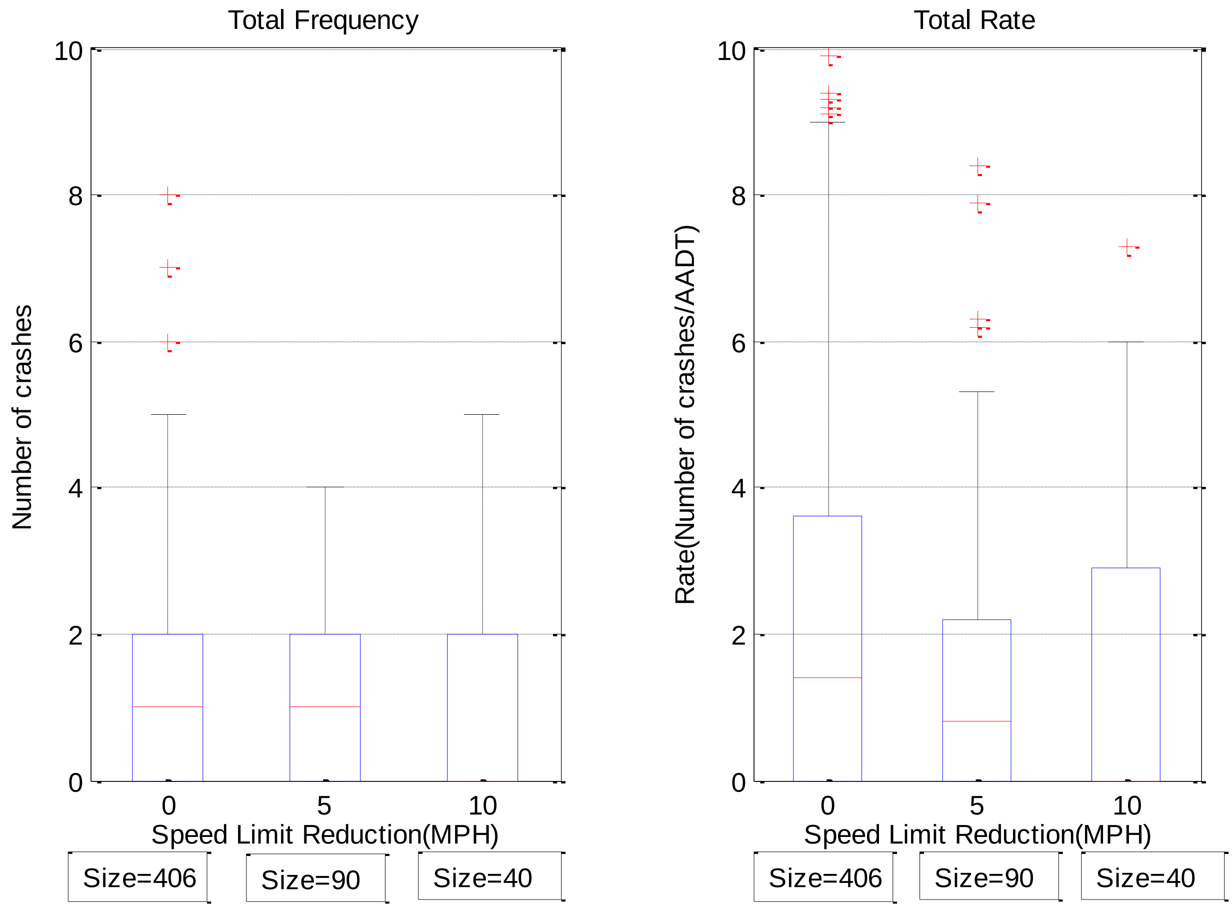


Figure 5.1 Distribution of crash frequency and rate by accident type and speed limit reduction

5.3 Crash Frequency Model

5.3.1 Literature Review

Numerous studies have been conducted to investigate the effects of traffic characteristics and traffic on crash frequency (27, 28, 29, 32, 33, 34). Due to the discrete response variable, the Poisson model is appropriate to apply when the mean and the variance are approximately equal. Whenever the equality does not hold, the parameter vector of the Poisson model would be biased. If the data is over-dispersed (i.e., the variance is significantly greater than the mean) for what is common in crash frequency data, a negative binomial (NB) regression model fits better.

However, neither the Poisson nor the NB model considers the possibility that crash frequency likelihood may be affected by two or more underlying processes. For example, if the observation of reported crashes for a one-year period is zero, there are two possible states for this observation. One is a normal count-process state in which zero crashes is one outcome of all the possible outcomes of the Poisson or NB distribution; the other one is zero-state, in which this observation comes from a road section that is inherently safe and the occurrence of crash on it is so extremely rare that it will be zero most of the time. Trying to model a dual-state system as a single state system would provide erroneous conclusion; for example, an NB model is chosen while a Poisson distribution is correct. Shanker et al. compared a zero-inflated Poisson Model (ZIP) and a zero-inflated NB model (ZINB) with the NB model on studying crash frequency for non-intersection roadway sections (29). The results showed that different variants of the ZIP and ZINB Models are plausible for road sections in different functional classification.

5.3.2 Poisson Model and NB Model

Poisson regression models define the probability of intersection i having y_i crashes in the observed period as:

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!} \tag{5.3}$$

where λ_i: is the Poisson parameter for intersection i and equal to the expected number of crashes per five years at intersection i. And λ_i is estimated by $EXP(\beta X_i)$ and X_i is a vector of the explanatory variables such as signal speed limit. β will be estimated by standard maximum likelihood methods using Limdep.

However, Poisson distribution requires equality of the mean and variance. In actual studies, the main variables influencing the crash frequency may not be included in the available data; this will lead to over-dispersed data, which violates the assumption of the Poisson regression model. In this case, an NB regression model is the alternative to a Poisson model. The λ_i in an NB regression model is calculated by

$$\mathrm{EXP}(\boldsymbol{\beta}\mathbf{X}_i + \varepsilon_i) \tag{5.4}$$

where $\mathrm{EXP}(\varepsilon_i)$ is a gamma-distributed error with mean 1 and variance σ^2. The added error term would release the restrains of Poisson and accommodate the data with a variance different from the mean. The model choice will be based on the dispersion parameter.

5.3.3 Zero-Altered Probability Processes

In reality, crashes do not happen very frequently; therefore, there could be a zero count for an intersection or approach in a given year. A zero count could result from two cases: 1) the intersection is safe enough that no accident will ever happen there, or 2) the zero is one observation from a regular count process (29). Case 1 violates the assumption of the Poisson regression model and negative binominal model since it is not from a regular count process. Zero-altered probability processes such as the ZIP and ZINB distributions relax this assumption, and are more flexible to model the accident dataset with a significant number of zero.

ZIP assumes events Y= (y1, y2, y3...yn) are independent. The model is as presented below.

$$y_i = 0 \text{ with probability } p_i + (1 - p_i)\mathrm{EXP}(-\lambda_i) \tag{5.5a}$$

$$y_i = Y \text{ with probability } \frac{(1-p_i)\mathrm{EXP}(-\lambda_i)\lambda_i^y}{y!} \tag{5.5b}$$

Similarly like ZIP, for ZINB,

$$y_i = 0 \text{ with probability } p_i + (1-p_i)[\frac{\frac{1}{\alpha}}{(\frac{1}{\alpha})+\lambda_i}]^{1/\alpha} \tag{5.6a}$$

$$y_i = Y \text{ with probability } (1-p_i)\left[\frac{\Gamma\left(\left(\frac{1}{\alpha}\right)+y\right)u_i^{\frac{1}{\alpha}}(1-u_i)^y}{\Gamma\left(\frac{1}{\alpha}\right)y!}\right], y = 1,2,3 \ldots \tag{5.6b}.$$

To test whether ZIP and ZINB models are better than the traditional Poisson and negative binominal model, a Vuong test can be applied. For each observation i, the statistical calculation is

$$m_i = LN(\frac{f_1(y_i|X_i)}{f_2(y_i|X_i)}) \tag{5.7}$$

where $f_1(y_i|X_i)$ and $f_2(y_i|X_i)$ is the probability density function of model ZIP and ZINB reprehensively.

The Vuong statistic is:

$$V = \frac{\sqrt{n}[(\frac{1}{n})\sum_{i=1}^{n} m_i]}{\sqrt{(\frac{1}{n})\sum_{i=1}^{n}(m_i-\bar{m})^2}} = \frac{\sqrt{n}(\bar{m})}{S_m} \tag{5.8}.$$

If |V| is less than 1.96 (for a 95% confident level), it indicates ZIP and ZINB are no better than the tradition model. A value for a Vuong statistic greater than 1.96 favors ZINB. The decision guideline for selecting the correct model is shown in table 5.1 (30).

Table 5.1 Guideline of model selection

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">t-Statistic of the NB Overdispersion Parameter α</td></tr>
<tr><td><|1.96|</td><td>>|1.96|</td></tr>
<tr><td rowspan="2">Vuong Statistic for ZINB (f_1) and NB (f_2) comparison</td><td><-1.96</td><td>ZIP or Poisson as alternative to NB</td><td>NB</td></tr>
<tr><td>>1.96</td><td>ZIP</td><td>ZINB</td></tr>
</table>

5.3.4 Random Parameter Count Model

The count models introduced above all assume that parameters are fixed across observations. However, in this study, each observation is the annual accident frequency on one approach of intersection in one of the ten year history. That is, generally, there would 10 observations from the same approach and 20 observations from the same intersection. The sample has repeat observations for each approach or intersection. In this case, there may be some unobserved effects among these repeated observations.

Random parameter count model considers the variations of the effect of variables across observations and is applicable for the sample available in this study. The estimable parameters for Poisson and NB models incorporating random parameters are:

$$\beta_i = \beta + \varphi_i \tag{5.9}$$

Where, φ_i is a randomly distributed term (e.g., normally distributed).

Considering the random effects of φ_i, the Poisson parameter is $\lambda_i|\varphi_i = EXP(\boldsymbol{\beta X_i})$ and the negative binomial parameter is $\lambda_i|\varphi_i = EXP(\boldsymbol{\beta X_i} + \varepsilon_i)$ with the corresponding probabilities as $P(n_i|\varphi_i)$. The resulted log-likelihood is:

$$LL = \sum_{\forall i} ln \int_{\varphi_i} g(\varphi_i)\, P(n_i|\varphi_i)\, d\varphi_i \tag{5.10}$$

where $g(\varphi_i)$ is the probability density function of the φ_i.

Due to the numerical integration of the Poisson or NB function over the distribution of the random parameters in equation 5.10, the random-parameter count model is computationally demanding. Thus, a simulation-based maximum likelihood method is commonly used by applying Halton draws.

5.3.5 Interpretation of Count Models

For all the count models above, it is difficult to make inferences directly from the parameter estimation. Elasticities are computed to determine the marginal effects of 1% change in independent variables x_i on the expected crash frequency. For continuous variables (e.g., AADT), the elasticity of frequency λ_i is calculated as:

$$E_{x_{ik}}^{\lambda_i} = \frac{\partial \lambda_i}{\lambda_i} \times \frac{x_{ik}}{\partial x_{ik}} = \beta_k x_{ik} \tag{5.11}$$

where

E: is the elasticity;

x_{ik}: is the value of k-th independent variable x_k for i-th intersection;

β_k: is the estimated parameter for x_k.

For indicator variables (e.g., 10 mph reduction) with values only as 0 or 1, a pseudo-elasticity provides an inference about the incremental change of the number of crashes from the indicator variable. This is also referred to as marginal effect. The calculation is:

$$E_{x_{ik}}^{\lambda_i} = \frac{EXP(\beta_k) - 1}{EXP(\beta_k)} \tag{5.12}$$

5.3.6 Data Preparation and Model Development

The independent variables tested during model development are summarized in table 5.2. The statistics of all variables are collected in appendix C. Random Parameter NB (RPNB) model is applied to analyze the impact of speed limit reduction on accident frequency. NB is selected due to the over-dispersion of the data. The outputs of coefficient estimation and marginal effects are shown in table 5.3 and 5.4, respectively.

Table 5.2 Variables selection

Variable	Explanation
ID	Identification of 536 sample points from the 29 intersections with 2 approaches of its main street and with 10 years crash data on each approach (which is supposed to be 29*2*10=580), excluding some infeasible data.
Dependent Variable	
Crash Frequency	The annual crashes for each sample
Independent Variables	
0 mph	Dummy variable of Speed Limit Reduction: The data is collected at three types of intersections in terms of speed limit: 1) the same as the highway speed limit (0 mph reduction); 2) 5 mph lower than the highway speed limit (5 mph reduction); 3) 10 mph lower than the highway speed limit (10 mph reduction). Since these reductions are calculated through regular speed limit and signal speed limit, the speed limit will not be used as an independent variable due to their dependency with each other.
5 mph	
10 mph	
Grade	Dummy variables about the grade of the highway close to the intersection: If there is a grade rather than level, Grade=1
Truck%	The percentage of the truck volume at the approach.
Left%	The percentage of the left-turn volume at the approach.
Truck	The average daily truck traffic at the approach
ADT	The Average Daily Traffic at the approach.
Left	The Left-turn volume in the ADT.
Number of Lanes	At the intersection, the original two-lane on regular highway section may expand to three or four lanes by adding Left and/or Right turn lane.
3-Lane 4-Lane	Dummy variables for the Number of Lanes; the intersection may have 2, 3, or 4 lanes at the entry of the intersections in the dataset. Take two-lane as the base, 3-Lane is 1 if there are three lanes and 4-Lane is 1 if there are four lanes.
Raised Median	There are five median types: raised, grass, paint, concrete, and non-median. Non-median is used as the base. Each dummy variable would be 1 if the sample point fell into a certain type.
Grass Median	
Paint Median	
Concrete Median	
Undivided Median	If the median type is paint or non-median, this dummy variable is 1.
Yellow	The variable will be 1 if the actual yellow time is longer than the theory yellow time which is calculated by: $y = t(reaction) + \frac{1.47S_{85}}{2a+(64.4*0.01G)}$ If the actual yellow time is greater than the theoretical value, this dummy variable is 1.
Flasher Dummy	If the difference between the actual flasher time and the theory value is less than 2, Flasher Dummy is 1.

Table 5.3 Coefficient estimation of RPNB model

<table>
<tr><td colspan="3">Dependent Variable: Accident Frequency</td><td colspan="2">Number of Observations: 536</td></tr>
<tr><td colspan="3">Iterations completed: 10</td><td colspan="2">McFadden Pseudo R-squared: 0.31</td></tr>
<tr><td colspan="3">Log likelihood function: -756.93</td><td colspan="2">Restricted log likelihood: -1098.11</td></tr>
<tr><td colspan="3">Chi squared: 682.36</td><td colspan="2">Prob [ChiSqd>value]=.00 (Degree of Freedom=1)</td></tr>
<tr><td>Variable</td><td>Coefficient
(Std. Err)</td><td>P value
(t stat)</td><td>Mean</td><td>Explanation</td></tr>
<tr><td colspan="5">Non-Random Parameter</td></tr>
<tr><td>Constant</td><td>-1.31
(0.29)</td><td>.00
(-4.59)</td><td></td><td></td></tr>
<tr><td>Truck Percent</td><td>3.59
(1.16)</td><td>.00
(3.08)</td><td>0.08</td><td>The percent of average daily truck volume in the total average daily traffic at the approach ranging within [0, 1]</td></tr>
<tr><td>ADT</td><td>0.18
(0.03)</td><td>.00
(6.83)</td><td>5.63</td><td>Average daily traffic at the approach with unit of thousand vehicles</td></tr>
<tr><td>5 mph Reduction</td><td>-0.60
(0.17)</td><td>.00
(-3.61)</td><td>0.17</td><td>Dummy variable for 5 mph reduction at the signal speed limit</td></tr>
<tr><td>10 mph Reduction</td><td>-0.40
(0.21)</td><td>.06
(-1.88)</td><td>0.07</td><td>Dummy variable for 10 mph reduction at the signal speed limit</td></tr>
<tr><td>Undivided Median</td><td>-0.39
(0.17)</td><td>.02
(-2.32)</td><td>0.17</td><td>Dummy variable for undivided median type including non-median and paint median</td></tr>
<tr><td colspan="5">Means for Random Parameter</td></tr>
<tr><td>Flasher
(Normal
Distribution)</td><td>0.28
(0.14)</td><td>.05
(1.97)</td><td>0.70</td><td>If the flasher time at the approach is less than the time required for the vehicle at signal speed limit traveling from flasher to stop line, this dummy variable is 1.</td></tr>
<tr><td colspan="5">Scale parameters for dists. of RANDOM parameters (Standard Deviation)</td></tr>
<tr><td>Flasher</td><td>0.42
(0.06)</td><td>.00
(6.70)</td><td></td><td>Flasher is normally distributed with a mean 0.28 and standard deviation 0.42; that is 74.86% of the distribution is greater than 0.</td></tr>
<tr><td colspan="5">Dispersion parameter for NegBin distribution</td></tr>
<tr><td>ScalParm</td><td>2.61
(0.63)</td><td>.00
(4.14)</td><td></td><td>The dispersion parameter is significant; NB model is more suitable than Poisson model.</td></tr>
</table>

Table 5.4 Marginal effects of NB model with random effects

Variable	Coefficient (Std. Err)	P value (t stat)	Explanation
Truck Percent	3.48 (1.36)	.01 (2.56)	An approach with all-truck traffic will get about 3.5 more accidents per year, compared with non-truck traffic.
ADT	0.17 (0.03)	.00 (4.97)	An increase of 10,000 vehicles will increase about 1.7 accidents per approach per year on average.
5 mph Reduction	-0.58 (0.16)	.00 (-3.60)	On average, an approach with a 5 mph reduction for signal speed limit has 0.6 less accidents than the approach with no speed limit reduction.
10 mph Reduction	-0.38 (0.21)	.07 (-1.79)	On average, an approach with 10 mph reduction for signal speed limit has 0.4 less accidents per year than the approach with no speed limit reduction at the significance level of 90%.
Undivided Median	-0.38 (0.16)	.02 (-2.33)	The approach with no or paint median has less accident than that with divided median; this may be from the fact that intersections do not need median (e.g., with less traffic demand) are generally safer than those who do.
Flasher	0.27 (0.17)	.10 (1.65)	If the flasher time is less than the time needed for the vehicle at signal speed limit traveling from flasher to stop bar, the approach will have generally 0.27 more accidents per year at the significance level of 90%. However, the effect varies across observations.

5.3.7 Interpretation of Results

1) Traffic volume also impacts crash frequency at 95 % level of significance. 1% increase in the average daily traffic (1,000 vehicles) of one approach will increase total accidents by 0.17%; a 1% increase in truck composition of traffic flow will increase total accidents by 3.48%.

2) Approaches with undivided median have 0.38 less crashes per year compared with approaches with other type of median. This seems opposite to common expectation that divided median should improve safety by reducing number of accidents. One explanation is that, using divided median is one measure to address unsafe sites; the approaches with 'undivided median'

are the sites with less or no safety concerns and less crashes. Also, although the divided median did not show reducing impact on crash frequency, it shows the impact to reduce possibility of PDO crashes in the severity analysis at section 5.4.

3) Flasher is one random parameter with normal distribution with a mean 0.28 and standard deviation 0.42; that is 74.86% of the distribution is greater than 0. In most of time (74.86%), if a flasher time is less than the required time for drivers traveling from flasher to stop bar at speed according to signal speed limit, the approach will have more accident. However, the effect varies across observations since there is still 25.14% percent of time when its distribution is greater than 0 and increase crash frequency would be resulted.

4) Annually, on average, 10 mph reduction approaches have 0.4 fewer crashes than approaches with 0 mph reduction at a 90% level of significance. That is, 10 mph drop in the speed limit in the vicinity of an intersection on a facility designed to serve traffic at 65 mph leads to a significant reduction in crash count. 5 mph reduction approaches, on average, have 0.6 few annual crashes than approaches with 0 mph reduction at a 95% level of significance.

It is notable that 5 mph reduction did not have any impact on average speed or speed standard deviation based on the speed analysis in chapter 4 while it has significant impact on reducing accident frequency. There could be many reasons for this seeming inconsistency. Besides travel speed, there are many other factors that would lead to traffic accidents, especially human factors. Although based on the speed data collected in this research, 5 mph reduction did not show significant impact on reducing travel speeds. The signal speed limit sign with reduced limit may still be able to keep drivers aware and vigilant of the possible braking and other maneuvers in the vicinity of intersections. Also, the speed data in this research is collected within limited range; there is no way to understand a speed change beyond this range. Furthermore, the seven intersections in speed analysis are a subset in the dataset used in accident analysis and only include two intersections with 5 mph reduction. A speed analysis with larger dataset may yield a more confident conclusion.

To compare the accident frequency distribution among the intersection in the dataset for accident analysis, figure 5.2 shows the distributions of accident frequency for the sites in speed analysis and the sites in accident analysis but not in speed analysis separately through box-plot. Y-axis is the number of accident. X-axis shows the group name for each box where A stands for being in speed and accident analysis simultaneously and B stands for being in accident analysis only. For example, A-0MPH group is for the sites with 0 mph reduction in speed analysis, B-0MPH group is for the sites with 0 mph reduction in accident analysis excluding the sites in group A-0MPH.) For 10 mph reduction, both speed analysis and accident analysis used the same intersections. Thus, single group A/B-10MPH is shown in the figure. From this figure, it is easy to tell that the sites in group A-0MPH has less accidents compared to group B-0MPH while the sites in A-5MPH is not better than those in group B-5MPH. If compare the accident frequency for only A-groups for 0 mph reduction and 5 mph reduction in speed analysis, the accident frequency is not reduced for 5 mph reduction group compared with 0 mph reduction group; this is consistent with the conclusion in speed analysis that 5 mph reduction did not have impact on reducing average speed, neither does 0 mph reduction.

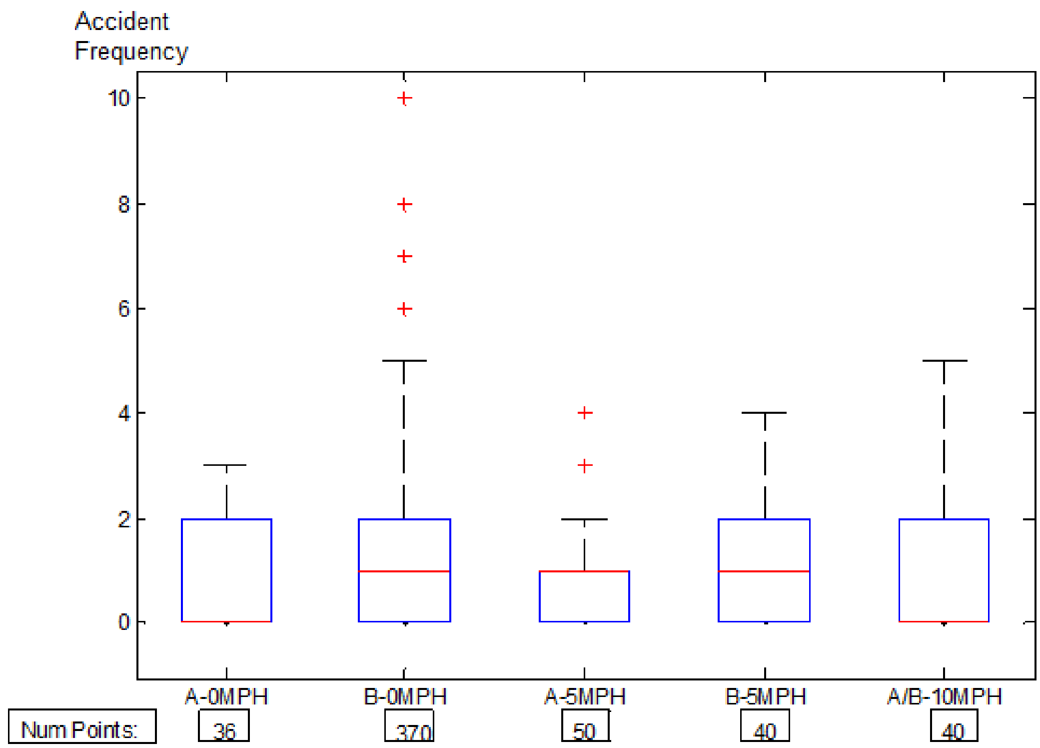


Figure 5.2 Box plots for various groups

5.4 Crash Severity Model

5.4.1 Literature Review

Studies of the effects of traffic characteristics as well as driver characteristics on crash severity are widely studied for various kinds of crashes. Johansson applied time series count data regression models (i.e., Poisson Model, Negative Binomial Model, Zeger Model, and Structure Approach Model) for each severity level of crashes (27). Due to the ordinal scale of the dependent variable, level of severity, an ordered discrete model could be applied. O'Donnell and Connor identified risk factors that increase the probabilities of serious injury and fatalities with the ordered Logit model and ordered Probit models (35). Jin et al. applied an ordered Logit model to study the factors significantly contributing to the severity of right-angle crashes (31). The results showed that factors such as whether the person was ejected, alcohol and/or drug use, the driver's age, point of impact, and standardized yellow time have significant impacts on the average severity of crashes. However, traditionally ordered probability models are susceptible to underreporting of crash-injury data; also, the shift in thresholds is constrained to move in the same direction (42). These two drawbacks make it improper to use ordered probability models in accident severity analysis. In the current research, a Multinomial Logit model (MNL) was used to study the critical factors for accident severity. MNL has been applied widely in this area. Lee and Mannering studied the relationship between observable characteristics such as season, weekday, daylight, and other roadway factors through developing an MNL model (33). Shankar and Mannering used an MNL model specification to estimating the severity of motorcycle rider crash severity given that a crash has occurred (43). Carson and Mannering developed MNL models to identify the effect of warning signs on ice-related crash severities on interstates, principal arterials, and minor arterial state highways (44). Sriniva et al. applied MNL to predict the proportion of crashes by manner of collision.

5.4.2 Multinomial Logit Model (MNL)

Let T_{in} be a linear function that determines discrete the severity i for observation n as

$$T_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{5.13}$$

where,

β_i is a vector of estimable parameters of discrete severity level i; and X_{in} is a vector of the observable characteristics which determine discrete outcomes for observation n. ε_{in} is a disturbance term which can account for the unobserved effects. Under the assumption that the disturbance term is independently and identically distributed, extreme value Type I distributed, the standard multinomial logit formulation can be built as

$$P_n(i) = \frac{EXP(\beta_i X_{in})}{\sum_{\forall I} EXP(\beta_I X_{In})} \tag{5.14}$$

Maximum likelihood can estimate the parameter beta. The log maximum likelihood function is

$$LL = \sum_{n=1}^{N}\left(\sum_{i=1}^{I} \delta_{in}\left[\beta_i X_{in} - LN \sum_{\forall I} EXP(\beta_I X_{In})\right]\right) \tag{5.15}$$

where,

I is the total number of outcomes and δ is defined as being equal to 1 if the observed discrete outcome for observation n is i and 0 otherwise (30).

5.4.3 Mixed Logit Model

The Mixed Logit Model is also referred to as the Random Parameter Logit (RPL) or Mixed Multinomial Logit Model (MMNL), as shown in equation 5.16. The MNL mode has three assumptions: 1) the data is case specific (i.e., each independent variable has a single value for each case; 2) colinearity of independent variables is relatively low, high correlation makes it difficult to differentiate the impacts of different variables; 3) independence of irrelevant alternatives. Mixed Logit Model obviates these three assumptions since it allows for random parameters which are varied across observations. The β_i in equation 5.13 could be randomly distributed according to normal, lognormal, triangle, uniform and other distribution (i.e., $\beta_i \sim f(\beta_i|\theta)$).

$$P_n(i) = \int \frac{EXP(\boldsymbol{\beta}_i \boldsymbol{X}_{in})}{\sum_{\forall I} EXP(\boldsymbol{\beta}_I \boldsymbol{X}_{In})} \mathrm{f}(\boldsymbol{\beta}|\theta)\mathrm{d}\boldsymbol{\beta} \tag{5.16}$$

5.4.4 Data Preparation and Model Development

Most of the variables in previous studies, such as one-way, light condition, weather condition, curve and slope, concrete or asphalt pavement, and functional classification do not have enough variability in terms of intersection accidents; and are not included in this study. The analysis of severity based on identical traffic-related characteristics for accident frequency studies is listed in table 5.2. A summary of the statistics of all the variables in accident severity model is given in appendix D. Besides. Accident-related variables are also considered and listed in table 5.5.

Table 5.5 Variable explanation

Variable	Explanation
ID	Identification of 635 accident in the dataset
Dependent Variable	
Crash Severity	Level 0: Property Damage Only (PDO) Level 1: Possible Injury Level 2: Injury (including fatality, incapacitating injury and non-incapacitating injury)
Independent Variables	
Angle Acc	Dummy variables related to crash type; the value is 1 if the accident is corresponding type. Out-of-Control is used as base.
Rear-end Acc	
Head-on Acc	
Out-of-Control	
Weekday	If the accident happed at weekday, this variable is 1.
Multivehicle	If there are more than two vehicles involved in the accident, this variable is 1.
Heavy vehicle	If there is heavy vehicle involved, this variable is 1.
Old Driver	If the driver of the at-fault-vehicle in the accident is older than 60 years old, the Old Driver variable is 1; if the driver of the cause-vehicle in the accident is younger than 20 years old, the Young Driver variable is 1.
Young Driver	
Alcohol	If the driver in accident was driving under the influence of alcohol, this variable is 1.
Gender	If the driver of at-fault vehicle is male, this variable is 1.
Divided Median	If the median type is grass, raised and concrete, this variable is 1.
Left-Lane	If the intersection has exclusively left-turn lane, this variable is 1.
Signal Speed Limit=60	If the signal speed limit is 60 mph, this variable is 1.
ADTL	ADT per lane in the unit of 1,000 vehicles

The coefficient estimation of the MNL model using Property Damage Only (PDO) level as a base is listed in table 5.6. The elasticity analysis is shown in table 5.7.

Table 5.6 Coefficient estimation of Mixed Logit Model of significant variables

Dependent variable: Crash Severity			Restricted log likelihood: -697.62 Log likelihood function: -626.12
Number of observations: 635			Chi squared: 142.99
McFadden Pseudo R-square: 0.10			Prob[ChiSqd > value] = .00
Variable	Coefficient (Std. Err)	P value (t stat)	Explanation
PDO crash			
Multivehicle	-1.15 (0.36)	.00 (-3.19)	If there are more than two vehicles involved in the accident, this variable is 1.
Divided Median	-0.95 (0.27)	.00 (-3.49)	If the median type is grass, raised and concrete, this variable is 1.
Yellow	0.44 (0.20)	.03 (2.17)	If the actual yellow time is greater than the theoretical value, this dummy variable is 1.
Possible injury crash			
Constant	-1.29 (0.30)	.00 (-4.37)	
Rear-end Acc	0.75 (0.22)	.00 (3.38)	Out-of-control, head-on and angle crashes is the base for possible injury modeling.
10 mph reduction	-0.90 (0.45)	.05 (-1.98)	If the approach is with 10 mph reduction for its signal speed limit, this variable is 1.
Left%	-4.03 (2.19)	.07 (-1.84)	The percentage of the left-turn volume at the approach. This variable is a random parameter with triangle distribution. This is probably resulted from the interaction between left-turn traffic volume and exclusive left-turn lane.
STD of Left% (Triangle Dist)	10.77 (6.62)	.10 (1.63)	
Injury and fatal crash			
Constant	-3.55 (1.37)	.01 (-2.58)	
Rear-end Acc	-0.82 (0.25)	.00 (-3.32)	Dummy variables related to crash type: angle, rear-end, head-on, and out-of-control. The value is 1 if the accident belongs to corresponding type. Out-of-control and angle crashes are the base for injury and fatal crash modeling.
Head-on Acc	1.16 (0.43)	.01 (2.67)	
Gender	-0.40 (0.19)	.04 (-2.10)	If the at-fault vehicle driver is male, this variable is 1.
Alcohol	1.54 (0.55)	.01 (2.81)	If the driver in the accident was driving under the influence of alcohol, this variable is 1.
ADTL	0.20 (0.10)	.06 (1.89)	ADT per lane in the unit of 1,000 vehicles
Signal SL	0.04 (0.03)	.09 (1.71)	Signal speed limit (mph)

Table 5.7 Elasticity analysis of Mixed Logit Model

Elasticity Averaged Over Individuals: Mean (St. Dev.)				
Variable	Y=0 (PDO)	Y=1 (Possible)	Y=2 (Injury)	Comments
Rear-end Acc	*	0.13 (0.20)	-0.20 (0.31)	Rear-end collisions are more likely to be in the severity level of possible injury; but less likely to be injury and fatal crashes.
Head-on Acc	*	*	0.02 (0.09)	Head-on accidents are more likely to be associated with fatal and injury crashes.
Multivehicle	-0.06 (0.23)	*	*	Accidents with multiple vehicles are less likely to be PDO accidents.
Alcohol	*	*	0.01 (0.10)	Alcohol involvement increases the probability of fatal and injury crashes.
Gender	*	*	-0.18 (0.15)	Male drivers are less likely to cause injury and fatal crashes.
10 mph reduction	*	-.04 (0.17)	*	A 10 mph reduction on the signal speed limit reduces the possibility of getting possible injury crashes at 95% level of significance.
ADTL	*	*	0.28 (0.13)	Increase at ADT per lane tends to increase the probability of fatal and injury crashes.
LEFT%	*	-0.14 (0.11)	*	Higher percentage of left-turn volume will reduce the probability of possible injury crashes; but this effect varies among observations.
Divided Median	-0.46 (0.21)	*	*	Divided median would reduce the probability of PDO crashes.
Signal SL	*	*	1.60 (0.33)	The crashes under higher signal speed limit are more likely to be a fatal and injury crashes.
Yellow	0.07 (0.10)	*	*	A yellow time longer than theoretical value increase the possibility of PDO crashes.

5.4.5 Interpretation of Results

The impact of each factor is explained in table 5.7. In terms of speed limit, lower speed limit in the vicinity of signalized intersections was found to be statistically significant in alleviating crash severity by reducing the probability of fatal and injury crashes Moreover, the dummy variable of 10 mph reduction at signal speed limit reduces the probability of possible injury accidents at a 95% level of significance. To sum up, for a high-speed signalized intersection on a highway with a regular speed limit of 65 mph, a 10 mph reduction will reduce possible injury accidents, and the resulting signal speed limit (i.e., 55 mph) will reduce the probability of injury and fatal accidents significantly.

Compared to angle accidents and out-of-control accidents, rear-end accidents are more likely to result in possible injury, while head-on accident are more likely to result in injury or fatality. Head-on accidents therefore are often the most severe accidents, and require case-by-case study to determine if there are potential factors related to the traffic system that cause this type of accident. Further, accidents involving multiple vehicles are less likely to be PDO accidents in comparison to two-vehicle accidents. However, this reduction of probability on PDO crashes will probably be accompanied with increase of probability on severe crashes although this is not significant in this model. Another risk factor for fatal and injury accidents is alcohol. Education and policy implementation are required to improve this problem. Also, female drivers are more likely to cause injury and fatal accidents.

Moreover, traffic conditions like ADT per lane would increase the probability of fatal and injury crashes. Increased percentage of left-turn volume reduces the chance of possible injury; this impact, however, varies across observation and is triangularly distributed. Yellow time longer than theoretical value and divided median both reduce the probability of PDO crashes.

5.5 Summary

Table 5.8 summarizes this chapter in terms of the impact of various speed limit reductions on accident frequency and severity. "NS" indicates no significant effect. These findings are specified for the speed limit setup, shown in the second row of table 5.8. For the studied intersection approaches with 10 mph reduction from the regular highway speed limits of

65 mph in this project, there is some evidence that speed limit reduction with presence of AWF increases driver safety. A limitation of this study was that there existed only four approaches having a 10 mph reduction from 65 to 55 mph. Another limitation is a need to estimate the explanatory variable utilizing a larger sample size in order to arrive at firmer conclusions. And for a specific site with problematic safety issues, a before-and-after study should be implemented to justify the 10 mph speed limit reduction. For 5 mph speed limit reduction (i.e., reductions from 60 mph to 55 mph and from 55 mph to 50 mph), there were statistically significant effects on reducing the accident frequency but not on severity of the nine approaches studied in this research. In future research, sites with 5 mph reduction from 65 mph to 60 mph should be included to draw further conclusions. It was also found that higher speed limits are more likely to result in fatal and injury crashes.

Table 5.8 Summary of the safety effects of speed limit reduction

Speed Limit Reduction (mph)	10	5	0
Highway/Upstream Speed Limit (mph)-Signal/Downstream Speed Limit (mph) [Number of Approach Studied]	65-55 [4]	60-55 [7] 55-50 [2]	40-40 [2] 45-45 [4] 50-50 [4] 55-55 [29] 60-60 [4]
Total Number of Approaches Studied	4	9	43
Accident Frequency	Reduced by 0.4 per approach per year (at a 90% level of significance)	Reduced by 0.6 per approach per year (at a 95% level of significance)	
Accident Severity	At 95% level of significance, probability of getting possible injury crashes is reduced when that of PDO accident is increased.	NS	
Note: Signal speed limit would decrease the possibility of fatal and injury at 90% level of significance.			

Note: NS-Not Significant at 90% level of significance.

Chapter 6 Conclusions

This study provides empirical analysis of the effect of reduced transitional speed limits in the vicinity of high-speed, signalized intersections with AWF on speed distribution and crash frequency and severity. AWF is recommended by MUTCD, and commonly used at high-speed intersections in Nebraska, where around 60 advance warning beacons are installed on roads having a speed limit of 50 mph or higher. For intersections already equipped with AWF, the necessity and effectiveness of speed limit reduction has not been thoroughly studied in previous research. In Nebraska, typically speed limits in the vicinity of high-speed signals are not greater than 55 mph. That is, the speed limit is usually reduced to 55 mph for signals if the highway speed limit is higher than 55 mph. However, there is no official document to guide AWF implementation in terms of the magnitude of limit reduction and its effect. In the procedures that establish speed zone in Texas, a speed limit could be lowered by up to 10 mph in lieu of limited field of vision near the intersection. If the intersection crash rate is higher than the state average, the speed limit could be lowered by as much as 12 mph. However, there is no specific recommendation in terms of high-speed intersections installed with other safety measures. This study provides several helpful observations in terms of the advantages of reduced transitional speed limits at high-speed intersections with AWF over intersections only having AWF.

First, the effect of speed limit reduction on reducing speed in the field was tested with speed data collected from seven intersections having AWF. The seven intersections were grouped into 0 mph reduction, 5 mph reduction (from 60 mph to 55 mph) and 10 mph reduction (from 65 mph to 55 mph) intersections. Wavetronix sensor was used to collect vehicle speed and corresponding distance. By collecting speed data for two separate locations—one close to the signal speed limit sign and the other approximately 600 ft from the stop bar—the question of whether there is significant difference among the mean speeds at these two locations was studied using quantile regression models and SURE models. Quantile regressions for the individual average speeds at 10 mph reduction showed that 10 mph reductions from 65 mph to 55 mph incurred a more uniformly distributed speed distribution in the vicinity of signals. The quantile regression of 85^{th}, 50^{th}, and 15^{th} percentile speeds indicated a 4.6 mph, 4.2 mph, and 3.2 mph reduction, respectively. By further reducing the fast traffic, the 10 mph reduction reduced the dispersion of speed distribution at the vicinity of high-speed intersections in terms of an inter-percentile range between the 85^{th} and 15^{th} percentiles. Reduced speed limit variability has, in the past, been found to correlate positively with improved safety. However, the seemingly unrelated equation models did not show any significant negative impact of 10 mph limit reduction on the standard deviation of grouped individual average speeds. On the other hand, this proves that there is no increase in the standard deviation of speeds by 10 mph limit reduction. SURE models estimate the variables for both the mean and the standard deviation collectively, and take into consideration the possibility of unobserved factors impacting both mean and standard deviation. The results indicated a significant, 3.8 mph reduction in mean speed for the 10 mph reduction intersections and no significant reduction for the 5 mph reduction intersections. This result coincides with a study conducted in Virginia, in which increases of 1.7 mph and 4.3 mph in mean speeds were observed from a 10 mph increase on speed limits (9).

Aside from the effect of reducing driving speeds in the field, the intent of this research also included providing a methodological study of the effect of the implementation of a transitional speed zone at signalized, high-speed intersection with AWF on increasing driver safety. A crash analysis was performed to identify the effects of speed limit reductions on crash severity and frequency. The accident dataset included four approaches with 10 mph speed limit reduction from 65 mph to 55 mph and nine 5 mph-speed-limit reduction approaches, seven of which were from 60 mph to 55 mph and two of which were from 55 mph to 50 mph. Based on the available information from 28 intersections in Nebraska State, both 5 mph and 10 mph reduction demonstrate a significant effect on reducing crash frequency based on a RPNB model with a dependent variable of annual crash count for each approach. This conclusion supports the Texas procedure which recommends as much as 12 mph reduction in speed limit whenever the crash rate of an intersection is higher than the state average. A Mixed Logit model was developed to study the impact of speed limit reduction on crash severity; 10mph reduction showed significant effects on reducing the probability of possible injury crashes at a at 95% level of significance. It was also found that the higher the signal speed limit is, the more likely the occurrence of fatal and injury crashes.

The study shows that even with AWF facility, reduction on speed limit in the vicinity of high-speed signalized intersection still improves the safety condition in comparison with those without speed limit reduction. The conclusions of this study, however, are limited by the small sample size, especially for the approaches with 10 mph speed limit reduction from 65 mph to 55 mph. Also, for the approaches with 5 mph reduction, most were from 60 mph to 55 mph. Future research should include more varieties of limit reduction sets, as well as larger sample size. For a specific site of interest, a before-and-after study is strongly recommended to identify the impact of a specific speed limit reduction.

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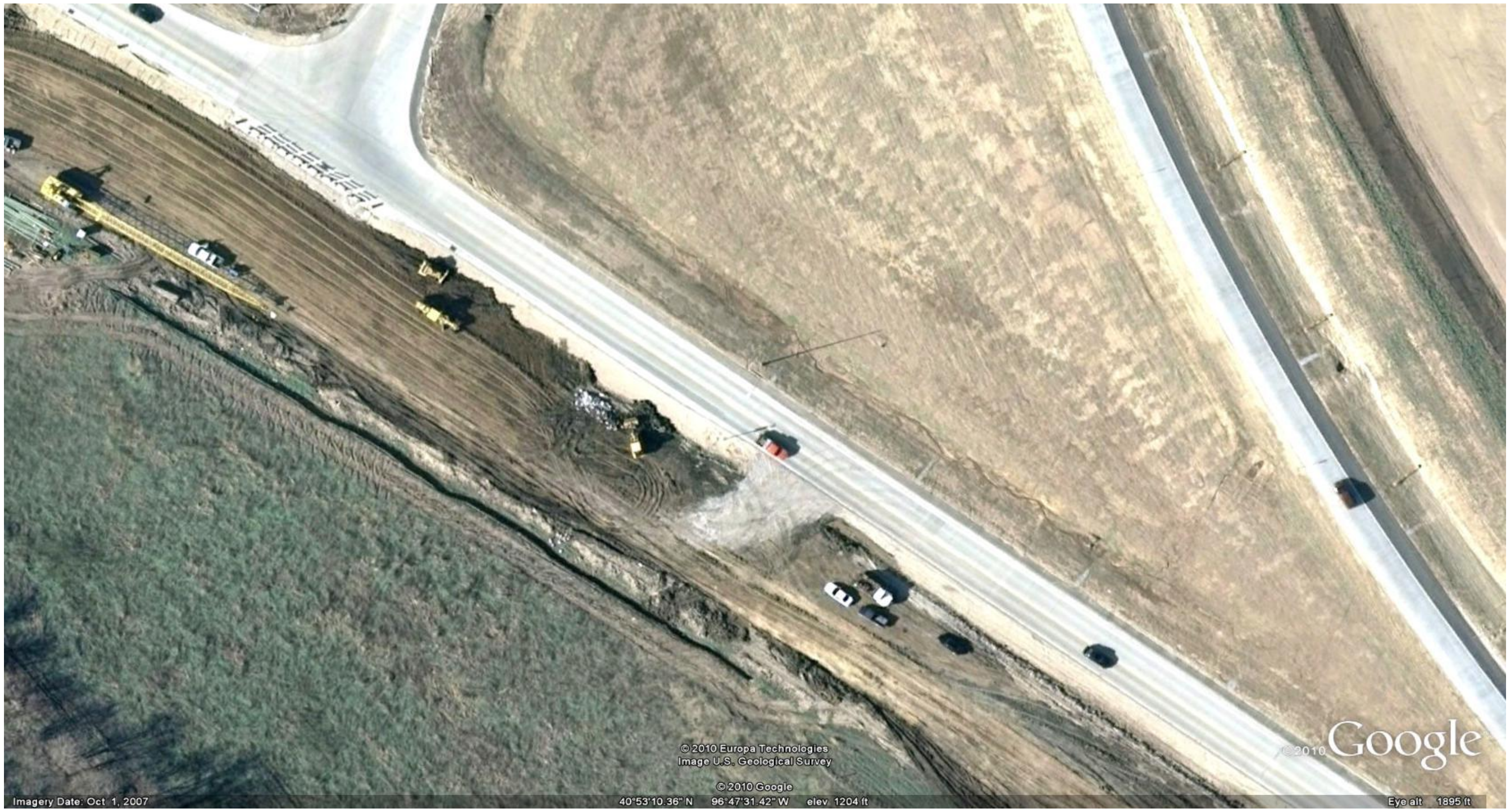
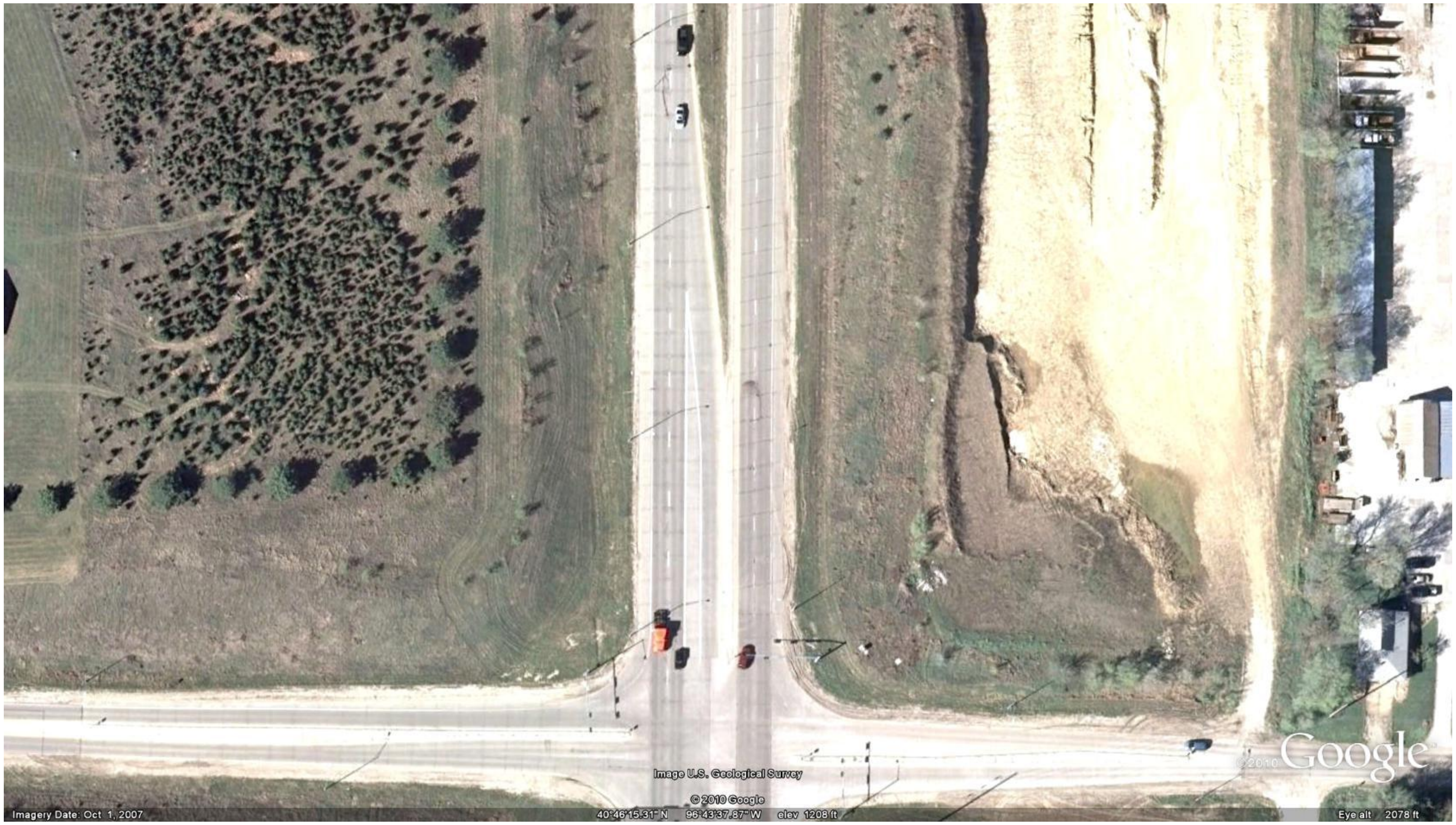
Appendix A Information on the Intersections

#1 – US-34 and N-79 (Westbound Approach)



Speed limit through signal (mph)	Speed limit prior to signal (mph)	Number of lanes	Nearest intersection	Area type	Road curvature	Comments: **Westbound Approach Selected** Good feasibility for communicating with the traffic cabinet and parking the trailer along US-34
60	60	2 WB 1 NB	0.7 mi East	Rural	No	

#2– US-77 & Pioneers Blvd. (Southbound Approach)



Speed limit through signal (mph)	Speed limit prior to signal (mph)	Number of lanes	Nearest intersection	Area type	Road curvature	Comments:
55	55	2 SB; 1WB/1EB	1.0 mi North	Rural	No	**Southbound Approach Selected** Good feasibility for parking the trailer along US-77. Potential problem with communicating with the traffic cabinet, as there is a sign in the line of sight.

#3 – N-133 and N-36 (Northbound Approach)

Speed limit through signal (mph)	Speed limit prior to signal (mph)	Number of lanes	Nearest intersection	Area type	Road curvature	Comments: **Northbound Approach Selected**
55	55	2 NB & 1EB/WB	1.1 mi South	Rural	No	Speed limit sign was only 1,000 ft from the intersection. End of curve approx. 2,000 ft from intersection

#4 – US-75 & Platteview Rd. (Southbound Approach)

Speed Limit through signal (mph)	Speed limit prior to signal (mph)	Number of lanes	Nearest Intersection	Area Type	Road Curvature	Comments:
55	60	2 SB & 1EB/WB		Rural	No	**Southbound Approach Selected** Good parking and traffic cabinet feasibility. Cabinet is located on NE side of intersection. Traffic merging from Fairview Rd. Prior to speed limit sign there is an advance speed reduction sign.

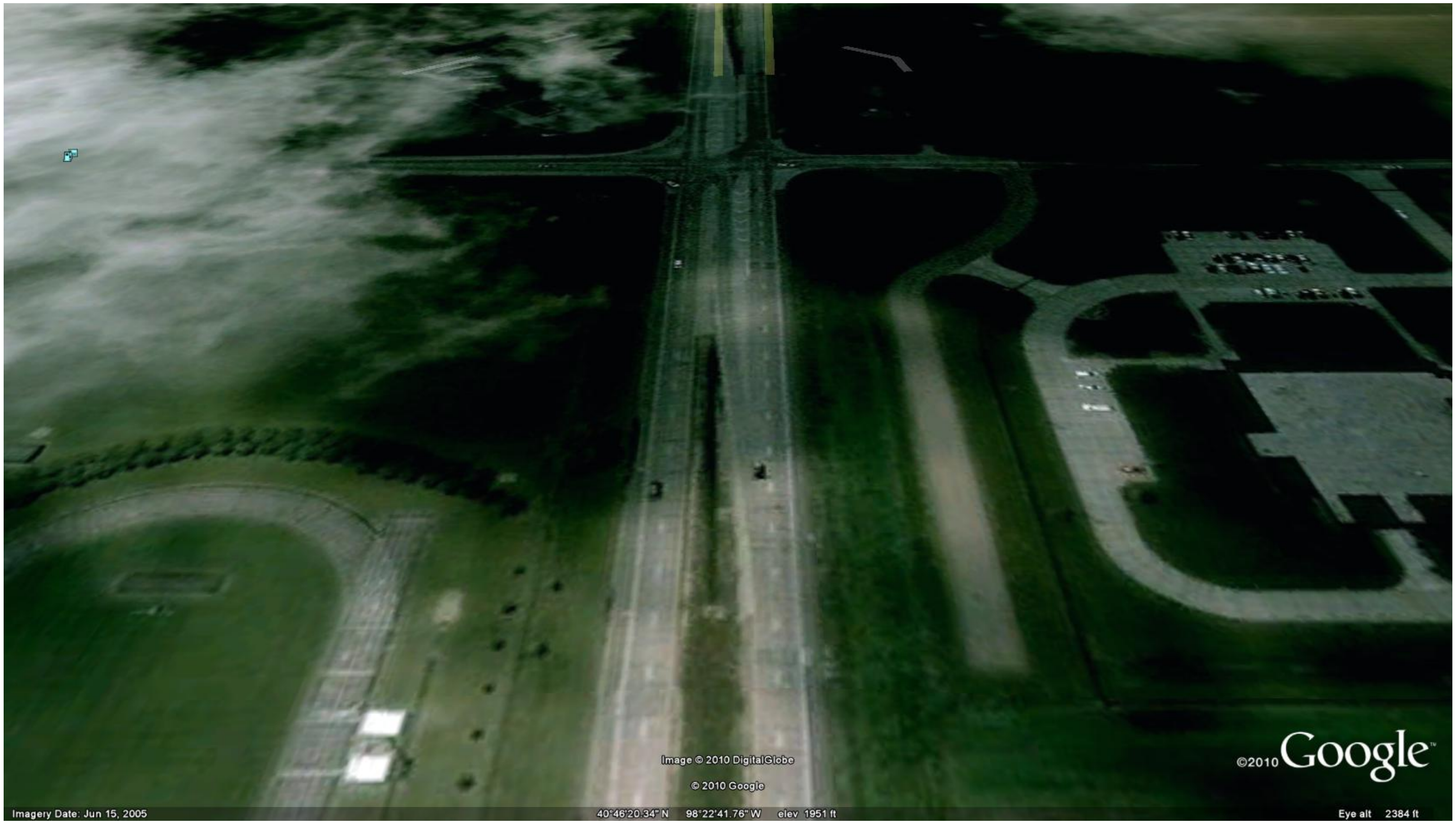
#5– US-81 & S. Lincoln Ave. (Southbound Approach)

Speed limit through signal (mph)	**Speed limit prior to signal (mph)**	**Number of lanes**	**Nearest intersection**	**Area type**	**Road curvature**	**Comments:**
55	60	2 NB & 1 EB/WB		Rural	No	**Southbound Approach Selected** Approach includes a reduced speed sign. Good feasibility for parking the trailer. No problems communicating between traffic cabinet and pole cabinet.

#6 – US-77 & Saltillo Rd. (Northbound Approach)

Speed limit through signal (mph)	Speed limit prior to signal (mph)	Number of lanes	Nearest intersection	Area type	Road curvature	Comments: **Northbound Approach Selected** Northbound approach has a slight grade, still able to communicate
55	65	2 SB & 1 WB/1EB	1.0 mi North	Rural	No	

#7 – US-281 & W. Platte River Dr. (Southbound Approach)



Speed limit through signal (mph)	Speed limit prior to signal (mph)	Number of lanes	Nearest intersection	Area type	Road curvature	Comments: Southbound Approach Selected
55	65	2 SB & 1 EB/WB		Rural	No	Approach includes a reduced speed sign. Good feasibility for parking the trailer. No problems communicating between traffic cabinet and pole cabinet.

Appendix B Intersection Information of Crash Analysis

No.	Highway	Cross Street	Highway Speed Limit	Signal Speed Limit	Speed Limit Reduction	Number of Approaches	Approaching Lanes	Median Type	Distance to AWF	Yellow Time	Flasher Time
1	US-30	30th Ave.	40	40	0	2	2+L	Raised	650	4.5	10
2	US-83	J St.	45	45	0	2	2+L	Concrete	650	4.5	8
3	US-75	N-2 (S. Jct. Bypass)	45	45	0	2	2+L+R (WB) & 2+L (EB)	Grass	650	4.5	10
4	US-275	N-24	50	50	0	2	2+L	Raised	650	4.5	9
5	US-81	Ta-Ha-Zouka	50	50	0	2	2+L	Raised	650	4.5	9
6	US-30	US-81 (S. Jct.)	55	55	0	2	2+L+R (SB) & 2T+L (NB)	Raised	650	4.5	8
7	US-30	29th Ave. E.	55	55	0	2	2+L	Raised	650	4.5	9
8	N-36	N-133	55 (NB)	55 (NB)	0	1	2+L	Raised	650	4.5	8
9	US-6	Q ST.	55	55	0	2	1+L	Raised	650	4.5	8
10	US-34	US-281	55	55	0	2	2+L+R	Grass	650	5	8
11	US-77	Old Cheney Rd.	55	55	0	2	2+L	Grass	650	5	7
12	US-77	Pioneers	55	55	0	2	2+L	Grass	650	5	8
13	US-6	Wal-Mart/ Wedgwood	55	55	0	2	1+L+R (W)	None	650	4.5	10
14	N-370	108th St.	55	55	0	2	2T+R (W) & 2+2L (E)	Grass	650	4	8
15	US-75	N-66	55	55	0	2	1+L	None	650	4.5	9
16	US-75	Ave. B	55	55	0	2	1+L	None	650	4.5	8
17	N-370	168th St.	55	55	0	2	1+L (W) & 2+L (E)	None	650	4.5	8
18	N-370	132nd St.	55	55	0	2	2+L+R	Grass	650	4.5	8
(continued)											

19	US-6	I-80 ramp	55	55	0	2	2 (W) & 2+L (E)	Raised	650	4.5	8
20	US-34	N-79	60	60	0	2	2T+L (W) & 2T (W)	Raised	650	4.5	7
21	US-34	NW 48th St.	60	60	0	2	2+L+R (W) & 2+L (E)	Raised	650	4.5	7
22	N-36	N-133	60 (SB)	55 (SB)	5	1	2+L	Raised	650	4.5	8
22	N-36	72nd St.	55 (NB)	55 (NB)	0	2	2+L	Painted	650	4.5	8
23	L17J	Old Post Rd.	55	50	5	2	2+L+R	Raised	650	4.5	8
24	US-75	LaPlatte Rd.	60	55	5	2	2+L	Grass	480	4.5	6
25	US-75	Platteview Rd.	60	55	5	2	2+L+R	Grass	480	4.5	6
26	US-81	Lincoln Ave.	60	55	5	2	2+L (N) & 2 (S)	Raised	650	4.5	7
27	US-34	Pine St.	65	55	10	2	2+L	Raised	650	4.5	7
28	US-77	Saltillo Rd.	65	55	10	2	2+L (N) & 2+L+R (S)	Grass	650	4.5	7

Appendix C Statistics of Variables in Accident Frequency Model

Variable	Mean	Std. Dev.	Minimum	Maximum	Cases
Angle Accident Frequency	0.68	1.03	0	6	536
Rear-End Accident Frequency	0.35	0.72	0	5	536
Head-on Accident Frequency	0.05	0.24	0	2	536
Out-of-Control accident frequency	0.06	0.25	0	2	536
Total Accident Frequency	1.14	1.42	0	10	536
UP_SL	54.96	5.45	40	65	536
Sig_SL	53.38	4.16	40	60	536
Dis_AWF	636.19	48.83	450	650	536
AMBER	4.54	0.19	4	5	536
Flasher	8.03	1.05	6	10	536
Left%	0.13	0.14	0	0.55	536
Truck%	0.08	0.06	0	0.37	536
0 mph	0.76	0.43	0	1	536
5 mph	0.17	0.37	0	1	536
10 mph	0.07	0.26	0	1	536
3-Lane	0.57	0.50	0	1	536
4-Lane	0.28	0.45	0	1	536
Raised Median	0.46	0.50	0	1	536
Grass Median	0.34	0.47	0	1	536
Paint Median	0.02	0.14	0	1	536
Concrete Median	0.04	0.19	0	1	536
Non-Median	0.15	0.36	0	1	536
Yellow	0.11	0.32	0	1	536
ADT	5.63	2.75	1.139	16.081	536
LEFT	0.66	0.78	0	4.1	536
TRUCK	0.36	0.23	5.00E-03	2.059	536
FLASH	0.70	0.46	0	1	536

Appendix D Statistics of Variables in Accident Severity Model

Variable	Mean	Std. Dev.	Minimum	Maximum	Cases
Crash Severity	0.845669	0.854452	0	2	635
Weekday	0.76063	0.427035	0	1	635
Angle Acc	0.607874	0.488609	0	1	635
Rear-end Acc	0.300787	0.458962	0	1	635
Head-on Acc	3.94E-02	0.194627	0	1	635
Out-of-Control	5.20E-02	0.222138	0	1	635
Old Driver	0.177953	0.382774	0	1	635
Gender	0.63937	0.480562	0	1	635
Alcohol	2.52E-02	0.156846	0	1	635
2-Lane	0.137008	0.344127	0	1	635
3-Lane	0.511811	0.500255	0	1	635
4-Lane	0.351181	0.477716	0	1	635
Left Lane	0.944882	0.228391	0	1	635
Divided Median	0.87874	0.326686	0	1	635
0 mph	0.801575	0.399128	0	1	635
5 mph	0.138583	0.345783	0	1	635
10 mph	5.98E-02	0.237382	0	1	635
TRUCK%	7.42E-02	6.41E-02	4.46E-03	0.372731	635
LEFT%	0.111372	0.119984	0	0.484754	635
Young Driver	0.146457	0.353842	0	1	635
Hwy. Speed Limit	54.7795	5.44098	40	65	635
Signal Speed Limit	53.4882	4.31392	40	60	635
Flasher Dummy	0.267717	0.443118	0	1	635
Multivehicle	7.56E-02	0.26455	0	1	635
Heavy Vehicle	0.103937	0.305419	0	1	635
ADT	6.3165	2.70927	1.512	15.612	635
TRUCK	0.399699	0.270933	7.00E-03	2.059	635
LEFT	0.639367	0.774102	0	4.1	635
Signal Speed Limit=60	5.98E-02	0.237382	0	1	635

Appendix E Survey Emails

In the following pages is the email correspondence between the researchers and survey respondents. The respondents include representatives from California, Colorado, Iowa, Kansas, Missouri, South Dakota, Texas, and Wyoming (respectively).

Subject:	Fw: Questions ...supplement
From:	Ahmad Rastegarpour (ahmad_rastegarpour@dot.ca.gov)
To:	zifengwu2008@yahoo.com;
Cc:	shaila_chowdhury@dot.ca.gov; roberta_mclaughlin@dot.ca.gov;
Date:	Friday, November 18, 2011 11:09 AM

Hi Zifeng,

I am responding to your question below:

Question:

And for the advance warning devices, do you use advance warning flasher which can be timed with the signal and begin to flash when the car is expected to arrive the intersection at red?

Answer:

We do use advance warning flashing beacon, but they are not timed to the operation of traffic signal.

Thanks,

Ahmad Rastegarpour, P.E.
Division of Traffic Operations
California Department of Transportation
916.651.6128
----- Forwarded by Ahmad Rastegarpour/HQ/Caltrans/CAGov on 11/18/2011 09:03 AM -----

Roberta McLaughlin/HQ/Caltrans/CAGov
11/17/2011 01:59 PM

To
Shaila Chowdhury/HQ/Caltrans/CAGov@DOT
cc
Ahmad Rastegarpour/HQ/Caltrans/CAGov@DOT
Subject
Re: Fw: Questions ...supplement
(Document link: Ahmad Rastegarpour)

That question is best answered by Ahmad is the signal section.

Roberta L. McLaughlin, PE, TE, PTOE
Office of Signs, Markings and CA MUTCD
Division of Traffic Operations
California Department of Transportation
PHONE: 916-651-1248

Shaila Chowdhury/HQ/Caltrans/CAGov
11/17/2011 01:43 PM

To: Roberta McLaughlin/HQ/Caltrans/CAGov@DOT
cc:
Subject: Fw: Questions ...supplement

Please see the new inquiry from Zifeng.

Thanks,
Shaila Chowdhury, P.E.
Executive Engineering Assistant
Division of Traffic Operations
California Department of Transportation
Ph: (916) 651 9377
Cell: (916) 969 6186
----- Forwarded by Shaila Chowdhury/HQ/Caltrans/CAGov on 11/17/2011 01:37 PM -----

Zifeng Wu <zifengwu2008@yahoo.com>
11/17/2011 01:36 PM
Please respond to Zifeng Wu <zifengwu2008@yahoo.com>

To: Shaila Chowdhury <shaila_chowdhury@dot.ca.gov>
cc:
Subject: Re: Questions ...supplement

Yes, I saw them! I was looking for blue thing; so didn't pay attention there.
And for the advance warning devices, do you use advance warning flasher which can be timed with the signal and begin to flash when the car is expected to arrive the intersection at red?
Zifeng
From: Shaila Chowdhury <shaila_chowdhury@dot.ca.gov>
To: Zifeng Wu <zifengwu2008@yahoo.com>
Sent: Thursday, November 17, 2011 2:52 PM
Subject: Re: Questions ... I cannot find the answer

Hi Zifeng,
I see them under your questions but they are in black. Please call me if you are still not able to see.

Thanks,
Shaila Chowdhury, P.E.
Executive Engineering Assistant
Division of Traffic Operations
California Department of Transportation
Ph: (916) 651 9377
Cell: (916) 969 6186

Zifeng Wu <zifengwu2008@yahoo.com>	To	Shaila Chowdhury <shaila_chowdhury@dot.ca.gov>
11/17/2011 12:42 PM	cc	
	Subject	Re: Questions ... I cannot find the answer
Please respond to Zifeng Wu <zifengwu2008@yahoo.com>		

Hello, Shaila:
I am not sure what do you mean by "blue". I can't find the answer except

one small picture.... Maybe there are some mistake during the delivery.
Could you send me again?
Thank you very much for your help!
Zifeng
From: Shaila Chowdhury <shaila_chowdhury@dot.ca.gov>
To:
Cc: Robert Copp <robert_copp@dot.ca.gov>; Wayne Henley <wayne_henley@dot.ca.gov>; Janice Benton <janice_benton@dot.ca.gov>; Roberta McLaughlin <roberta_mclaughlin@dot.ca.gov>
Sent: Thursday, November 17, 2011 12:32 PM
Subject: Fw: Questions about the policy regarding speed limit at signalized high-speed intersection

Hi Zifeng,
Our responses are shown in blue below.

Thanks,
Shaila Chowdhury, P.E.
Executive Engineering Assistant
Division of Traffic Operations
California Department of Transportation
Ph: (916) 651 9377
Cell: (916) 969 6186
----- Forwarded by Shaila Chowdhury/HQ/Caltrans/CAGov on 11/17/2011 10:21 AM -----

Robert Copp/HQ/Caltrans/CAGov	To: Shaila Chowdhury/HQ/Caltrans/CAGov@DOT
11/14/2011 02:19 PM	cc: zifengwu2008@yahoo.com
	Subject: Fw: Questions about the policy regarding speed limit at signalized high-speed intersection

This could be Wayne and Janice. Please coordinate.

Robert Copp

Chief, Division of Traffic Operations
California Department of Transportation
1120 ' N' Street, MS #36
Sacramento, CA 95814
Phone: 916-654-2352
Fax: 916-653-6080
Cell Phone: 916-952-6436
----- Forwarded by Robert Copp/HQ/Caltrans/CAGov on 11/14/2011 02:18 PM

Zifeng Wu
<zifengwu2008@yah
oo.com> To
"Robert.Copp@dot.ca.gov"
11/14/2011 01:02 <Robert.Copp@dot.ca.gov>
PM cc

Subject
Please respond to Questions about the policy
Zifeng Wu regarding speed limit at signalized
<zifengwu2008@yah high-speed intersection
oo.com>

Mr. Copp:
Hello!

This is Zifeng Wu, from Nebraska Transportation Center at University of Nebraska-Lincoln.
Currently, we are conducting a research about speed limit in the vicinity of rural signalized high-speed intersections. As a part of a survey about what are other states doing in this area, we need the information about the policy of speed limit at high-speed intersections in California state. Here are some questions,
1.
2. Do you have some safety issues around the rural signalized high-speed intersections?
We continuously monitor the safety performance at rural signalized high-speed intersections to identify potential safety concerns. These may include visibility, sight distance or other items that can be addressed thru infrastructure improvements, including signing. Other concerns include those from the driver behavior aspect such as drivers that are inattentive, drowsy, or under the influence.

3. When it approaches the signalized, high speed intersections, do you have any advanced warning devices?
We have used the following sign as advanced warning.

(Embedded image moved to file: pic10867.jpg)
4. When it approaches the intersection, does the speed limit remain same or reduced? Is there any documented policy? If not, what are you generally do?
In general, we do not reduce the speed limit on the approach to a signalized intersection.

We really appreciate your help. If you are not familiar about this area, could you forward this Email to the one who is responsible for this area? Thank you again!

Zifeng

Subject:	RE: IC3 Form Submission $mapping
From:	Matthews, KC (KC.Matthews@dot.state.co.us)
To:	zifengwu2008@yahoo.com;
Cc:	Tara.Galvez@dot.state.co.us;
Date:	Thursday, October 20, 2011 1:27 PM

Mr. Wu,

CDOT usually does not reduce speed limits close to intersections. This practice is supported in Section 2B.13, paragraph 14 of the 2009 Manual on Uniform Traffic Control Devices, which reads: "Advance warning signs and other traffic control devices to attract the motorist's attention to a signalized intersection are usually more effective than a reduced speed limit zone."

Instead, we employ a number of methods, including regular-sized and oversized advance warning signs (with or without flashing beacons), blank out signs that are activated by vehicles exceeding a certain speed threshold, and the installation of dilemma-zone technology for the signal controller.

Regards,

K.C. Matthews, P.E.

HQ Safety and Traffic Engineering

Traffic Specs & Standards Engineer

4201 E. Arkansas Ave, 3rd Floor

Denver, CO 80222

303.757.9543 Phone

303.757.9219 Fax

<Mailto:K.C.Matthews@dot.state.co.us>

-

Check the latest Traffic Specs & Standards @

http://www.dot.state.co.us/S_Standards/index.html

From: Galvez, Tara
Sent: Wednesday, October 19, 2011 12:09 PM

To: Matthews, KC
Subject: FW: IC3 Form Submission $mapping
Importance: High

Can you help with this one?

Tara

Title: Speed Limit for intersections on highway
E-Mail Address: zifengwu2008@yahoo.com
First Name: Zifeng
Last Name: Wu
Contact Number: 402-570-3381
Date of Occurrence: Oct 18, 2011 12:00 AM
Location: Highway
Comment:

For academic research reason, I am interested in transitional speed limit policy. That is: the speed limits close to intersections are lower than the regular speed limit of the highway out of the safety consideration. Besides, do you also use advance warning flash at such signalized intersections on highways? Both ways are for safety considerations. Or is there any other operational implementation for safety at such high-speed intersections?
I know this may not be the right place to ask, but I am not sure which number to call. So, it would be good you can provide the contact information for the right person who is in charge of this area.

Subject:	RE: Help needed for speed limit policy (supplement)
From:	Crouch, Tim [DOT] (Tim.Crouch@dot.iowa.gov)
To:	Kurtis.Shackelford@dot.iowa.gov; zifengwu2008@yahoo.com;
Date:	Monday, October 17, 2011 10:54 AM

Typically, the Department does not lower the speed limit for a signalized intersection. The traffic signals are designed based on the speed limit or the 85th percentile speed. For isolated rural high speed signalized intersections, the department would install advance warning flashers/signs (BE PREPARED TO STOP WHEN FLASHING) systems at these locations. The department also installs these at the first high speed traffic signal coming into a city. I don't have an accurate count of these installations, but would estimate that we have between 15 and 20 of the systems installed.

Timothy D. Crouch, PE, PTOE
State Traffic Engineer
Iowa Department of Transportation
515-239-1513
fax 515-239-1891
tim.crouch@dot.iowa.gov

From: Shackelford, Kurtis [DOT]
Sent: Friday, October 14, 2011 3:29 PM
To: 'Zifeng Wu'
Cc: Crouch, Tim [DOT]
Subject: RE: Help needed for speed limit policy (supplement)

This email has been copied to the state traffic engineer so maybe he will respond to you soon. THX

Kurtis Shackelford

District 1/Traffic Tech
1020 South 4th St
Ames, Iowa 50010
515-239-1199 Office
515-239-1472 Fax
Kurtis.Shackelford@dot.iowa.gov

From: Zifeng Wu [mailto:zifengwu2008@yahoo.com]
Sent: Friday, October 14, 2011 3:08 PM
To: Shackelford, Kurtis [DOT]
Subject: Re: Help needed for speed limit policy (supplement)

Sure! This is very helpful. So, do you have an idea about generally how many intersections have such lower-transitional-speed limit (or percentage)? Besides, do you also use advance warning flash at such signalized intersections on highways? Either way is for safety considerations. Or is there any other operational implementation for safety reason at such high-speed intersections?

Again, thank you very much for the help.

Sincerely

Zifeng

From: "Shackelford, Kurtis [DOT]" <Kurtis.Shackelford@dot.iowa.gov>
To: 'Zifeng Wu' <zifengwu2008@yahoo.com>
Sent: Friday, October 14, 2011 7:09 AM
Subject: RE: Help needed for speed limit policy

Normally we would try to have a speed study done, run crash history and check volumes before considering lowering the speed limit at a particular location. Each intersection would be a case by case basis. Does this help?

Kurtis Shackelford
District 1/Traffic Tech
1020 South 4th St
Ames, Iowa 50010
515-239-1199 Office
515-239-1472 Fax
Kurtis.Shackelford@dot.iowa.gov

From: Zifeng Wu [mailto:zifengwu2008@yahoo.com]
Sent: Tuesday, October 11, 2011 11:00 AM
To: Shackelford, Kurtis [DOT]
Subject: Help needed for speed limit policy

Good morning, Mr.Shackelford :
I am a research assistant in the University of Nebraska Lincoln majoring in transportation engineering. We are doing one research about Transitional Speed Limit for signalized, high-speed intersections. That is: the speed limits close to intersections are lower than the regular speed limit of the highway out of the safety consideration. We are collecting the information about this kind of policy in neighbor states. Do you have any formal or informal special ***speed limit policy for the signalized intersection on highways*** in your state? If possible, the related policy documents would help a lot. Otherwise, you can just explain what you do in simple sentence. Whatever the information is, I appreciate that very much.
I found your Email address online and know that you are in charge of District one of Iowa. Do you have any idea that what other districts do? If you are not familiar about this part, could you provide the contact information for the right person who is in charge of traffic operation and policy to me?
Thanks very much for your attention and help!
Sincerely.
Zifeng Wu

Subject:	FW: Help needed for ttransitional speed limit policy
From:	Brian Gower (Gower@ksdot.org)
To:	zifengwu2008@yahoo.com;
Cc:	Clay@ksdot.org; Randy@ksdot.org; Jeff@ksdot.org; michael@ksdot.org; RobertC@ksdot.org; LarryT@ksdot.org;
Date:	Monday, October 17, 2011 2:00 PM

ZW:

My name is Brian D. Gower. I work for Kansas DOT in the Traffic Engineering Unit.

Speed Limits

The state has no policy on setting speeds around traffic signals. Ideally, we would like the speed limit to be the same through the intersection (ie US-75 north/south – both legs have the same speed limit) but that is not always the case. In some instances, the speed break is at the intersection which is signalized.

Advanced Warning

Typically on high speed approaches, we have a warning sign scheme of {signal ahead ½ mile with flashing beacons and be prepared to stop ¼ mile}. Most locations beacons are not tied to the signal system. Some locations the beacons are tied into the signal system but they are few. Some locations do not have beacons at all. So I suppose there is really no policy other than installing the actual signs themselves.

If a high speed corridor has signals at every intersection, we will have advanced warning sign scheme listed above prior to the first signal encountered but for signals in the middle, we may only have the signal ahead sign.

If you need to contact me, my info is below.

Thx.

Brian D. Gower (BDG)

785 296 1181

gower@ksdot.org

From: Jeff Stewart
Sent: Monday, October 17, 2011 10:00 AM
To: Brian Gower
Subject: FW: Help needed for ttransitional speed limit policy

Should this go to you? If not, any suggestions?

From: Zifeng Wu [mailto:zifengwu2008@yahoo.com]
Sent: Thursday, October 13, 2011 6:18 PM
To: Randy West; Jeff Stewart; Mike Stringer; Robert Cook; Larry Thompson
Subject: Help needed for ttransitional speed limit policy

Hello!

I am a research assistant in the University of Nebraska Lincoln majoring in transportation engineering. We are doing one research about Transitional Speed Limit for signalized, high-speed intersections. That is: the speed limits close to intersections are lower than the regular speed limit of the highway out of the safety consideration. We are collecting the information about this kind of policy in neighbor states. Do you have any formal or informal special ***speed limit policy for the signalized intersection on highways*** in your district? If possible, the related policy documents would help a lot. Otherwise, you can just explain what you generally do in simple sentences. Whatever the information is, I appreciate that very much. Besides, do you also use advance warning flash at such signalized intersections on highways? Both ways are for safety considerations. Or is there any other operational implementations for safety at such high-speed intersections?

I found your Email address online and know that you are in charge of the District in Kansas. If you are not familiar about this part, could you provide the contact information for the right person who is in charge of this kind of traffic operation and policy to me?

Thanks very much for your attention!

Sincerely.

Zifeng Wu

Print - Close Window

Subject:	Re: Fw: MoDot Web Site - Information Request
From:	Jonathan.Nelson@modot.mo.gov (Jonathan.Nelson@modot.mo.gov)
To:	zifengwu2008@yahoo.com;
Date:	Friday, October 14, 2011 7:53 AM

Zifeng,

Yes, we typically do use an advance warning sign with a dynamic flasher in these situations. Usually, the flasher will be timed with the signal, so that it begins flashing if the approaching vehicles are expected to arrive at the intersection during a red light. Below is a picture of the sign and flasher.

Jon Nelson, P.E.
Traffic Management and Operations Engineer
Traffic and Highway Safety Division
Missouri Department of Transportation
573.751.1157

From: Zifeng Wu <zifengwu2008@yahoo.com>
To: "Jonathan.Nelson@modot.mo.gov" <Jonathan.Nelson@modot.mo.gov>
Date: 10/13/2011 06:09 PM
Subject: Re: Fw: MoDot Web Site - Information Request

Hello, Jon:
Thank you for the answer. I appreciate it very much. And I got one more question here: is there any other operation

implementation for safety close to the intersections on highway? For example, advance warning flash... There exists some opinions like no need for both advance warning flash and transitional speed limit in Lincoln.
Best regards.
Zifeng

From: "Jonathan.Nelson@modot.mo.gov" <Jonathan.Nelson@modot.mo.gov>
To: zifengwu2008@yahoo.com
Cc: Charlett.Scott@modot.mo.gov
Sent: Tuesday, October 11, 2011 12:21 PM
Subject: Re: Fw: MoDot Web Site - Information Request

Zifeng,

We do not have any policy specifically dictating what the speed limit should be in transition zones leading up to signalized intersections at high-speed locations. In general, the speed limit is reduced prior to the signal, but we do not have specific guidelines in place that govern such reductions. Speed limits in Missouri are determined based on a number of factors. The link below will provide you with some information as to how that's accomplished.

http://epg.modot.mo.gov/index.php?title=949.2_Speed_Limit_Guidelines

If you have any more questions, feel free to contact me.

Thanks.

Jon Nelson, P.E.
Traffic Management and Operations Engineer
Traffic and Highway Safety Division
Missouri Department of Transportation
573.751.1157

From: Charlett T Scott/D5/MODOT
To: Jonathan A Nelson/SC/MODOT@MODOT
Date: 10/11/2011 11:16 AM
Subject: Fw: MoDot Web Site - Information Request

Good Morning, Can you please help the customer below. Thanks!

Charlett Scott
Senior Customer Service Representative
MoDOT Central Missouri District - Customer Relations -Jefferson City
573-522-8472
1-888-ASK-MODOT (275-6636)
www.modot.org/central
----- Forwarded by Charlett T Scott/D5/MODOT on 10/11/2011 11:13 AM -----

From:
To: CDCRRep@modot.mo.gov
Date: 10/10/2011 05:14 PM
Subject: MoDot Web Site - Information Request

Contact Information:

Zifeng Wu

NE

zifengwu2008@yahoo.com

Requested Item:

1. see my comments below

Comments: Hello! I am a research assistant in the University of Nebraska Lincoln. We are doing one research about Transitional Speed Limit for signalized, high-speed intersections. That is: the speed limits close to intersections are lower than the rest segments of the highway due to the safety consideration. We are collecting the information about this kind of policy in neighbor states. Do you have special speed limit policy for the signalized intersection on highways in Missouri? Maybe this is not the right place I should ask. But I was not able to find other contact information. If you could provide the right person who is in charge of traffic operation and policy, I would appreciate that very much. Thanks very much for your attention and help!

129.93.64.56
129.93.64.56

Subject:	Re: One Question about speed limit policy on highway ---supplement
From:	Doug.Kinniburgh@state.sd.us (Doug.Kinniburgh@state.sd.us)
To:	zifengwu2008@yahoo.com;
Cc:	Laurie.Schultz@state.sd.us;
Date:	Friday, October 14, 2011 9:03 AM

We do have one location where we have advance warning signs with flashing lights connected to a traffic signal to warn motorists that the signal is about to change. It is in a rural location on a 65mph roadway at an intersection with entrance road to a major traffic generator (Crazy Horse Memorial). Aside from this one location, our standard of practice is to utilize dilemma zone detection at all isolated signals (non-coordinated) on roadways with speeds greater then or equal to 45mph. We also have coordinated systems that are coordinated with time of day programs and run free during non-peak hours that also utilize advance detection and volume-density based timing to find adequate safe gaps to change phases.

Doug

From: Zifeng Wu [mailto:zifengwu2008@yahoo.com]
Sent: Thursday, October 13, 2011 04:38 PM
To: Kinniburgh, Doug (DOT)
Subject: Re: One Question about speed limit policy on highway ---supplement

Mr. Kinniburgh:
Thank you for the answer. I appreciate it very much. And I got one more question here: is there any other operation implementation for safety close to the intersections on highway? For example, advance warning flash... There exists some opinions like no need for both advance warning flash and transitional speed limit in Lincoln.
Best regards.
Zifeng

From: "Doug.Kinniburgh@state.sd.us" <Doug.Kinniburgh@state.sd.us>
To: zifengwu2008@yahoo.com
Cc: Todd.Seaman@state.sd.us; Laurie.Schultz@state.sd.us
Sent: Thursday, October 13, 2011 12:01 PM
Subject: RE: One Question about speed limit policy on highway ---supplement

Mr. Wu,

The State of South Dakota does not have a policy specifically in addressing lowering speed limits close to intersections. Aside from state statute, which designates maximum speeds (and minimum on interstate), our policy on setting speed limits is simply to follow recommend practice as set forth in the Manual on Uniform Traffic Control Devices.

Doug Kinniburgh
Traffic Safety Engineer
Office of Project Development
700 East Broadway
Pierre, SD 57501
605.773.5361
Doug.kinniburgh@state.sd.us

-----Original Message-----
From: Zifeng Wu [mailto:zifengwu2008@yahoo.com]
Sent: Monday, October 10, 2011 5:27 PM

To: Seaman, Todd (DOT)
Subject: Re: One Question about speed limit policy on highway ---supplement

I realized that I mentioned Missouri in last email. I am very sorry for that mistake. I am asking several states one by one, and didn't notice that mistake. I am really sorry and I also need the information about related speed limit policy on the highways in Rapid City or in South Dakota. Hope you don't mind my mistake...
Thanks.
Zifeng

From: Zifeng Wu <zifengwu2008@yahoo.com>
To: "Todd.seaman@state.sd.us" <Todd.seaman@state.sd.us>
Sent: Monday, October 10, 2011 6:11 PM
Subject: One Question about speed limit policy on highway

Hello, Todd:
I am a research assistant in the University of Nebraska Lincoln. We are doing one research about Transitional Speed Limit for signalized, high-speed intersections. By transitional speed limit, we mean the speed limits close to intersections may (or may not be) lower than the rest segments of the highway due to the safety consideration. We are collecting the information about this kind of policy in neighbor states. Do you have special speed limit policy for the signalized intersection on highways in Missouri? If yes, is it OK to offer me related document? Or just some informal standards? Maybe this is not the right place for this question... If you could provide the right person who is in charge of traffic operation and policy, I would appreciate that very much.
Thanks very much for your attention and help!
Best regards.
Zifeng Wu

Subject:	Log 90-12 - Transitional Speed Limits
From:	Derryk Blasig (Derryk.Blasig@txdot.gov)
To:	zifengwu2008@yahoo.com;
Date:	Thursday, October 20, 2011 4:23 PM

Ms. Zifeng Wu

The Texas Department of Transportation (TxDOT) has received your e-mail dated October 10, 2011. We offer the following response to your question regarding details on transitional speed limits.

TxDOT strives to maintain the highest standards of safety on our highways. It is our responsibility to ensure that all posted speed limits on the state highway system are in accordance with state law and established speed zoning procedures.

Speed limits on Texas highways are set by the 85th percentile method, which represents the speed the majority of drivers will be traveling at or below. This is a sound engineering principle by which speed limits have been set on highways nationwide for the past 60 years.

The Texas Transportation Commission adopted procedures that enable TxDOT to lower speed limits on roadways by as much as 10 mph (12 mph if traffic accident rate is above the statewide average) below the 85th percentile speed if factors such as pavement width, curves, number of driveways, crash history at a given location, rural residential or developed areas, and the lack of improved and striped shoulders are considered. These procedures were developed as a result of comments received at speed limit town meetings. TxDOT and cities must use these procedures when establishing speed zones on state highways. The procedures for establishing speed zones may be viewed at the following link:

http://onlinemanuals.txdot.gov/txdotmanuals/szn/index.htm

According to Chapter 3, Section 2, TxDOT typically performs a speed study midway between signals or 0.2 miles from any signal, whichever is less, to ensure an accurate representation of speed patterns.

TxDOT does use advance warning signs for signalized intersections. This would typically be used when there is a crash history at a certain location, or vertical curves present limited sight distance. Sometimes these signs will have flashing beacons to bring more awareness to the driver.

State law requires that TxDOT adopt a traffic control devices manual. We have adopted the Texas Manual on Uniform Traffic Control Devices (TMUTCD), which regulates both the types and location of the various devices that we install on our roadways. Information for signals can be found in part 4, and speed limits are discussed in section 2B.13. The TMUTCD can be accessed at the following web address:

http://www.txdot.gov/txdot_library/publications/tmutcd.htm

I hope this information is helpful to you. If you have any questions, please contact me by e-mail at dblasig@dot.state.tx.us or by telephone at (512) 416-3226.

Derryk Blasig

Traffic Operations Division
Texas Department of Transportation

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Texas Transportation Forum
For more information on registration and program details visit
www.texastransportationforum.com

Subject:	Re: Fwd: Transitional speed limit policy
From:	Paul Jones (paul.jones@wyo.gov)
To:	zifengwu2008@yahoo.com;
Date:	Monday, October 24, 2011 3:30 PM

We may install advanced warning such as a flashing beacon only if crash data indicates that a problem exists.

On Thu, Oct 13, 2011 at 5:08 PM, Zifeng Wu <zifengwu2008@yahoo.com> wrote:

Hello, Paul:
Thank you for the answer. I appreciate it very much. And I got one more question here: is there any other operation implementation, due to safety consideration, close to the intersections on highway? For example, advance warning flash... There exists some opinions like no need for both advance warning flash and transitional speed limit in Lincoln.
Best regards.
Zifeng

From: Paul Jones <paul.jones@wyo.gov>
To: Zifeng Wu <zifengwu2008@yahoo.com>
Sent: Tuesday, October 11, 2011 4:27 PM
Subject: Fwd: Transitional speed limit policy

Zifeng Wu,

When entering signalized intersections on roads with speed limits greater than 45 mph, Wydot generally lowers the speed limit to 45 mph10 feet to 1500 feet before the intersection. If the road is to maintain a higher speed limit, it is raised after the intersection.

Paul Jones

---------- Forwarded message ----------
From: **DOT Public Affairs** <dot-publicaffairs@wyo.gov>
Date: Tue, Oct 11, 2011 at 1:31 PM
Subject: Transitional speed limit policy
To: Paul Jones <paul.jones@wyo.gov>

---------- Forwarded message ----------
From: **Zifeng Wu** <zifengwu2008@yahoo.com>
Date: Tue, Oct 11, 2011 at 1:28 PM
Subject: Other - Select One If Available

Hello! I am a research assistant in the University of Nebraska Lincoln. We are doing one research about Transitional Speed Limit for signalized, high-speed intersections. That is: the speed limits close to intersections are lower than the rest segments of the highway due to the safety consideration. We are collecting the information about this kind of policy in neighbor states. Do you have special speed limit policy for the signalized intersection on highways in Wyoming? Maybe this is not the right place I should ask. But I was not able to find other contact information. If you could provide the right person who is in charge of traffic operation and policy, I would appreciate that very much. Thanks very much for your attention and help!

E-Mail to and from me, in connection with the transaction of public business,
is subject to the Wyoming Public Records Act and may be disclosed to third parties.