NEBRASKA TRANSPORTATION CENTER

NEBRASKA DEPARTMENT OF TRANSPORTATION

MID-AMERICA TRANSPORTATION CENTER

Report SPR-P1(19) M092

Final Report
26-1121-0033-001

Research on School Zone Safety

Aemal Khattak
Professor
Department of Civil and Environmental Engineering
University of Nebraska-Lincoln

Yashu Kang
Ph. D. Candidate

2020

Nebraska Transportation Center
262 Prem S. Paul Research Center at Whittier School
2200 Vine Street
Lincoln, NE 68583-0851
(402) 472-1993

"This report was funded in part through grant[s] from the Federal Highway Administration [and Federal Transit Administration], U.S. Department of Transportation. The views and opinions of the authors [or agency] expressed herein do not necessarily state or reflect those of the U.S. Department of Transportation."

Research on School Zone Safety

Dr. Aemal Khattak
Professor
Department of Civil and Environmental Engineering
University of Nebraska-Lincoln

Yashu Kang
Ph.D. Candidate
Department of Civil and Environmental Engineering
University of Nebraska-Lincoln

A Report on Research Sponsored By

Nebraska Department of Transportation and U.S. Department of Transportation Federal Highway Administration

and

Nebraska Transportation Center

University of Nebraska-Lincoln

June 2020

Technical Report Documentation Page

1. Report No. M092	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Research on School Zone Safety		**5. Report Date** June 2020 **6. Performing Organization Code**
7. Author(s) Dr. Aemal Khattak Yashu Kang, Ph. D. Candidate		**8. Performing Organization Report No.**
9. Performing Organization Name and Address UNL Nebraska Transportation Center 2200 Vine St. PO Box 830851 Lincoln, NE 68583-0851		**10. Work Unit No.** **11. Contract or Grant No.** SPR-PI (19) M092
12. Sponsoring Agency Name and Address Nebraska Department of Transportation 1500 Nebraska 2 Lincoln, NE 68502		**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This research investigated different aspects of school zone safety including the effects of speed differentials on drivers' speeds in active school zones, the effects of school and surrounding characteristics on drivers' speeds in active school zones, and the safety benefits and costs associated with active school zones. The research team identified 18 schools in Nebraska for data collection that consisted of drivers' speed data, school and surrounding characteristics, and 2014-2018 reported crash data. The 18 schools were categorized by the school zone speed limit differentials: 35 to 25 mph, 40 to 25 mph, 30 to 25 mph, and 35 to 15 mph. The collected motor vehicle related data included vehicle classification, vehicle speed and time of observation. In aggregate, 378,506 vehicles were observed at the study sites. Motor vehicle speed data analysis showed that drivers at 17 of the 18 schools slowed significantly in response to active school zones. However, their non-compliance with the lowered speed limit of the active school zone increased with greater speed limit differentials. An estimated linear regression model on drivers' speeds indicated that key contributing factors affecting drivers' speeds were speed limit differentials, status of school zones (passive/active), vehicle classification (small, medium, large), time of day (AM/PM), presence of on-street parking and presence of traffic signals. On average drivers travelled 6.23 mph faster in passive school zones compared to when the school zones were active. Analysis of 5-year crashes showed that crash rates were higher in active school zones compared to their passive status and that this increase was consistent across motor vehicle only crashes and motor vehicle and non-motorist involved crashes. Using the Federal Highway Administration crash costs, crash severity analysis revealed that on average a crash during active school zone period cost $53,984 less than a crash during the passive school zone period. Research recommendations include the following.

- Transportation agencies should establish school zones with great caution as higher crash rates exist in active school zones.
- Transportation agencies can expect active school zones to mitigate crash severity and thereby provide safety benefits from reduced crash costs.
- Transportation agencies should exercise caution in setting speed limits for passive and active school zone periods. Due to drivers' relatively high levels of non-compliance, speed limit differences of 15 mph should be rarely used and greater than 15 mph differences avoided.

The conclusions and recommendations in this report are based on past data when travel patterns were relatively stable. The situation with Coronavirus Disease 2019 (COVID-19) may change travel patterns especially around schools and consequently travel safety will change, depending on the arrangements adopted by school districts. A comparative study of schools with and without established school zones is recommended for the future.

17. Key Words School zone, driver speed, crash, safety		**18. Distribution Statement** No restrictions.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 67	**22. Price**

Table of Contents

List of Tables iv
List of Figures v
Disclaimer vi
Abstract vii
Chapter 1 Introduction 9
1.1 Background 9
1.2 Objectives 10
1.3 Outline 11
Chapter 2 Literature Review 12
2.1 Speed Analysis in School Zones 12
2.2 Safety Effectiveness Studies of School Zone Establishment 16
Chapter 3 Data Collection 18
3.1 Driver Speed Data at School Zones 18
3.2 Crash History Data at Study Sites 23
Chapter 4 Speed and Crash Analysis 27
4.1 Driver Speed Analysis at School Zones 27
4.2 Crash Analysis and Safety Benefits of School Zones 35
4.3 Summary 42
Chapter 5 Conclusions and Recommendations 44
5.1 Conclusions 44
5.2 Recommendations 46
5.3 Study Limitations and Future Expectations 46
References 48
Appendix A 51

List of Tables

Table 3.1 School Zone Characteristics 22
Table 3.2 Schools Categorized by Speed Limit Changes 23
Table 3.3 School Zone Spatial Information and Crash Count (2014-2018) 25
Table 4.1 Observed Speed Data at Each Study School 28
Table 4.2 Observed Speed Data Grouped by Speed Limit Differential 28
Table 4.3 Observed 85th percentile Speed Grouped by Speed Limit Differential 30
Table 4.4 Estimated Linear Regression Model for Drivers' Speeds 33
Table 4.5 School Zone Crash Count and Rate Summary 38
Table 4.6 Motorist and Non-Motorist Crash Rate Summary 39
Table 4.7 School Zone Crashes by Crash Type 39
Table 4.8 Crashes by Injury Severity Outcome 40
Table 4.9 Crash Severity and Costs During Flashing Lights Off and On Periods 41

List of Figures

Figure 1.1 School Zone Signs 10
Figure 3.1 Belmont Elementary, Lincoln (Site 1) 19
Figure 3.2 Calvert Elementary, Lincoln (Site 2) 19
Figure 3.3 Speed Data Collection Device 20
Figure 3.4 Radar Tracker Deployment 20
Figure 3.5 Vehicle Classification 21
Figure 3.6 Clinton Elementary, Lincoln (Site 3) 21
Figure 4.1 Speed Limit Differential, Percent Reduction in Driver Mean Speed and Non-Compliance with Speed Limit in Active School Zones 29
Figure 4.2 Speed Profile for Schools 35 to 25 mph, School Hour 8:15 – 14:55 30
Figure 4.3 Speed Profile for Schools 35 to 25 mph, School Hour 9:00 – 15:38 30
Figure 4.4 Speed Profile for Schools 40 to 25 mph, School Hour 9:00 – 15:38 31
Figure 4.5 Speed Profile for Schools 35 to 15 mph, School Hour 8:00 – 15:10 32
Figure 4.6 Speed Profile for Schools 30 to 25 mph, School Hour 8:00 – 15:25 32
Figure 4.7 Crash Mapping in Lincoln 35
Figure 4.8 Clinton Elementary, Lincoln (Site 3) 36
Figure 4.9 Crashes Identified in Clinton School Zone 36

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The contents do not necessarily reflect the official views or policies neither of the Nebraska Department of Transportations nor the University of Nebraska-Lincoln. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report.

The United States (U.S.) government and the State of Nebraska do not endorse products or manufacturers. This material is based upon work supported by the Federal Highway Administration under SPR-1(19) (M092). Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration."

Abstract

This research investigated different aspects of school zone safety including the effects of speed differentials on drivers' speeds in active school zones, the effects of school and surrounding characteristics on drivers' speeds in active school zones, and the safety benefits and costs associated with active school zones. The research team identified 18 schools in Nebraska for data collection that consisted of drivers' speed data, school and surrounding characteristics, and 2014-2018 reported crash data. The 18 schools were categorized by the school zone speed limit differentials: 35 to 25 mph, 40 to 25 mph, 30 to 25 mph, and 35 to 15 mph. The collected motor vehicle related data included vehicle classification, vehicle speed, and time of observation. In aggregate, 378,506 vehicles were observed at the study sites. Motor vehicle speed data analysis showed that drivers at 17 of the 18 schools slowed significantly in response to active school zones. However, their non-compliance with the lowered speed limit of the active school zone increased with greater speed limit differentials. An estimated linear regression model on drivers' speeds indicated that key contributing factors affecting drivers' speeds were speed limit differentials, status of school zones (passive/active), vehicle classification (small, medium, large), time of day (AM/PM), presence of on-street parking and presence of traffic signals. On average drivers travelled 6.23 mph faster in passive school zones compared to when the school zones were active. Analysis of 5-year crashes showed that crash rates were higher in active school zones compared to their passive status and that this increase was consistent across motor vehicle only crashes and motor vehicle and non-motorist involved crashes. Using the Federal Highway Administration crash costs, crash severity analysis revealed that on average a crash during an active school zone period cost $53,984 less than a crash during the passive school zone period. Research recommendations include the following.

- Transportation agencies should establish school zones with great caution as higher crash rates exist in active school zones.
- Transportation agencies can expect active school zones to mitigate crash severity and thereby provide safety benefits from reduced crash costs.

- Transportation agencies should exercise caution in setting speed limits for passive and active school zone periods. Due to drivers' relatively high levels of non-compliance, speed limit differences of 15 mph should be rarely used and greater than 15 mph differences avoided.

The conclusions and recommendations in this report are based on past data when travel patterns were relatively stable. The situation with Coronavirus Disease 2019 (COVID-19) may change travel patterns especially around schools and consequently travel safety will change, depending on the arrangements adopted by school districts. A comparative study of schools with and without established school zones is recommended for the future.

Chapter 1 Introduction

1.1 Background

The safety of children in the vicinity of schools is of paramount importance. A school zone is a designated roadway segment approaching, adjacent to, and beyond school buildings or grounds, or along which school-related activities occur, according to the definition in the Manual on Uniform Traffic Control Devices (*FHWA, 2010*). School speed zones are meant to make areas around schools safer for children. The standard speed for motor vehicles in active school zones is 25 mph in most places but may vary depending on site conditions. Motorist compliance with school zone speed limit may be different due to speed differentials, i.e., drivers' speed reduction may vary when a speed limit changes from 45 mph to 25 mph versus a speed limit change from 35 mph to 25 mph. Additionally, there may be differences in motorist speed reduction depending on land use in the vicinity of schools and in urban versus rural settings. For example, motorist compliance with an active school zone speed limit may be higher when a school is visible from the street/roadway, crosswalks and signs are present, or when drop off/pickup lanes are adjacent to a school zone street/roadway. Similarly, motorist speed compliance may be different around schools in small rural communities (population less than 5,000) compared to schools in urban areas.

This study undertook a comprehensive investigation of school zone safety in Nebraska taking into account the safety effects of various elements in and around schools and provides guidelines on improving safety at school zones. Specifically, drivers' speed data and school zone related crash history were examined to identify elements affecting safety of school zones in Nebraska. For this study, a school zone was identified as the street segments indicated by the school zone signs in the state of Nebraska, as shown in figure 1.1.

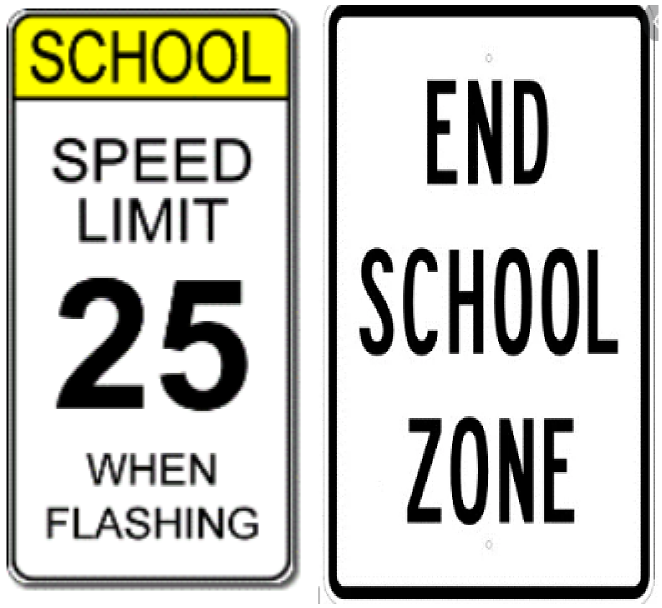


Figure 1.1 School Zone Signs

<u>1.2 Objectives</u>

The objectives of this research include: 1) to assess the effects of speed differential on speed compliance in active school zones; 2) investigate the effects of surrounding land use on drivers' speed in active school zones; 3) quantify the safety benefits and costs associated with the creation of school zones; and 4) develop guidelines for school zone establishment in Nebraska. Considerations that can impact the best-practice recommendations may include speed limit change, land use and safety benefit analysis.

The research is intended to enable NDOT and other public agencies to make more informed and consistent decisions regarding establishing school zones in a uniform manner to ensure the safety of children walking in proximity of schools. The results will provide guidance on assessing when school zones will best serve to help improve public safety.

1.3 Outline

This research was conducted in five steps. In the first step, an initial meeting was held with the Technical Advisory Committee (TAC) members to discuss the research approach and review published literature on school zones conducted with an emphasis on uncovering documented evidence of changes in safety due to the establishment of school zones and their economic costs. Chapter 2 of this report presents a summary of the publications pertinent to this research. Chapter 3 presents the second step which involved selecting several schools in urban and rural communities with school zones for collecting motor vehicle speed data and utilizing Nebraska crash history data. The third step included assessing and analyzing the collected data; Chapter 4 provides the statistical analysis results. The fourth step focused on providing guidance on estimating the benefits of school zone establishment based on the metrics of motorist drivers' compliance and crash reduction. The final step of this research was the documentation of the final report and a presentation to the TAC members.

Chapter 2 Literature Review

The establishment of school zones requires careful assessment since it deals with the safety of children and other users around schools. Elements pertaining to school zone safety involve traffic control devices, traffic calming measures, motor vehicle speed differentials, land use, etc. There have been various studies on school zone safety, which mainly focused on school-related treatments or driver behavior in school zones. However, the findings of studies on the safety aspects of school zones are mixed and contradictory in some cases. These contradictions are mostly about the effects of different control devices on motor vehicle speed reduction in school zones. Some studies showed that these differences may be due to the role of traffic and road characteristics *(Hidayati et al., 2012; Kattan et al., 2011; Trinkaus, 1996; Ash and Saito, 2007)*. In this section, a number of relevant studies on school zone safety and speed reduction are introduced, with an emphasis on the methods and useful results pertaining to the research at hand.

2.1 Speed Analysis in School Zones

Kattan et al. investigated speed compliance, mean speed and 85th percentile speed at selected school and playground zones in the city of Calgary in Alberta (*Kattan et al., 2011*). Results of their study on 4580 vehicles in 41 locations showed that the mean speed was lower and the rate of compliance was higher in school zones compared to playground zones. Two-lane roads relative to four-lane roads, roads with fencing, traffic control devices (lights, stop sign, etc.) and the presence of speed display devices or children, and longer zones also had lower speeds and a higher rate of compliance. Accordingly, this study provided recommendations to improve the effectiveness of school and playground zone speed limits.

Zhao et al. proposed an approach to examine the effectiveness of various traffic control devices deployed in school zones through driving simulator-based experiments (*Zhao et al., 2015*). They considered different variables, including average speed, relative speed difference, and traffic control device performance. They found that the effectiveness of a sign/marking was closely related to traffic characteristics and roadway geometric conditions.

Strawderman et al. investigated the effects of different factors on driver behavior (vehicle speed and compliance) and accident frequency in school zones (*Strawderman et al., 2015*). They introduced a new term, sign saturation (if a driver observes too many of the same signs, he/she may no longer pay attention to those signs) and presented a methodology to calculate sign saturation for school zones. Results showed a significant effect of sign saturation on vehicle speed, compliance, and accident frequency. This study also examined drivers' speeding behavior in school zones for different times of the day and days of the week. Results indicated speeding was more prevalent in the early mornings and during the weekends.

According to Gregory et al. (*Gregory et al., 2016*), drivers whose trip has been interrupted by signalized traffic intersections in school zones resume their journey at a faster vehicle speed than drivers who have not been required to stop. They examined the effects of a reminder sign intended to reduce the speeding behavior of interrupted drivers. Signs that combined written text and flashing lights reduced interrupted drivers' speeding behavior, while with only the flashing lights or only the written text the interrupted drivers' travelled over the speed limit. This study also highlighted the benefit of using exogenous visual cues in traffic signs to capture drivers' attention.

Some researchers focused on the effects of Speed Monitoring Displays (SMDs) on speed compliance in school zones. Ash and Saito found that SMDs were installed in four reduced speed school zones in Utah to evaluate their effectiveness on speed compliance (*Ash and Saito, 2007*). Speed data were collected, analyzed, and compared from before and after the SMDs were installed. In some cases the SMDs were associated with greater speed compliance; in other cases they were not effective. For the most part, these SMDs resulted in decreasing motorist speeds and increasing speed compliance, based on the decrease in mean speed, standard deviation, 10 mph pace range and the percentage of vehicles exceeding the 20 mph school-zone speed limit. Lee et al. also studied the effects of SMDs on school zone speed reduction and had relatively consistent results with the Utah study (*Lee et al., 2006*).

Schrader tested the effectiveness of five school zone traffic control devices on speed, in a before-after study (*Schrader, 1999*). The five devices tested in the study were fiber optic signs, spanwire-mounted flashing yellow beacons, post-mounted flashing yellow beacons, transverse lavender stripes, and large painted legends. The results showed that fiber optic signs decreased the speed statistically significantly, while the other devices were found not effective in speed reduction.

Simpson evaluated the effects of flashers in school zones on motorist speed (*Simpson, 2008*). A sample set of 15 treatment school zones with flashers and 15 comparison school zones without flashers was selected for analysis throughout North Carolina. The percentage of vehicles exceeding the speed limit, average speed, 85th percentile speed, and pace speed was used as comparison criteria. Results showed no practical difference in vehicle speeds between the flasher and non-flasher locations during school-time hours.

Fitzpatrick et al. collected field data from 24 school zones in Texas and conducted statistical analysis on the interactions between speed and site characteristics and drivers' speed change behavior (Fitzpatrick et al., 2009). Field data were collected using laser guns, traffic counters and on-pavement traffic analyzers, videos, etc. Data included posted speed limit, presence of sidewalk, school zone length, speed data, etc. The study found the observed speeds when the school zone was active were statistically lower than the speeds when the school zone was not active. School speed limit dominated other variables in the regression analysis on contributing factors affecting operating speed. In addition, excluding school speed limit, statistically significant factors were land use type, number of lanes and school driveway density.

A survey on school zone speed limits was conducted in January 2018 by the committee on traffic engineering of the American Association of State Highway Transportation Officials (AASHTO). In the 23 states that regulated statutory school zone speed limits, 6 states had set the speed limit at 15 mph; 8 states set the speed limit at 20 mph; 4 states indicated 25 mph at school zones; 4 states suggested a 10 mph lower speed than the original posted speed limit while one state suggested 15 or 20 mph below the original posted speed limit.

As for regulations on school zones, multiple peer cities of the city of Lincoln have indicated that traffic engineers have the discretion to determine the implementation for school zones (*Overland Park Kansas, 2020; Champaign Illinois, 2020; City of Lincoln, 2020*). Some states have regulated the statutory school zone speed limits. For instance, in the State of Illinois, the speed limit is set at 20 mph regardless of the original speed of the road (*Vince and Staff, 2016*). House Bill No. 4424 in the State of Michigan stated that school zone speed limits must not be less than 25 mph and no more than 20 mph slower than the usual posted speed limit (*Michigan Act No. 446, 2017*).

A recent report published from the City of Lincoln suggested engineering studies should be conducted over setting reduced speed zones on streets that have base posted speed limit over 40 mph or higher (*City of Lincoln, 2020*). It also examined the effects of various features on motorist speed within the reduced speed zone, including police enforcement, proximity to school, average daily traffic, signalization within zone, length of zone and number of lanes. However, the study mainly assessed the changes in average speed and 85th percentile speed within the reduced speed zone. More in-depth analysis such as a multivariate regression model estimation may better reveal how these features affected motorist speed.

Overall, there is literature covering various topics related to school zones, including speed compliance, traffic control devices, driver behaviors, etc. However, limited existing studies have been carried out in Nebraska focusing on the effects of elements such as the visibility of schools, speed differentials, etc. To provide more information on the safety of school zones, the current study evaluated both collected speed data and crash history relevant to school zones.

2.2 Safety Effectiveness Studies of School Zone Establishment

With regard to the safety effectiveness of school zone establishment, the important criteria include the number of crashes and the injury severity outcome. School zones typically have higher pedestrian density, particularly with young children who are potentially at a higher risk when crossing the road. When school zone warning signs (beacons) are flashing, it is unclear what effects the drivers' compliance would have on crash occurrence. For the purposes of this study, the crash history of both pedestrian-vehicle and vehicular crashes was considered.

A study by Warsh et al. used five-year pedestrian collision data from the city of Toronto's Traffic Data Center and Safety Bureau to examine the contributing factors (*Warsh et al., 2009*). A school zone was defined as a 150-meter radius around the school. The study focused on collisions occurring at distances of 150, 150-300, 300-450, etc. and showed that fatal collisions were highest in school zones and decreased as distance from schools increased. It also suggested the age of pedestrian, travel times, and crossing locations were associated with risk of injury for the children. However, a limitation was non-consideration of traffic volume in this study as it is an important indicator of collision risk.

Clifton and Kreamer-Fults also examined pedestrian-vehicular crashes near schools and the potential environmental features (*Clifton and Kreamer-Fults, 2007*). They built multivariate models of crash severity and crash risk and found significant factors included the presence of a driveway, presence of recreational facilities, transit access, commercial access and population density, etc. The study focused on physical and social attributes near the schools but did not emphasize other important factors such as traffic volume, speed data, and driver behavior.

Medina et al. assessed the infrastructure condition of school zones in Puerto Rico, finding lack of maintenance in crossing markings, signs, and pedestrian signals at intersections as important (*Medina et al., 2010*). They indicated the need for crash analysis to further identify potential safety issues at school zones.

Chapter 3 Data Collection

Safety data for each school zone was collected and statistically analyzed, including school zone characteristics, driver speed, observed traffic volume and 2014-2018 police-reported crashes in the vicinity of schools. Specifically, the time period when the school zone sign beacon became active is referred to as “flashing ON”. The flashing time was observed to be 30 minutes before school open time in the AM, and 30 minutes starting from 5 minutes before school dismissal time in practice. For instance, if a school was in session from 9:00 AM to 3:00 PM then its flashing time was 8:30-9:00 AM and 2:55-3:25 PM.

3.1 Driver Speed Data at School Zones

To investigate the safety of school zones, drivers’ speed data was collected at various schools which were categorized based on speed differentials (difference in speed limits between flashing ON or OFF) and school session time. A total of 18 schools were included in this study that were located in the city of Lincoln, Central City, and La Vista. Fifteen of these schools were elementary while the remaining three were middle schools. High schools were not considered in this. In aggregate, 378,506 vehicles were observed at these 18 study sites, including 67,266 observations provided from City of Lincoln. The collected information included vehicle classification, vehicle speed and timestamp.

Streets comprising school zones were identified to select vehicular crashes reported in these zones. For instance, figures 3.1 and 3.2 below show examples of the studied sites and their school zone segments for elementary schools in Lincoln, NE. More details are attached in the Appendix A.

Figure 3.1 Belmont Elementary, Lincoln (Site 1)

Figure 3.2 Calvert Elementary, Lincoln (Site 2)

To prevent distracting drivers and to ensure naturalistic observations, a radar tracker (Houston Armadillo Tracker) was selected for traffic data collection. The equipment can be mounted to pole for data collection (figures 3.3 and 3.4). Speed data were collected for 24 hours using this radar tracker and validated using a laser gun (ProLaser laser gun).

Figure 3.3 Speed Data Collection Device

Figure 3.4 Radar Tracker Deployment

The radar tracker automatically classifies the observed into small, medium, and large. The classification is in accordance with FHWA's information, as shown in figure 3.5. A small vehicle refers to FHWA class 1; medium refers classes 2 & 3; and large indicates classes 4 through 12.

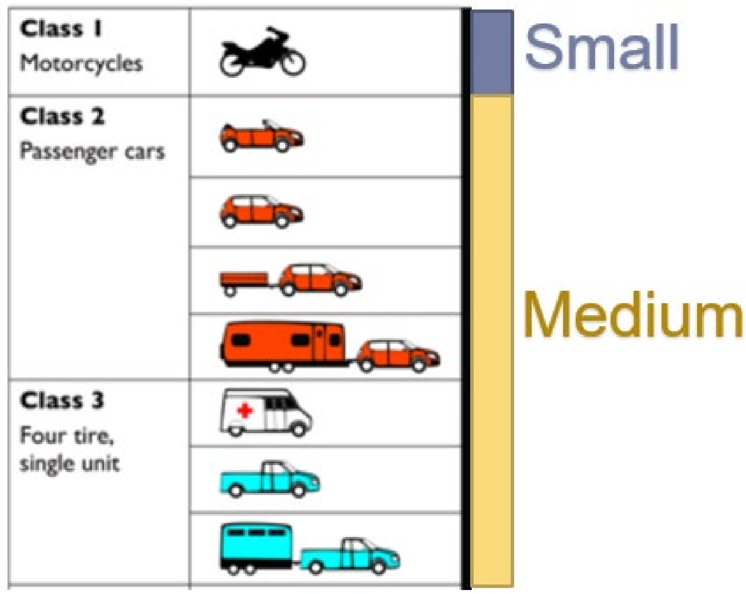


Figure 3.5 Vehicle Classification

Some characteristics of the study sites are shown below in table 3.1. Besides the number of lanes and crosswalks, other attributes were also considered including visibility of school, presence of fencing, types of traffic control devices present, school zone length, presence of loading areas, presence of on-street parking, etc. For instance, figure 3.6 is an example showing a school with a fence.

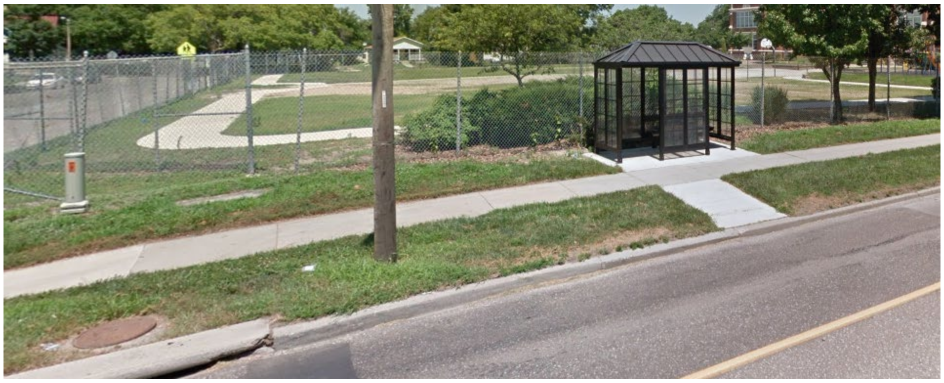


Figure 3.6 Clinton Elementary, Lincoln (Site 3)

Table 3.1 School Zone Characteristics

ID	Location	Type	Posted Speed	Reduced Speed	Number of Lanes	Number of Crosswalks inside Zone	Crash Count (2014-2018)
1	Belmont	Elementary	35	25	1	1	13
2	Calvert	Elementary	35	25	1	1	6
3	Clinton	Elementary	35	25	1	1	10
4	Elliott	Elementary	35	25	2	1	52
5	Prescott	Elementary	35	25	2	1	16
6	Sheridan	Elementary	35	25	1	1	3
7	Lefler	Middle School	35	25	1	1	16
8	Irving	Middle School	35	25	1	2	6
9	Rousseau	Elementary	35	25	1	1	5
10	Randolph	Elementary	35	25	1	2	3
11	McPhee	Elementary	35	25	3	2	30
12	Riley	Elementary	35	25	2	1	17
13	Campbell	Elementary	40	25	2	1	29
14	Morley	Elementary	40	25	2	1	41
15	Zeman	Elementary	40	25	2	3	14
16	Pyrtle (on 84th St.)	Elementary	40	25	2	2	6
17	Central City Elem	Elementary	30	25	1	2	0
18	LaVista MS	Middle School	35	15	2	2	10

Based on speed limit differential, the 18 observed schools were further categorized into 4 groups to examine the drivers' compliance with the speed limit reductions, as shown in table 3.2. Groups 3 and 4 contain only one school because of the non-typical speed limit changes in La Vista Middle School and Central City. The observed speed reductions in Groups 3 and 4 were not as large as their respective speed limit changes.

Table 3.2 Schools Categorized by Speed Limit Changes

Category	Schools	Speed Reduction	Observations	Mean Speed Off	Mean Speed On	Mean Speed Diff
1 (35to25)	Belmont, Calvert, Clinton, Elliott, Prescott, Sheridan, Rousseau, Randolph, McPhee, Riley, Lefler MS, Irving MS	35 – 25 mph	245,442	32.63	27.15	5.48
2 (40to25)	Campbell, Morley, Pyrtle, Zeman	40 – 25 mph	92,873	39.01	30.27	8.74
3 (30to25)	Central City Elem	30 – 25 mph	6,863	25.99	24.19	1.8
4 (35to15)	La Vista MS	35 – 15 mph	33,328	34.1	27.69	6.41

3.2 Crash History Data at Study Sites

Five year (2014-2018) crash data were obtained from the Nebraska Department of Transportation (NDOT). The Nebraska crash report does not include any information on crash proximity to schools. Therefore, relevant crashes were identified based on spatial location within a school zone along with use of the local school district calendar. For example, the Lincoln Public School calendar was used to determine days and times of school sessions for school sites located in Lincoln. Only crashes reported on regular school days were identified for analysis with partial school days excluded as the research team did not collect any traffic data on such days. Table 3.3 presents the relevant spatial information for school zones and crash statistics for the 18 schools

Table 3.3 School Zone Spatial Information and Crash Counts (2014-2018)

ID	Location	Lat	Long	Crash Count On Period	Crash Count Off period	Total Crashes
1	Belmont	40.844733	-96.701119	5	8	13
		40.847888	-96.701065			
2	Calvert	40.777096	-96.655472	1	5	6
		40.777123	-96.658566			
3	Clinton	40.828030	-96.677375	4	6	10
		40.828016	-96.681074			
4	Elliott	40.813463	-96.686785	5	47	52
		40.813474	-96.684224			
5	Prescott	40.791714	-96.690421	2	14	16
		40.791726	-96.693517			
6	Sheridan	40.791697	-96.676239	1	2	3
		40.791669	-96.678752			
7	Lefler	40.804763	-96.653686	1	15	16
		40.802104	-96.653630			
8	Irving	40.784468	-96.694420	2	4	6
		40.784474	-96.688117			
9	Rousseau	40.777634	-96.672857	2	3	5
		40.775560	-96.672860			
10	Randolph	40.806193	-96.666844	0	3	3
		40.806162	-96.670280			
11	McPhee	40.806467	-96.698234	4	26	30
		40.804506	-96.698247			
		40.804305	-96.696801			
		40.806600	-96.696783			
12	Riley	40.826493	-96.653853	1	16	17
		40.824488	-96.653777			
13	Campbell	40.857276	-96.689030	0	29	29
		40.857358	-96.693052			
14	Morley	40.795965	-96.625119	7	34	41
		40.792810	-96.624996			
15	Zeman	40.764327	-96.644389	2	12	14
		40.761463	-96.644263			
16	Pyrtle (on 84^{th} St.)	40.807869	-96.605897	0	6	6
		40.805631	-96.605864			
17	Central City Elem	41.114794	-98.001683	0	0	0
		41.113210	-98.001706			

Table 3.3 continued

ID	Location	Lat	Long	Crash Count On Period	Crash Count Off Period	Total Crashes
18	LaVista MS	41.178950	-96.035706	3	7	10
		41.176174	-96.038729			
		41.176280	-96.036349			
		41.178455	-96.036355			
		41.177627	-96.037129			
		41.176554	-96.037472			

Chapter 4 Speed and Crash Analysis

4.1 Driver Speed Analysis at School Zones

Assessment of school zone safety was undertaken by investigating changes in drivers' speeds during active (i.e., flashing lights on) and passive school zones. A statistical comparison of the mean speeds was performed using data collected at individual schools as well as using data aggregated into categories based on the speed limit differentials. Table 4.1 presents the results for individual schools. All schools except one indicated a statistically significant difference in drivers' speed when the school zone became active. Drivers speeds observed at Elliot Elementary School did not show a statistically significant difference in mean speed between active and passive school zone periods. The mean speeds when school zones were passive were close to or somewhat lower than the designated speed limit. However, the mean speeds reduced when school zones were active but were higher than the reduced speed limits except at the Central City Elementary school where drivers were traveling slightly slower than the reduced speed limit.

The schools were categorized based on speed limit differential; table 4.2 shows the results of the speed comparisons. Drivers at Category 1 (35 to 25 mph) schools slowed down from 32.64 to 27.15 mph reflecting a 16.82 percent speed reduction in active school zones while those observed at schools in Category 2 (40 to 25) slowed down from 39.01 to 30.27 mph (22.40 percent reduction). There is only one school each in categories 3 (35 to 15 mph) and 4 (30 to 25 mph). Percent reductions in mean speeds in active school zones at these two locations were 18.80 and 6.93, respectively. Most observed drivers were traveling close to the speed limit and slowed down in active school zones but not to the lower speed limit of the active school zones.

Table 4.1 Observed Speed Data at Each Study School

ID	School/Location	Posted Speed	Reduced Speed	Mean Speed off	Mean Speed On	Mean Speed Diff.	Vehicle Count off	Vehicle Count On	Statistical Difference (α=5%)
1	Belmont	35	25	32.81	25.76	7.05	30010	2464	TRUE
2	Calvert	35	25	27.93	24.64	3.29	8551	965	TRUE
3	Clinton	35	25	31.51	26.16	5.35	15763	1318	TRUE
4	Elliott	35	25	29.07	28.69	0.38	5753	699	FALSE
5	Prescott	35	25	35.81	27.27	8.54	7900	461	TRUE
6	Sheridan	35	25	33.88	28.04	5.84	2155	198	TRUE
7	Lefler MS	35	25	32.55	25.4	7.15	56520	4200	TRUE
8	Irving MS	35	25	33.65	27.54	6.11	22153	2823	TRUE
9	Rousseau	35	25	34.09	28.97	5.12	8510	677	TRUE
10	Randolph	35	25	31.51	28.61	2.9	28387	2331	TRUE
11	McPhee	35	25	33.13	29.74	3.39	29707	2389	TRUE
12	Riley	35	25	35.67	28.86	6.81	10760	748	TRUE
13	Campbell	40	25	39.78	28.79	10.99	13932	778	TRUE
14	Morley	40	25	39.97	29.19	10.78	15194	1077	TRUE
15	Zeman	40	25	37.74	31.02	6.72	44464	3365	TRUE
16	Pyrtle (on 84th St.)	40	25	41.38	30.04	11.34	13160	903	TRUE
17	Central City Elem	30	25	25.99	24.19	1.8	6166	697	TRUE
18	LaVista MS	35	15	34.1	27.69	6.41	31009	2319	TRUE

Table 4.2 Observed Speed Data Grouped by Speed Limit Differential

School Category	Posted Speed	Reduced Speed	Mean Speed Off	Mean Speed On	Mean Speed Diff.	Percent Diff.	Vehicle Count Off	Vehicle Count On	Statistical Difference (α=5%)
1 (35 to 25)	35	25	32.64	27.15	5.49	16.82	226169	19273	TRUE
2 (40 to 25)	40	25	39.01	30.27	8.74	22.40	86750	6123	TRUE
3 (35 to 15)	35	15	34.1	27.69	6.41	18.80	31009	2319	TRUE
4 (30 to 25)	30	25	25.99	24.19	1.8	6.93	6166	697	TRUE

Note: Percent Difference = [(Mean Speed Off – Mean Speed On) x100] / (Mean Speed Off)

In table 4.2, a speed limit differential of 5 mph (Category 4) resulted in mean speeds reduced by 6.93 percent; a differential of 10 mph (Category 1) showed mean speeds reduced by

16.82 percent; a 15 mph differential (Category 2) gave a 22.4 percent reduction in mean speeds while a 20 mph differential (Category 3) brought about 18.8 percent slower speeds. figure 4.1 shows how percent speed reduction varied with the speed limit differential (left) and drivers' non-compliance with the reduced speed limit of active school zones as speed limit differential increased (right). Greater speed limit differentials resulted in larger percentage reductions in mean driver speeds but the effects started to decrease after the 15 mph speed limit differential. Drivers non-compliance with the active school zone speed limit increased with the speed limit differential—it was 12.69, 5.27, and 2.15 mph for speed limit differentials of 20 mph, 15 mph, and 10 mph, respectively. Speed limit differentials of 15 and 20 mph resulted in mean speeds that were highly non-compliant with the speed limits of active school zones.

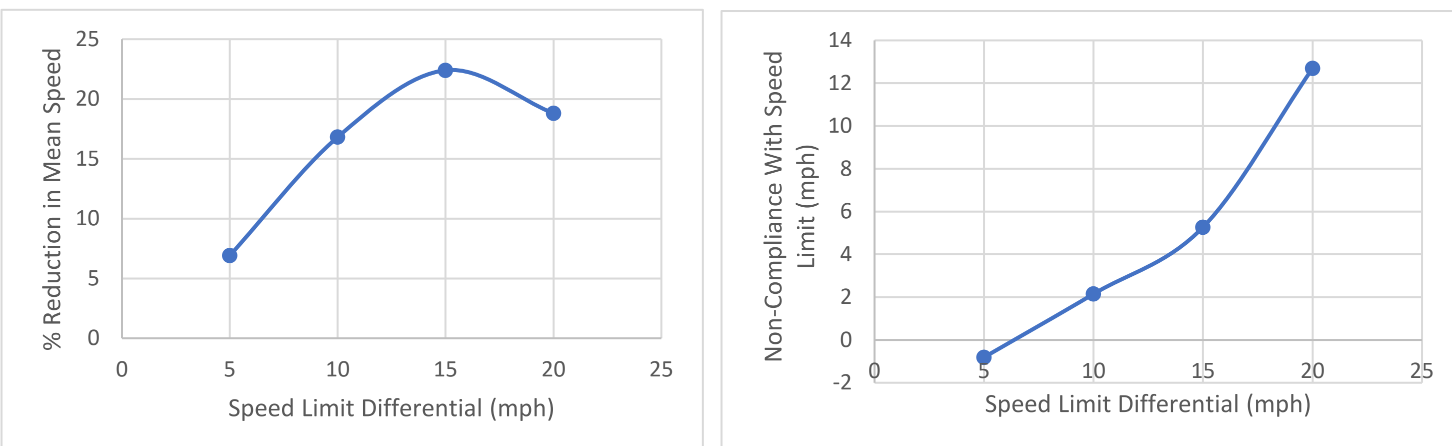


Figure 4.1 Speed Limit Differential, Percent Reduction in Driver Mean Speeds and Non-Compliance with Speed Limit in Active School Zones

Another aspect to fully evaluate driver compliance regarding school zones is to examine the 85th percentile vehicle speed with posted speed limit and reduced speed limit. The 85th percentile speed is a common criterion when assessing speed limits and provides additional information about the distribution of the speed data. Table 4.3 below presents the 85th percentile speeds during both school zone flashing passive period and active period. It indicates that in most cases the 85th percentile speeds are higher than the respective speed limits during both the school zone passive and school zone active periods. This finding conforms with the results from the recent City of Lincoln project (*City of Lincoln, 2020*).

Table 4.3 Observed 85th percentile Speed Grouped by Speed Limit Differential

School Category	School zone passive period, 'Off'			School zone active period, 'ON'		
	85th percentile speed, mph	Diff. from speed limit	Percent Diff. from speed limit	85th percentile speed, mph	Diff. from speed limit	Percent Diff. from speed limit
1 (35 to 25)	37	2	5.7	33	8	32
2 (40 to 25)	45	5	12.5	34	9	36
3 (35 to 15)	30.25	0.25	0.8	29	4	16
4 (30 to 25)	40	5	14.3	34	19	126.7

Besides examining the overall mean speed and 85th percentile speed, it is helpful to make time series plots to monitor how mean speeds change in terms of school zone activation. Based on the classifications by speed differentials shown in table 3.2, speed profiles can be displayed while grouped by speed limit changes and school hours. Figures 4.2 to 4.6 show drivers' speed changes across time in the AM and PM, categorized by speed limit change and school hours. The (red) dashed vertical line indicates the school start/dismissal time. The colored area indicates the time period when the school zone was active. The x-axis shows time in 5-minute increments and y-axis indicates 5-minute drivers' mean speed. Figure 4.2 displays the group that has the speed limit reduced from 35 mph to 25 mph while having school hours from 8:15 AM to 2:55 PM. As these figures show, drivers' mean speed started to decrease before the school zone became active, which is consistent across the five groups.

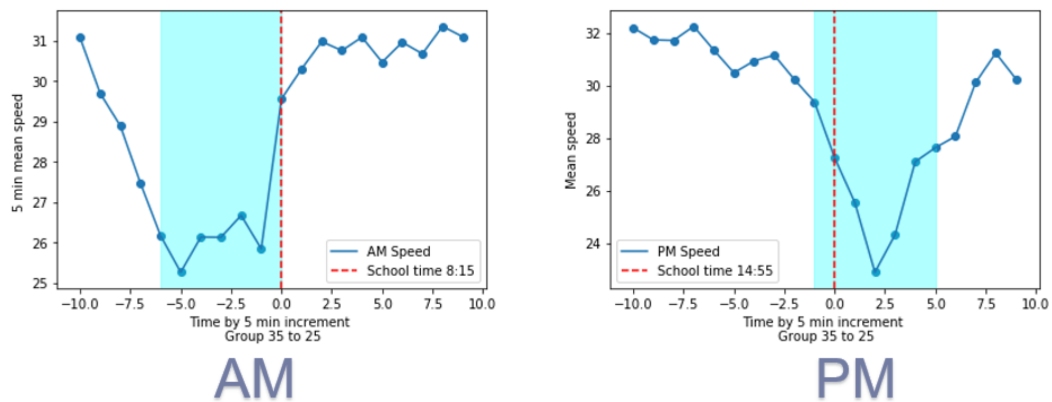


Figure 4.2 Speed Profile for Schools 35 to 25 mph, School Hour 8:15 – 14:55

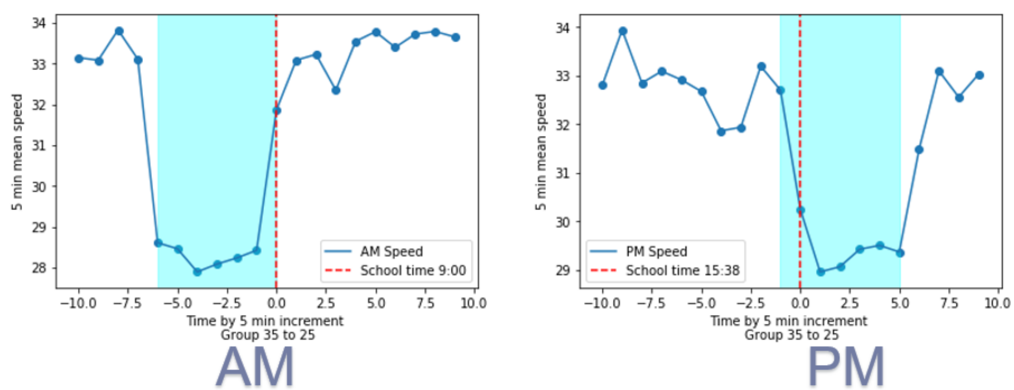


Figure 4.3 Speed Profile for Schools 35 to 25 mph, School Hour 9:00 – 15:38

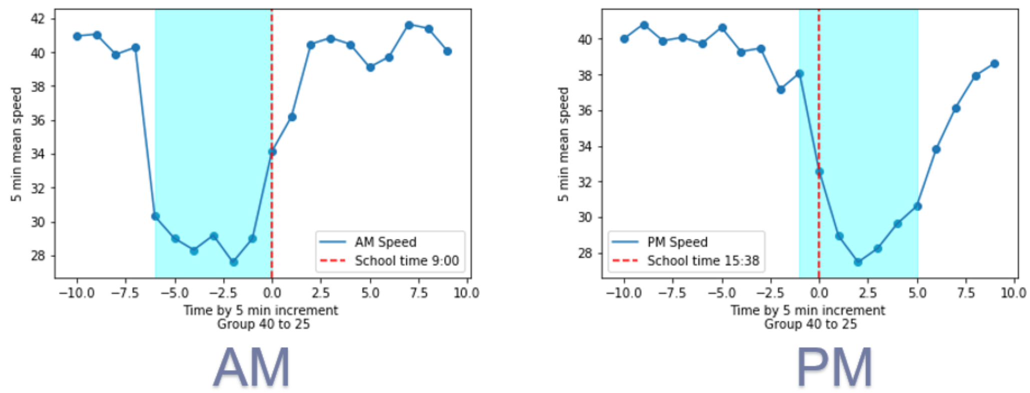


Figure 4.4 Speed Profile for Schools 40 to 25 mph, School Hour 9:00 – 15:38

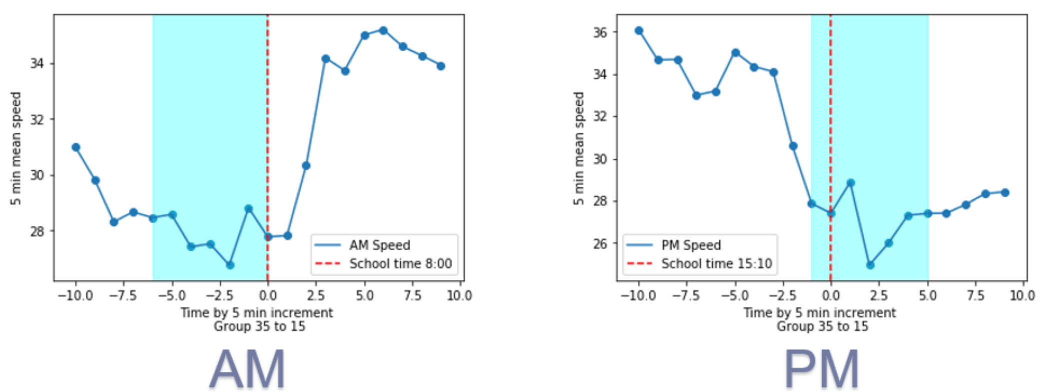


Figure 4.5 Speed Profile for Schools 35 to 15 mph, School Hour 8:00 – 15:10

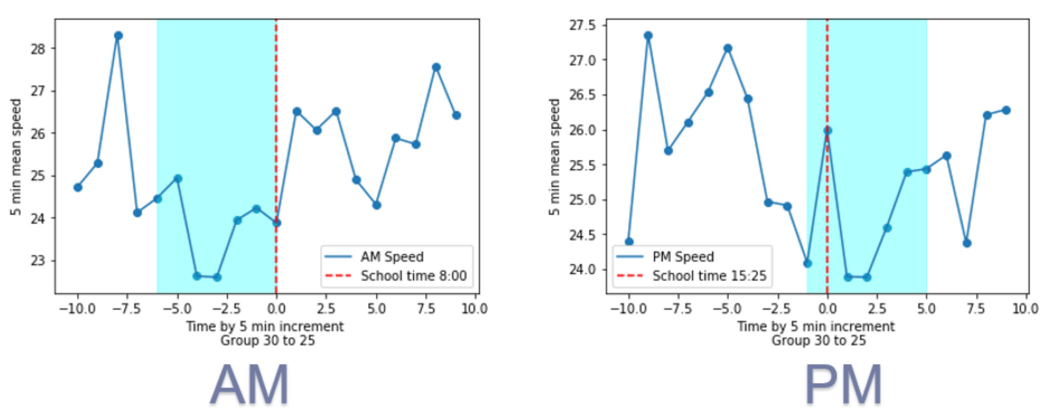


Figure 4.6 Speed Profile for Schools 30 to 25 mph, School Hour 8:00 – 15:25

A regression model with drivers' observed speeds as dependent variable and different independent variables provided insights into factors affecting drivers' speeds around schools. The independent variables included school category, status of school zone (active/passive), vehicle classification, time of day (AM or PM), presence of on-street parking, and presence of traffic signals. Many other variables were tried in the model specification but were not found to have statistically significant impacts on drivers' speeds. Table 4.4 presents the estimated model.

Table 4.4 Estimated Linear Regression Model for Drivers' Speeds

Variables	Coefficient	Std. Error	t-statistic	Sig.	95% C.I.		Variable Importance
					Lower	Upper	
Intercept	30.243	0.096	314.282	.000	30.054	30.431	-
Category 3 (30to25)	-12.361	0.070	-177.229	.000	-12.498	-12.225	0.682
Category 4 (35to15)	-4.728	0.032	-148.722	.000	-4.791	-4.666	0.682
Category 1 (35to25)	-6.030	0.021	-284.953	.000	-6.071	-5.988	0.682
Category 2 (40to25)	0*						
FlashingLight=OFF	6.234	0.031	202.148	.000	6.174	6.295	0.304
FlashingLight=On	0*						
CarClass=Large	0.786	0.099	7.908	.000	0.591	0.981	0.008
CarClass=Medium	1.954	0.088	22.287	.000	1.783	2.126	0.008
CarClass=Small	0*						
Time=AM	0.341	0.017	20.072	.000	0.374	0.374	0.003
Time=PM	0*						
St_Parking=No	0.316	0.022	14.058	.000	0.272	0.360	0.001
St_Parking=Yes	0*						
Traf_Signals=No	0.402	0.033	12.052	.000	0.337	0.468	0.001
Traf_Signals=Yes	0*						

* This coefficient is set to zero because it is redundant in the model; adjusted $R^2 = 30.4\%$

The model results indicate that key factors affecting drivers' speeds include speed limit differential category (1, 2, 3, and 4), school zone light flashing, vehicle class (large, medium, small), time of day (AM or PM), presence of on-street parking, and presence of traffic signals. Drivers drove slower around schools in categories 3, 4, and 1 compared to category 2. For school zone flashing lights, the estimated coefficients suggested that a higher speed (6.23 mph) was associated with school zone signs being inactive. In other words, motorists slowed down by 6.23 mph when the school zone lights started flashing. Compared to small vehicles, medium and large vehicles traveled faster while higher speeds (0.34 mph) were associated with the AM period compared to the PM period. Drivers traveled faster in the absence of on-street parking (0.31 mph) and when no traffic signals were present (0.40 mph).

The variable importance ranking indicated that the most important variable influencing drivers' speeds was the speed differential category of schools followed by the school zone flashing light status.

4.2 Crash Analysis and Safety Benefits of School Zones

To further investigate the safety benefits of school zones, crashes in the proximity of schools were examined based on spatial information associated with the crashes. Crashes reported during 2014 – 2018 were mapped in a geographic information system (GIS) to identify those reported in proximity of the observed schools. Figure 4.6 below shows the sixteen schools located in the city of Lincoln with mapped crashes.

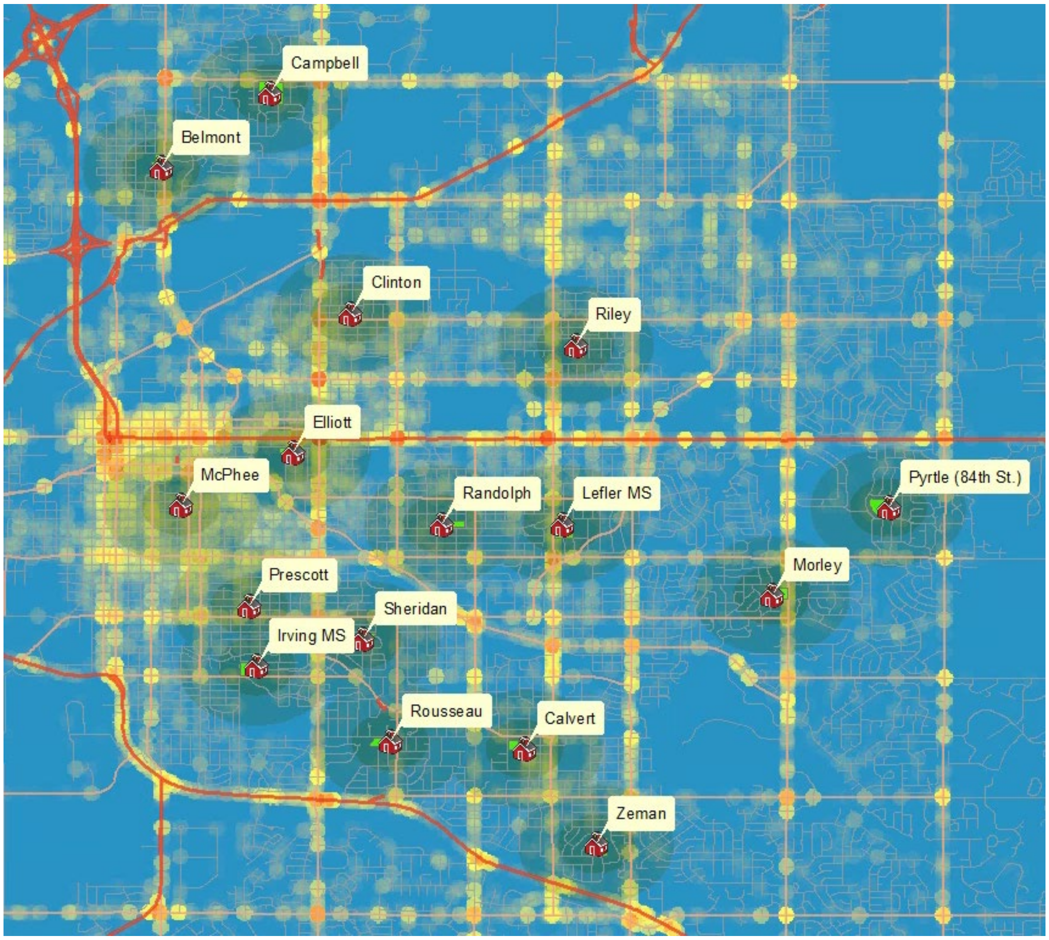


Figure 4.7 Crash Mapping in Lincoln

Crashes were identified on school zone segments for which hourly traffic data were collected during this study as such information was not available from other sources. The spatial information on the observed school zones was recorded manually by the research team and was shown in table 3.3. For instance, figure 4.7 shows the studied school zone segment on Holdrege Street. There were 10 crashes that were identified in this area during the period from 2014 to 2018, shown in figure 4.8. The shaded (blue) area indicates the school property according to the land use data provided by the city of Lincoln. In total, 277 crashes (237 during off and 40 during on periods) were identified in the studied school zone segments during the five-year period.

Figure 4.8 Clinton Elementary, Lincoln (Site 3)

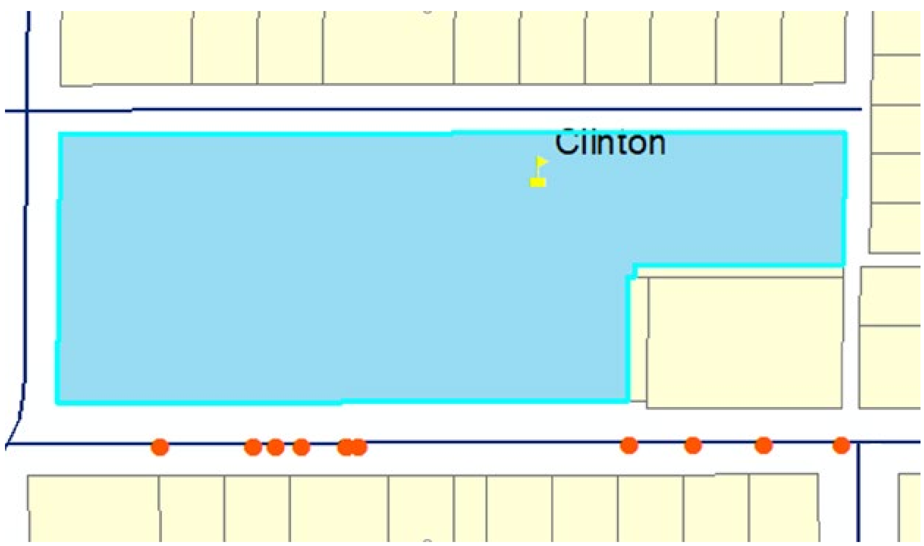


Figure 4.9 Crashes Identified in the Clinton School Zone

Crash rates during the school zone lights off and on periods were examined. The estimated 5-year reported crashes divided by observed vehicles during lights off/on periods were calculated for individual schools as well as grouped by speed differential categories and shown in table 4.5. The units for crash rate in this table are 5-year crashes per 1,000 vehicles. Crash zone lengths were ignored in the calculation as these were more or less similar. The proportion of traffic volume across the off and on periods during the five years at different schools was assumed to be the same as observed in this study at those respective schools. Detailed hourly traffic counts were not available for the study sites except the data collected in this study. No crashes were reported at the Central City Elementary school during the study period.

An examination of table 4.5 shows that the crash rates were lower during the school zone flashing lights off period at most of the observed schools. When aggregated by the speed differential categories, results were similar to individual school results showing lower crash rates during the lights off periods. The overall increase in crash rate at all observed schools was 108 percent indicating that motor vehicle crash rates increased during the periods when school zone lights were flashing compared to the off period. The research team also looked at crashes involving motor vehicles only and those involving motor vehicles and non-motorists (pedestrians and pedacyclists) across the two time periods. Table 4.6 summarizes the results for all observed schools. Results show that crash rates for both crashes involving motor vehicles only and crashes involving motor vehicles and non-motorists increased more than 100 percent during the flashing lights on period compared to flashing lights off period.

Table 4.5 School Zone Crash Count and Rate Summary

Name/ Category	Flashing Lights Off			Flashing Lights On			Difference (Off - On)
	Veh Count	Crash count	Crash rate	Veh Count	Crash count	Crash rate	
Belmont	30010	8	0.267	2464	5	2.029	-1.763
Calvert	8551	5	0.585	965	1	1.036	-0.452
Clinton	15763	6	0.381	1318	4	3.035	-2.654
Elliott	5753	47	8.170	699	5	7.153	1.017
Prescott	7900	14	1.772	461	2	4.338	-2.566
Sheridan	2155	2	0.928	198	1	5.051	-4.122
Lefler	56520	15	0.265	4200	1	0.238	0.027
Irving	22153	4	0.181	2823	2	0.708	-0.528
Rousseau	8510	3	0.353	677	2	2.954	-2.602
Randolph	28387	3	0.106	2331	0	0.000	0.106
McPhee	29707	26	0.875	2389	4	1.674	-0.799
Riley	10760	16	1.487	748	1	1.337	0.150
Categ 1 (35to25)	226169	149	0.659	19273	28	1.453	-0.794
Campbell	13932	29	2.082	778	0	0.000	2.082
Morley	15194	34	2.238	1077	7	6.500	-4.262
Zeman	44464	12	0.270	3365	2	0.594	-0.324
Pyrtle (on 84th St.)	13160	6	0.456	903	0	0.000	0.456
Categ 2 (40to25)	86750	81	0.934	6123	9	1.470	-0.536
Central City Elem; Categ 3	6166	0	0.000	697	0	0.000	0.000
LaVista MS; Categ 4 (35to15)	31009	7	0.226	2319	3	1.294	-1.068

Notes: Crash rate units are 5-year crashes per 1,000 vehicles in the school zone. Percent change in crash rate = [(Off - On) x 100] / (Off). NA = Not Applicable.

Table 4.6 Motorist and Non-Motorist Crash Rate Summary

Crash Rate Category	Flashing Lights Off Period	Flashing Lights On Period	Difference (Off - On)	Percent Change
Motor Vehicle Only Crash Rate	0.00064	0.00134	-0.0007	-109.4
Motor Vehicle and Non-Motorist Involved Crash Rate	0.0343	0.0703	-0.036	-105.0

Notes: Crash rate units are 5-year crashes per 1,000 vehicles in the school zone. Percent change in crash rate = [(Off - On) x 100] / (Off).

Next, the 277 crashes reported in the studied school zone segments during the five-year period were categorized by crash type and injury severity outcomes, as shown in tables 4.7 and 4.8. Rear-end and angle crashes were the most common types of crashes. Injury severity based crash costs were compared between the flashing lights off and on periods using the latest Federal Highway Administration (FHWA) published crash costs (*Harmon et al. 2018*).

Table 4.7 School Zone Crashes by Crash Type

Crash type	Crash count
Rear-end	126
Not applicable	46
Angle	39
Sideswipe (same)	31
Left-turn leaving	25
Backing	6
Sideswipe (opposite)	3
Head-on	1

Table 4.8 Crashes by Injury Severity Outcome

Crash Injury Level	Total Crash Count	Crash Count During Off Period	Crash Count During On Period
Non-reportable	82	69	13
Property damage only	100	86	14
Possible injury	67	59	8
Visible injury	25	20	5
Suspected serious injury	1	1	0
Disabling injury	1	1	0
Fatal	1	1	0
Total	277	237	40

According to the FHWA estimates, the crash costs for 2016 are:

- $11,295,400 for fatal, $655,000 for suspected severe injury,
- $198,500 for suspected minor injury,
- $125,600 for possible injury, and
- $11,900 for property damage only crashes.

Table 4.9 presents a summary of average crash cost calculations for the school zone flashing lights off and on periods at the observed schools. The calculations assumed the same cost for non-reportable crashes as property damage only crashes. The average crash cost during the school zone flashing lights off period was $102,837 while it was $48,853 during the flashing lights on period reflecting a 52.5 percent reduced cost. Thus, on average a crash during active school zone period cost $53,984 less than a crash during the passive school zone period.

Excluding the single fatal crash, the difference is reduced ($55,411 versus $48,853) but still costs are less by 11.8 percent during the lights on period. Overall, the analysis shows that crash costs are reduced during the flashing lights on period compared to the flashing lights off period. The reduction in injuries/costs is likely due to the drivers' slower speeds in active school zones.

Table 4.9 Crash Severity and Costs During Flashing Lights Off and On Periods

Crash Severity Level and Costs	Flashing Lights Off Period	Flashing Lights On Period
Non-Reportable	69	13
Property Damage Only	86	14
Possible Injury	59	8
Visible Injury	20	5
Susp. Serious Injury	1	0
Disabling Injury	1	0
Fatal	1	0
Total crashes	237	40
Total cost (2016 $)	24,372,300	1,954,100
Average Cost Per Crash	102,837	48,853

4.3 Summary

Overall, the major benefit of school zones is reduced drivers' speeds and reduced crash severity. In general, active school zone periods experience higher crash rates; this holds for both motor vehicle only crashes and motor vehicle and non-motorist involved crashes. Higher crash rates when school zones are active are not surprising given the plethora of things happening during these periods such as, frequent vehicular stop and go movements, parking and departure maneuvers, loading and unloading of students, greater number of pedestrians and bicyclists, greater levels of driver distractions, etc. Drivers slowdown in response to school zone flashing lights and mostly drive close to the reduced speed limit although not necessarily at the lowered speed limit. Non-traditional speed limit changes (e.g., 35 mph to 15 mph) do achieve speed reductions but those reductions are not as large as expected based on the speed limit difference.

Chapter 5 Conclusions and Recommendations

This research focused on three aspects regarding school zone safety in Nebraska: the effects of speed differential on drivers' speeds; effects of various elements such as on-street parking, traffic signals etc. on drivers' speeds; and safety benefits associated with school zones.

5.1 Conclusions

Drivers' speed data were collected at 18 school sites in Nebraska along with the crash history in school zones on school days from 2014 to 2018 to obtain insights into the safety of school zones. Specifically, speed and reported crashes were examined when the school zone flashing lights were off and on. These study sites were categorized by the speed limit differential, including 35 mph to 25 mph, 40 mph to 25 mph, 30 mph to 25 mph, and 35 mph to 15 mph. Drivers' mean speed analysis showed that 17 of the 18 school sites experienced a statistically significant speed reduction when the school zone flashing lights became active. However, they generally travelled faster than the lowered speed limit of active school zones. Speed profiles also illustrated that drivers' speeds decreased when the school zone signs were activated. Larger speed limit differentials brought about relatively larger percentage reductions in drivers' mean speeds but the effect started decreasing after the 15 mph speed limit differential. Importantly, drivers' non-compliance with the lower speed limit of active school zones was directly related to speed differentials. Speed limit differentials of 15 and 20 mph resulted in mean speeds that were 12.69 and 5.27 mph above the speed limit of active school zones. The conclusion from this part of the analysis is that while drivers slowdown in response to active school zones, their non-compliance with the lowered speed limit of the active school zone increases with greater speed limit differential.

Results of the linear regression modeling suggested the key contributing factors affecting drivers' speeds included speed limit differential category, school zone active/passive status, vehicle classification, time of day (AM or PM), presence of on-street parking and presence of traffic signals. Drivers slowed down by 6.23 mph when the school zone flashing lights were turned on. Medium and larger vehicles traveled faster compared to small vehicles; higher speeds were associated with the AM traffic, the absence of on-street parking and when no traffic signals were present. The conclusion from this portion of the analysis is that drivers' speeds are affected by speed limit differentials, status of the school zone, time of day (AM/PM), on-street parking, traffic signals, and that drivers slowdown in response to active school zones.

Crash rate analysis was undertaken by mapping 2014-2018 reported crashes in a GIS and identifying those reported within school zones and on the days when schools were in session. Compared to passive school zone flashing lights, overall 5-year crash rates during active flashing lights increased by 108 percent. This increase was consistent when motor vehicle only crash rates and motor vehicle and non-motorist involved crash rates were examined across the two periods (109 percent and 105 percent increase, respectively). The conclusion from the 5-year crash rate analysis is that higher crash rates exist in active school zones for both vehicle only and vehicle and non-motorist involved crashes. It is important to note that active school zones do not contribute to crashes; the reasons for higher crash rates during active school zone time periods are various things simultaneously happening such as stop and go movements, parking and departure maneuvers, loading and unloading of students, etc.

This study used FHWA crash cost estimates for crash injury severity cost analysis. Examination of crashes by severity across active/passive school zone periods showed that the average crash cost during active school zone periods was lower (52.5 percent) than passive school zone periods. On average a crash during an active school zone period cost $53,984 less than a crash during the passive school zone period. The conclusion is that crash costs are lower during active school zone periods compared to passive school zone periods and that school zones do not reduce crashes but help lower crash severity by slowing motor vehicles.

5.2 Recommendations

Based on the conclusions, the following recommendations are in order.

- Transportation agencies should establish school zones with great caution as higher crash rates exist in active school zones.
- An active school zone is not a tool to be used to reduce expected crashes.
- Transportation agencies can expect active school zones to mitigate crash severity and thereby provide safety benefits from reduced crash costs.
- Transportation agencies should exercise caution in setting speed limits for passive and active school zone periods. Due to drivers' relatively high levels of non-compliance, speed limit differences of 15 mph should be rarely used and greater than 15 mph differences avoided.

5.3 Study Limitations and Future Expectations

This study was based on several assumptions due to a variety of reasons including lack of available detailed hourly traffic data in school zones. The research relied on the limited traffic data collected in this study and assumed that traffic did not substantially change between 2014-2018 at the observed school sites. Another assumption was that the proportion of traffic during passive and active school zones remained constant 2014-2018. Another assumption was the use of FHWA crash costs for property damage only crashes for non-reportable crashes in the data. By definition, the non-reportable crash costs are less than $1,000 (the reporting threshold in

Nebraska). Analysis results may be different if the aforementioned assumptions are not valid. While the current study focused on data collected on school open days, it would be beneficial to investigate schools that do not have established school zones versus schools with established school zones. The comparison will reveal more information toward driver behavior in proximity of schools and the benefits of having established school zones.

The conclusions and recommendations in this report are based on past data when travel patterns were relatively stable over many years. The current situation with Coronavirus Disease 2019 (COVID-19) may very well change travel patterns especially around schools as school districts decide on how to accommodate large numbers of students in relatively confined spaces. Travel patterns around schools and consequently travel safety around schools will change, depending on what arrangements different school districts adopt and the duration/permanency of those arrangements.

Acknowledgments

The authors thank the members of the Technical Advisory Committee (Matt Neemann, Lonnie Burklund, Randy Hoskins, Alan Swanson, David Schoenmaker, Jodi Gibson, Anna Neben and Paul Gavin) for their guidance and input throughout this study. The authors are also thankful to Mark E. Lutjeharms from City of Lincoln for sharing speed data and technical report "School Zone Standards" and to the NDOT Research Division (Mark Fischer, Lieska Halsey, Angela Andersen) for help with all aspects of this research project.

References

Act No. 446, Public Acts of 2016, State of Michigan, 2017. Retrieved from http://www.legislature.mi.gov/documents/2015-2016/publicact/pdf/2016-PA-0446.pdf.

Ash, K. G., and M. Saito, 2007. Attitudes and concerns of drivers with respect to school zone safety and speed compliance: Results of an opinion survey of drivers. *International Conference on Transportation Engineering 2007, ICTE 2007*, Vol. 2007, No. Icte, pp. 3140–3145.

City of Lincoln, 2020. *City of Lincoln school zone standards*.

Clifton, K. J., & Kreamer-Fults, K, 2007. An examination of the environmental attributes associated with pedestrian–vehicular crashes near public schools. *Accident Analysis & Prevention*, Vol. 39, No. 4, pp. 708-715.

Driving regulations Section 33-24, Champaign, Illinois, 2020. Retrieved from https://library.municode.com/il/champaign/codes/code_of_ordinances?nodeId=MUCO_CH33TRMOVE_ARTIIDRRE_S33-19.3SAIEIN. Updated on Jan. 2020

Fitzpatrick, K., M. Brewer, K. Obeng-boampong, E. Sug, and N. Trout, 2009. *Speeds in School Zones*. (No. FHWA/TX-09/0-5470-1). TxDOT Report 0-5470-1

Gregory, B., J. D. Irwin, I. J. Faulks, and E. Chekaluk, 2016. Differential effects of traffic sign stimuli upon speeding in school zones following a traffic light interruption. *Accident Analysis & Prevention*, Vol. 86, pp. 114–120.

G., A. K., and S. Mitsuru, 2006. Field Evaluation of the Effect of Speed Monitoring Displays on Speed Compliance in School Zones. Retrieved from https://doi.org/10.1061/40799(213)125.

Harmon, T., G. Bahar, and F. Gross. Crash Costs for Highway Safety Analysis. FHWA Report FHWA-SA-17-071, January 2018.

Hidayati, N., R. Liu, and F. Montgomery, 2012. The Impact of School Safety Zone and Roadside Activities on Speed Behaviour: the Indonesian Case. *Procedia - Social and Behavioral Sciences*, Vol. 54, pp. 1339–1349.

Kattan, L., R. Tay, and S. Acharjee, 2011. Managing speed at school and playground zones. *Accident Analysis & Prevention*, Vol. 43, No. 5, pp. 1887–1891.

Lee, C., S. Lee, B. Choi, and Y. Oh, 2006. Effectiveness of speed-monitoring displays in speed reduction in school zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1973, pp. 27–35.

Federal Highway Administration, US Department of Transportation, 2009. *Manual on Uniform Traffic Control Devices*.

Federal Highway Administration, US Department of Transportation, 2018. *Report No. FHWA-SA-17-071: Crash costs for highway safety analysis*.

Medina, A. M. F., MECE, M. F. A. V., & Diaz, D. M. V, 2010. Simplified methodology for the evaluation of pedestrian safety in school zones. *Institute of Transportation Engineers. ITE Journal*, 80(6), p. 36.

Traffic ordinance article VII: speed regulations, Overland Park, Kansas, 2020. Retrieved from http://online.encodeplus.com/regs/overlandpark-ks/doc-viewer.aspx#secid-3098. Updated on Apr., 2020.

Strawderman, L., M. M. Rahman, Y. Huang, and A. Nandi, 2015. Driver behavior and accident frequency in school zones: Assessing the impact of sign saturation. *Accident Analysis & Prevention*, Vol. 82, pp. 118–125.

Schrader, M., 1999. Study of effectiveness of selected school zone traffic control devices. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1692, pp. 24–29.

Simpson, C., 2008. Evaluation of effectiveness of school zone flashers in North Carolina. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2074, pp. 21–28.

Trinkaus, J., 1996. Compliance With a School Zone Speed Limit: An Informal Look. *Perceptual and Motor Skills*, Vol. 82, pp. 433–434.

Vince, J., and Staff, P., 2016. Speeding in a school zone in Illinois: laws, fines. Retrieved from https://patch.com/illinois/lakeforest/speeding-school-zone-illinois-laws-fines.

Warsh, J., Rothman, L., Slater, M., Steverango, C., and Howard, A., 2009. Are school zones effective? An examination of motor vehicle versus child pedestrian crashes near schools. *Injury prevention*, Vol.15, Issue 4, pp. 226-229.

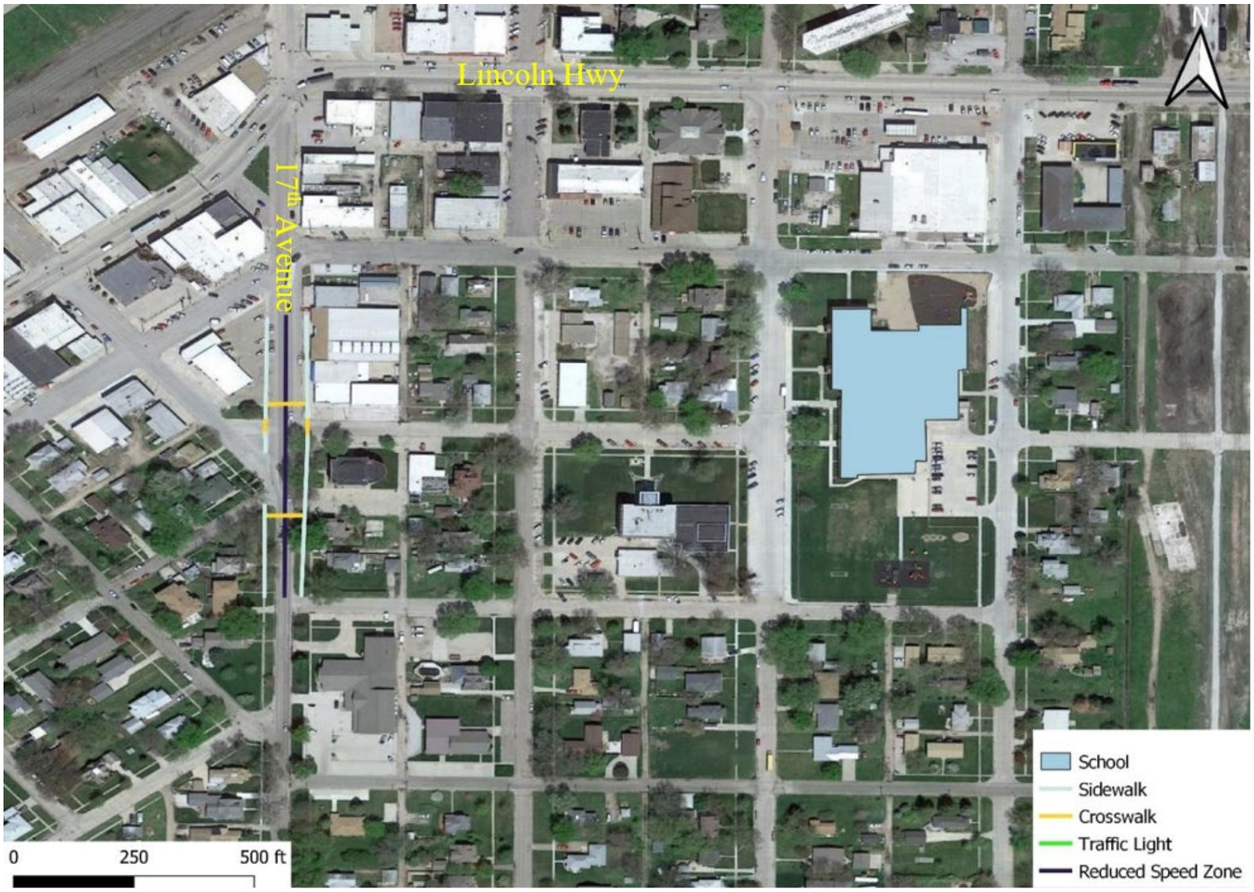
Zhao, X., J. Li, H. Ding, G. Zhang, and J. Rong, 2015. A generic approach for examining the effectiveness of traffic control devices in school zones. *Accident Analysis & Prevention*, Vol. 82, pp. 134–142.

Appendix A

Belmont Elementary

Calvert Elementary

Campbell Elementary



Central City Elementary

Clinton Elementary

Elliot Elementary

Irving Middle School

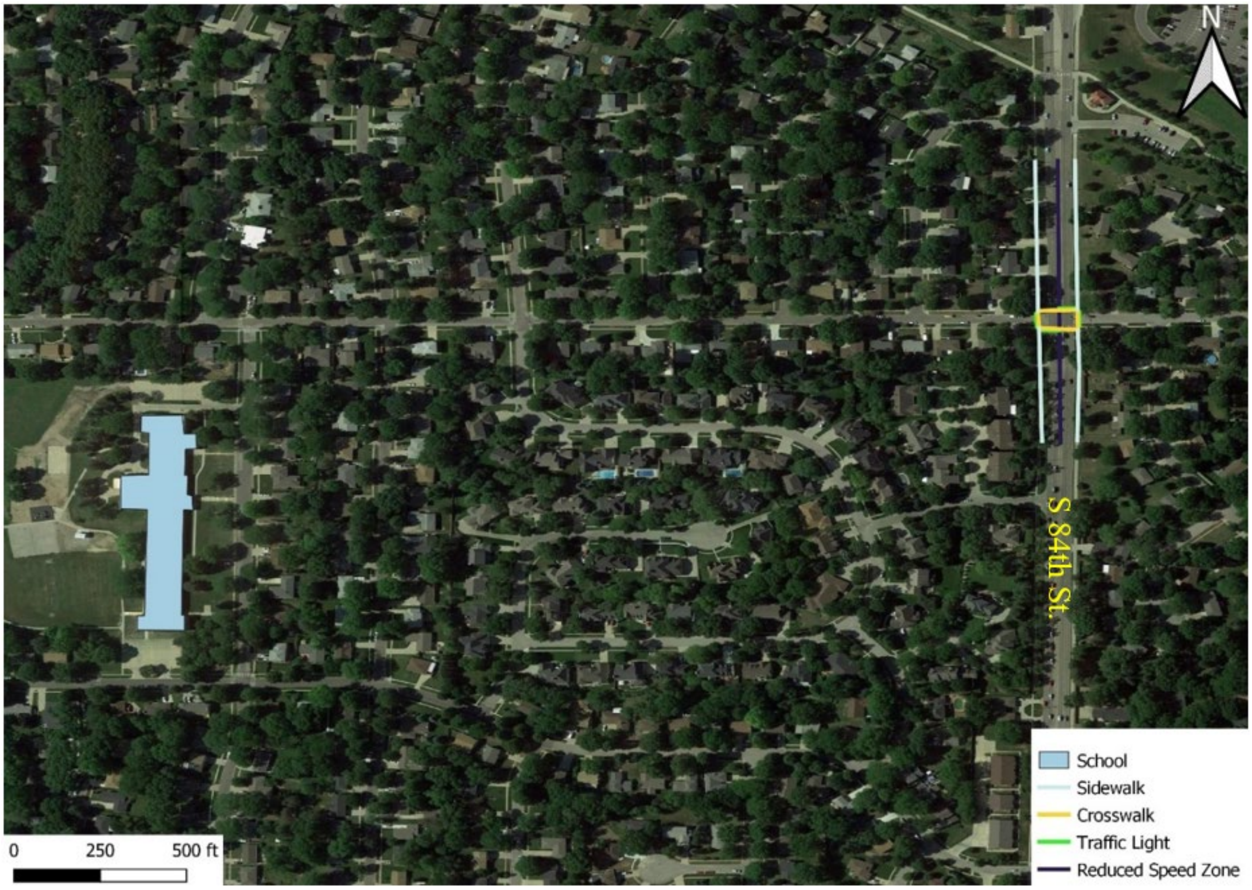
La Vista Middle School

Lefler Middle School

McPhee Elementary

Morley Elementary

Prescott Elementary



Pyrtle Elementary

Randolph Elementary

Riley Elementary

Rousseau Elementary

Sheridan Elementary

Zeman Elementary