2019

Improving Traffic Safety at School Zones by Engineering and Operational Countermeasures

Md Hasibur Rahman
University of Central Florida

IMPROVING TRAFFIC SAFETY AT SCHOOL ZONES BY ENGINEERING AND OPERATIONAL COUNTERMEASURES

by

MD HASIBUR RAHMAN
B.Sc. Bangladesh University of Engineering and Technology, 2015

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil, Environmental and Construction Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2019

Major Professor: Mohamed Abdel-Aty

ABSTRACT

Safety issues at school zone areas have been one of the most important topics in the traffic safety field. Although many studies have evaluated the effectiveness of various traffic control devices (e.g., sign, flashing beacon, speed monitoring display), there is a lack of studies exploring different roadway countermeasures and the relationship between school-related factors and crashes. In this study, the most crash-prone school zone was identified in Orange and Seminole Counties, Florida, based on crash rate. Afterward, a microsimulation network was built in VISSIM environment to test different roadway countermeasures in the school zones. Three different countermeasures: two-step speed reduction (TSR), decreasing the number of driveways (DD), and replacing the two-way left-turn lane (TWLTL) to the raised median (RM) were implemented in the microsimulation. Three surrogate safety measures-: (1) time exposed time to collision (TET), (2) time integrated time to collision (TIT) and (3) time exposed rear-end crash risk index (TERCRI) were utilized in this study as indicators for safety evaluation. The higher value of surrogate safety measures indicates higher crash risk. The results showed that both TSR and DD reduced TET, TIT and TERCRI values significantly compare to the base condition. Moreover, the combination of TSR and DD countermeasures outperformed their individual effectiveness. The One-way ANOVA analysis showed that all the sub-scenarios were significantly different from each other. Sensitivity analysis result has proved that all the sub-scenarios in TSR and DD reduced TET, TIT and TERCRI values significantly for different value of TTC threshold. On the other hand, for converting the TWLTL to RM, the crash risk was higher than the base condition because of the turning movements of vehicle. The results of this study could help transportation planners and decision makers to understand the effect of these countermeasures to improve safety at school zones.

Keywords: school zone safety, two-step speed reduction, surrogate safety measures, flashing beacon, microsimulation

ACKNOWLEDGMENT

I would like to convey my heartiest gratitude to my honorable supervisor Dr. Mohamed Abdel-Aty for his excellent supervision and constant support in this thesis. I would like to acknowledge Dr. Lee for his guidance and support. I would also like to acknowledge the support and encouragement from my family and friends.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

DD- Decreasing the number of Driveways

RM- Raised Median

TTC-Time to Collision

TET-Time exposed time to collision

TIT-Time integrated time to collision

TERCRI-Time exposed rear end crash risk index

TWLTL- Two way left turn lane

TSR- Two-step speed reduction

CHAPTER 1: INTRODUCTION

1.1 **Introduction**

Traffic crashes are a serious safety concern and it is more serious when it involves school-age pedestrian as there has been an increase in the number of school-age pedestrians and cyclists injured and killed throughout the years. Many states set a lower speed limit at school zone area to protect children from severe crashes. However, drivers often do not comply with these speed limits. Sometimes, some school zones require drivers to reduce their speed suddenly which may cause a large variation of speed between vehicles and it may result in rear-end crashes. The crash statistics near school zones in U.S. is increasing every year which is shown in Figure 1.1 below:

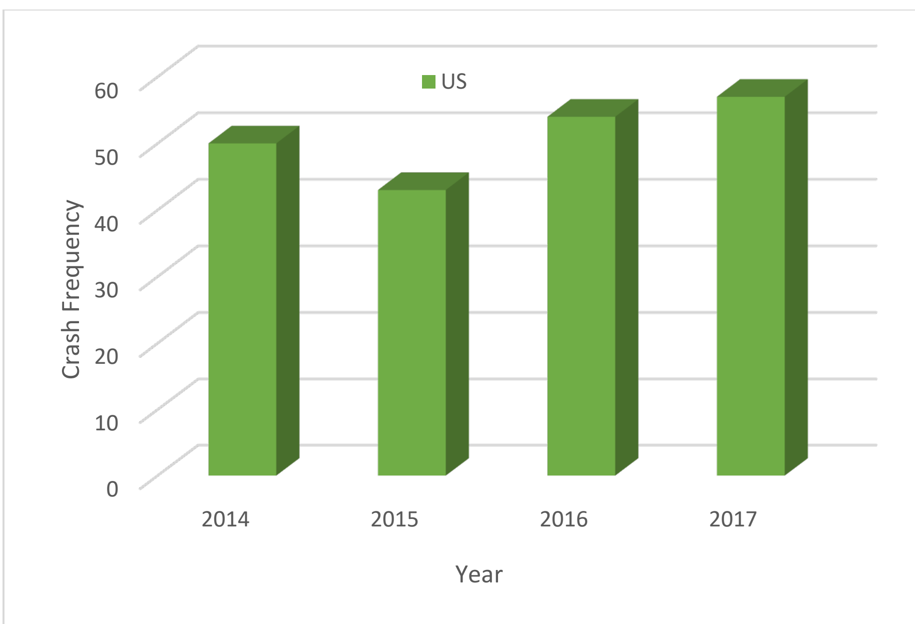


Figure 1.1- Previous crash statistics at school zone area in the United States (source FARS data)

From Figure 1.1, it can be seen that fatal crashes in school zone areas are large and it also has an increasing trend which means focus might be needed on school zones' safety.

1.2 **Thesis Contribution**

This thesis has made several contributions to traffic safety in the school zone area. In order to evaluate school zone safety, this study analyzed the crash statistics of all public schools in Orange and Seminole Counties in Florida. We also investigate and rank all the schools based on crash rates which is defined as crash per thousand daily vehicle miles traveled. Analyzing the crash statistics near the school zone area can help to identify most crash prone school zone area. Moreover, we build the real traffic condition in the simulation environment and analyze the traffic conflicts as a surrogate safety measure. We present three methodologies to improve traffic safety in the school zone area. Applying these methods, we measure traffic conflict and compare with the field condition. Quantifying the surrogate safety measures help us to identify which method is efficient in reducing traffic conflicts as well as improve safety.

1.3 **The Objective of the Thesis**

Previously many studies (Burritt et al., 1990; Simpson, 2008) evaluated the effectiveness of several traffic control devices near the school zone area to improve traffic safety but found that there was no significant improvement of safety in the school zone by implementing this change. Therefore, in this study we analyzed traffic safety by considering various engineering measures. So, the objective of this research is

- To analyze traffic changes for the reduced speed limit in school zones and countermeasures;
- To investigate the impact of geometric design of roadways and the number of driveways on the safety in school zones.

1.4 **Thesis Organization**

The rest of the thesis is organized as follows: Chapter 2 provides the literature review on school zone safety. Chapter 3 provides selection of the study area by analyzing crash data near the school zones. Chapter 4 describes the microsimulation setup, network building, calibration and validation of the study area. Chapter 5 presents the proposed methodologies to improve safety in the school zone. Chapter 6 represents surrogate safety measures which are used to analyze the traffic conflicts. Chapter 7 provides result and discussion of all the methods and comparison between them. Also, sensitivity analysis is described here. Chapter 8 finally describes the summary based on the result obtained in the previous chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Speeding in School Zone

The impact of speeding is acute with the presence of high percentage of vulnerable road users (Peden et al., 2004) and school zones are the prominent of them (Roper et al., 2006). Furthermore, child pedestrian crashes are more likely to happen closer to school zones than farther away (Abdel-Aty et al., 2007a; Warsh et al., 2009).

Ellison et al. (2013) examined the speeding behavior in school zones in Sydney, Australia by using GPS (Global Positioning System). In this study, they observed 147 drivers over five weeks and focused on both the duration and magnitude of speeding. The result showed that over 20 percent of the distance driven in school zone area is at speed higher than the posted speed limit (40 km/h) and 8 percent is driven at 10 km/h or more speed than the above speed limit. Also, the study implied that the over-speeding rate in school zone is higher than urban arterials and residential streets. In addition, Roper et al. (2006) found that approximately half of all vehicles exceeded the speed limit and Kattan et al. (2011) showed that around 10% of the vehicles exceeded the speed by 10 km/h or higher than the posted speed limit.

A posted speed limit in school zones depends on the roadway characteristics on which the school is located and the preceding segments of the roadway before the school zones start (Ellison et al., 2013). This study also showed that if the speed of the previous segment is higher than 70 km/h then it is difficult to reduce the speed with the posted speed limit (40 km/h). McCoy and Heimann (1990) also showed that the school zone speed limit not only depends on the effective signing and marking system but also the reasonable speed limit and the preceding roadway segments. For this reason, the study provided criterion for establishing school speed limits as follows (Table 2.1).

Table 2.1- Criterion for establishing school speed limits

Distance of school building from Roadway (feet)	Approach Speed Limit (mph)		
	25	**35-45**	**55**
0-55	20	20	30
56-100	25	25	30
Over 100	25	330	35

2.2 Effectiveness of various sign in School zones

A traffic sign is one of the most effective tools to control driver's actions. It is also used to deliver a warning and advice to drivers. A failure to regulate driver behavior is considered a major contributor to road traffic crashes (Kirmizioglu and Tuydes-Yaman, 2012). This situation is worse in school zone areas due to the presence of children.

Saibel et al. (1999) evaluated the effects of the various types of sign on drivers' speed at school zone in Washington State. They measured the vehicle speeds at school zone 30 minutes before the start of the school time and 30 minutes after the end of the school time. The school speed limit was 20 mph for all the sites and the project included 38 study sites. The sites were divided by the posted speed limit for the road either 25 mph or 30 mph and greater and the type of sign:

- Time of day: the sign indicates that school speed limit is in effect for all hours of the day or specific times of the day e.g. 7:30 am to 4:30 pm
- Flashing beacon: the sign indicates speed limit of 20 mph is in effective when the beacon is flashing.

- When present: the sign indicates the 20 mph speed limit is in active when children are present
- When flagged: the sign indicates the speed limit will be reduced when orange flags are attached to the sign post.

The result showed that there was no statistically difference for various signs with a posted speed limit of 25 mph but the roads with posted speed limit 30 or greater than 30, the average speed is higher with the “when children are present” and “ when flagged” sign. In contrast, flashing beacons signs were significantly lower the speeds of 22.5 mph, which is 5-7 mph slower speed than the other signs.

Flashing beacons are mainly used to indicate the “Begin school zone” sign and are required in some states. Rear facing beacons are normally used at either end of the school zone facing to serve as a reminder of the end of a school zone as drivers often do not understand whether they are in the school zone area or not. So, a study was conducted in College station, Texas to determine the effectiveness of rear facing school speed limit beacons to reduce the speed limit as sometimes drivers might forget that they are in the restricted speed area where school zone length is long. The study was conducted at four separate sites before and after the installation of the beacons and result showed that speed was reduced at three sites. The other site which experienced no change in speed compliance was the zone with no intersections and of a normal length. So, we can conclude that rear facing flashing beacons can reduce speed in school zone with substantial length (Hawkins, 2007).

In a study of differential effects of traffic sign in school zones in New South Wales, Sydney, Australia (Gregory et al., 2016), it was found that the combination of written text and flashing lights were the most effective in reducing vehicle speed at 40 km/h speed limit when drivers are interrupted by signalized intersections. It was also found that flashing lights only sign could reduce the speed but not below the posted speed limit where there was no difference between text only and no sign conditions. Another study was conducted in North Carolina about the effectiveness of school zone flashers and found that no practical difference in vehicle speed between flasher and non-flasher locations during school time hours (Simpson, 2008).

Speed monitoring display (SMD) provides actual feedback to drivers on their actions within the school zone. It also shows the drivers both the posted speed limit and their speed at which they are travelling. In South Korea, a study was conducted to evaluate the effectiveness of SMD to reduce the speed in school zone area and in this study the location was selected with high visibility, low congestion and no presence of other signal to evaluate the sole effect of SMD. The study also investigated the short and long-term effect of SMD and found that SMD can reduce speed more in short term than long term. Although in both case the speed is lower than the previous condition (Lee et al., 2006). For example, SMD can reduce speed in school zones area and found that average speed reduction was about 17.5% (8.2 km/h) and 12.4% (5.8 km/h) for short term and long-term study respectively. Also, another study of utilizing SMDs conducted in Utah 2005 and found that safety and efficiency vary by locations and SMDs can reduce speed and there is no negative impact on the safety of a location (Ash and Saito, 2006). Moreover, a study was conducted to measure the effectiveness of Dynamic Speed Display Signs (DSDSs) in school zone (Ullman and Rose, 2005). The main result of this study was that speeds were reduced by 9 mph at the school speed zone where DSDSs present, but it can be more effective if appropriate site conditions apply.

There is another way by which we can influence driver behavior through interactive traffic sign and devices. A study conducted by the National Highway Traffic Safety Administration (NHTSA) in Portland, Oregon determined how automated speed enforcements (ASE) impacted speed reduction efforts in school zones and how public accepted and perceived their presence (Freedman et al., 2006). ASE measure the vehicle speed and if the speed is higher than the posted speed it will automatically give ticket to the violators. School speed limits in Oregon are 20 mph and this study used ASE's in five different school zones 2-3 times a week for a three-month period during the school year. The results were compared to five school zones to the surrounding school where there were no ASE present. The result showed that average speed dropped when ASE's present when flashing beacon on and off. This drop was 3-4 mph more when flashing beacon is on. Therefore, it can be concluded that ASE dropped the vehicle speed and it is more effective when paired with flashing beacon.

Zhao et al. (2016) conducted a study in China to examine the effectiveness of traffic control devices on driver behavior. This research used driving simulator experiment to assess the effect of school zone signs and marking for two different types of schools. Average speed, relative speed difference, standard deviation of acceleration and 85th percentile speed was used to evaluate the effectiveness of traffic control device, which were derived from driving simulator. Result showed that flashing beacon with school crossing warning ahead, school crossing warning ahead with the school crossing pavement markings were recommended for the school zone adjacent to a major multilane roadway characterized by high traffic volume and median strip. It also showed that school crossing ahead pavement markings were recommended for minor two-lane roadway.

2.3 Environmental and Geometric Design

There are various physical and social attributes, which regulate the children pedestrian-vehicular crashes in the school zones area. Children are more exposed in school zone area and thus increase the pedestrian crashes (Khan and Rahman, 2016). Walking rates are higher among lower socio-economic groups (Pucher and Renne, 2005). Thus, children from lower income group people have to walk in their way from home to school and this will increase the probability of pedestrian crashes. Moreover, they have to travel twice like home to school and school to home and they are required to cross major road during their commute which double the probability of pedestrian crash.

Clifton and Kreamer-Fults (2007) examined the pedestrian vehicular crashes in the vicinity of public school, the severity of injuries sustained, and their relationship to the physical and social attributes near the schools. In this case, they developed multivariate models of crash severity and crash risk exposure as a function of social and physical characteristics of the area surrounding schools in Baltimore, Maryland. Result showed that the presence of driveway or turning bay on the school entrance decrease and the presence of recreational facilities increase both crash occurrence and severity in Baltimore City, Maryland.

Ben-Bassat and Shinar (2011) investigated the effect of shoulder width, guardrail and roadway geometry on driver perception and behavior. They found that shoulder width does not affect actual speed but if guardrail present at the right edge of the shoulder and it increases driving safety. Tay (2009) also found that width of the roadway and the presence of the fencing gives comfort to drivers' and insists to drive higher speed. The result of this study also showed that compliance rate is higher for two lane road as compared to four-lane road. This is because more lanes give driver more room to drive and hence increase the probability of crash. However, Strawderman et al. (2015) showed different result. In this study, the authors measured the compliance rate for both high and low saturation school zones. Result implied that Compliance rate is higher for 4 lane high saturation zone than 2 lane high saturation zone (46.79% to 20.19%). But In case of low saturation, 4 lane compliance is higher than 2 lanes but the difference is low. (7.23% to 2.56%).

Although the existing studies and established guidelines provide useful information regarding different traffic control devices in the school zones, very few studies investigated the effect of different roadway countermeasures in the school zones. So, the objective of this research is to find out the effectiveness of different roadway characteristics i.e., two-step speed reduction, decreasing the number of driveways, etc. in the school zone area and measure the traffic safety by using microsimulation software. Furthermore, in most of the previous studies (Burritt et al., 1990; Simpson, 2008), traffic control devices were installed in the school zones and the authors measured the effectiveness of them. Sometimes, there was no significant improvement of safety in the school zone by implementing this change. Hence, to address this problem, we analyzed the impact of different roadway characteristics in microsimulation environment which can give a quick and efficient indication of the safety effectiveness to transportation planners or engineers prior to implementing them.

CHAPTER 3: SELECTION OF THE STUDY AREA

3.1 Data Collection

In order to identify the most crash prone school zone for Orange and Seminole County in Florida, we have collected school location data, AADT, total crash for the year of 2012 to 2016 from Signal four Analytics (S4A), managed by the University of Florida GeoPlan Center.

3.2 Data Processing

The school zone area has defined by creating a 1000 ft. buffer zone around a school. In this study, we have selected only public schools in Orange and Seminole County in Florida. Sometimes two or more school zones had overlapped each other, so we have merged the overlapped school zone and counted them as one zone. Furthermore, we selected the AADT inside the buffer area only.

Hence, to identify the most crash-prone school zone, we used crash rate which is defined as total crash per daily vehicle miles (in 1000) traveled (DVMT) within the school zone area. Firstly, the number of crashes were counted inside the buffer area of a school which was further filtered by creating 200 feet radius along the length of those roadways only which had AADT value. Moreover, to calculate the DVMT, we multiplied the AADT values with segment length in miles within a school zone. The above process was continued separately in case of multiple roadway segments, and then added them together to calculate DVMT. Hence, the total number of the crash inside the buffer area was then divided by the DVMT for each school zone to find the crash rate. We excluded those schools where there was no roadway segment inside the buffer area because in this case, DVMT was equal to zero.

Table 3.1 Top ten school based on crash rate

Name	Type	Total Crash	DVMT	Crash Rate	Overlapped
WESTRIDGE MIDDLE	MIDDLE	248	9204	26.943	Yes
SADLER ELEMENTARY	ELEMENTARY				
INNOVATIONS MIDDLE SCHOOL	MIDDLE	411	19145	21.467	
ALOMA ELEMENTARY	ELEMENTARY	333	19451	17.119	
PINE HILLS ELEMENTARY	ELEMENTARY	50	2930	17.059	
OAK HILL ELEMENTARY	ELEMENTARY	416	26405	15.754	Yes
SUNSHINE HIGH CHARTER	SENIOR HIGH				
UNION PARK ELEMENTARY	ELEMENTARY	415	27418	15.136	Yes
UNION PARK MIDDLE	MIDDLE				
HOWARD MIDDLE	MIDDLE	199	13314	14.946	

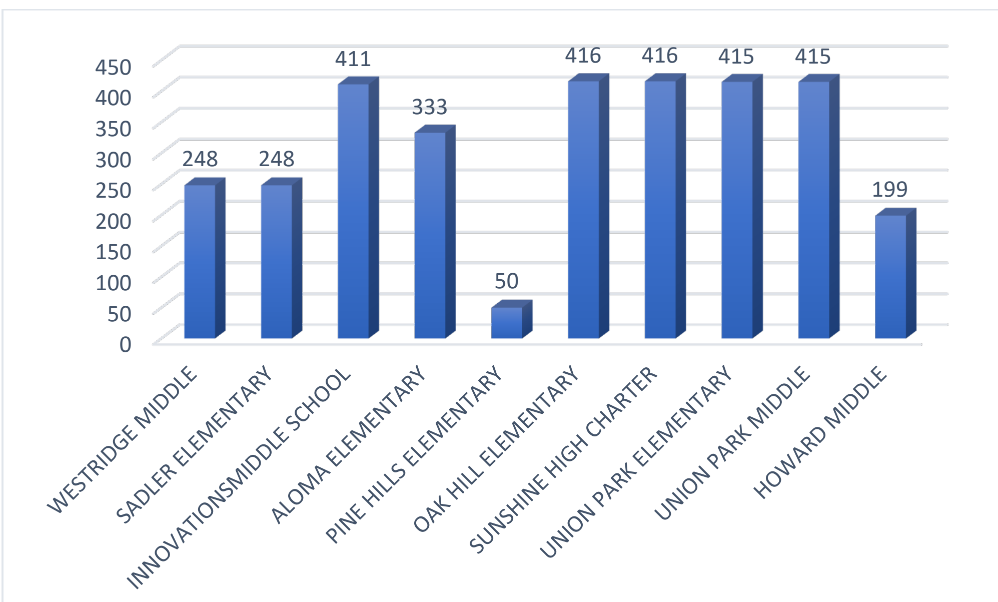


Figure 3.1 Total crashes of the ten school zones

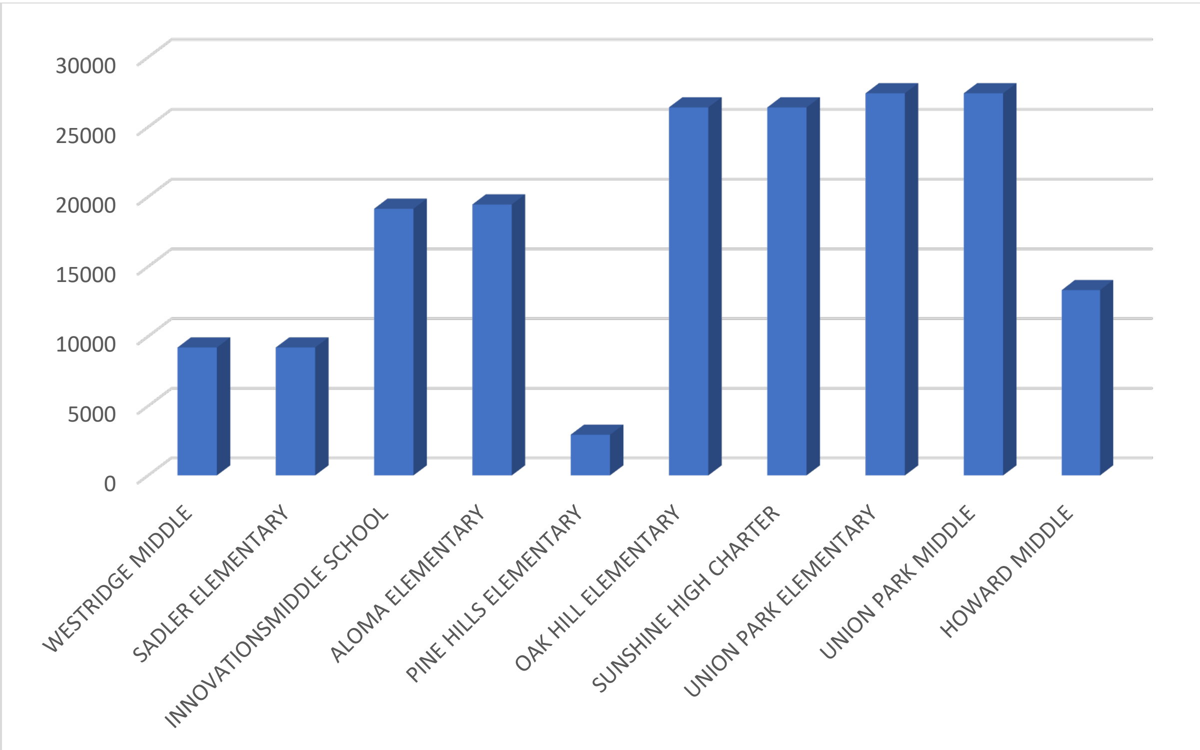


Figure 3.2 DVMT of the ten school zones

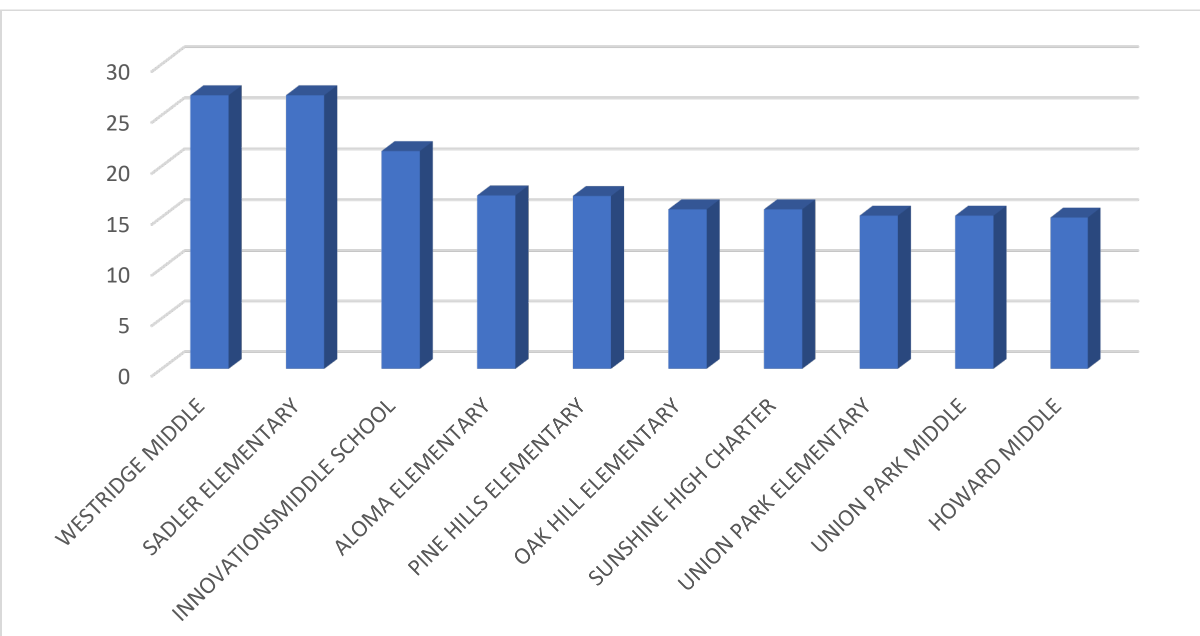


Figure 3.3 Crash rate of the ten school zones

Crash rate is higher for those school zone where number of crashes is larger and DVMT is smaller. From the Figure 3.1, it has been seen that Oak Hill Elementary and Sunshine High Charter School has the highest crash from 2012 to 2016. The lowest DVMT was observed at Pine Hills Elementary and Westridge Middle School (Figure 3.2). Finally, we have identified the top ten school zones based on crash rate which is shown in Figure 3.3. From the Table 3.1, it could be observed that Westridge Middle and Sadler Elementary School has higher crash rate than others. Moreover, we analyzed the crash type in the study area (West Oak Ridge and Sadler Elementary school) and found that around 49% of total crashes (Table 3.2) were rear-end crash.

Table 3.2 Different crash type in Study area

Crash Type	Count	Percentage
Rear End	120	48.39%
Left Leaving	44	17.74%
Same direction Sideswipe	16	6.45%
Left Rear	11	4.44%
Pedestrian	10	4.03%
Off Road	9	3.62%
Parked Vehicle	8	3.23%
Right Angle	5	2.02%
Bicycle	5	2.02%
Backed Into	5	2.02%
Single vehicle	4	1.61%
Right/Through	3	1.21%
Opposing Sideswipe	2	0.81%
Other	6	2.42%
Total	**248**	**100.0%**

CHAPTER 4: MICROSIMULATION NETWORK

4.1 Data collection

In order to obtain traffic volume data from the main corridor (West Oak Ridge Road), the research team conducted a volume study survey in the school zones. The team collected data for two-time periods: morning (7:20 to 8:30 am) and afternoon (2:55 to 3:55 pm) during the school hours (Thursday) from two different locations. The research team counted three types of vehicle separately (i.e., passenger car (PC), heavy vehicles (HV) and school buses (SB)). The composition of each vehicle type found in the survey is presented in Figure 4.1.

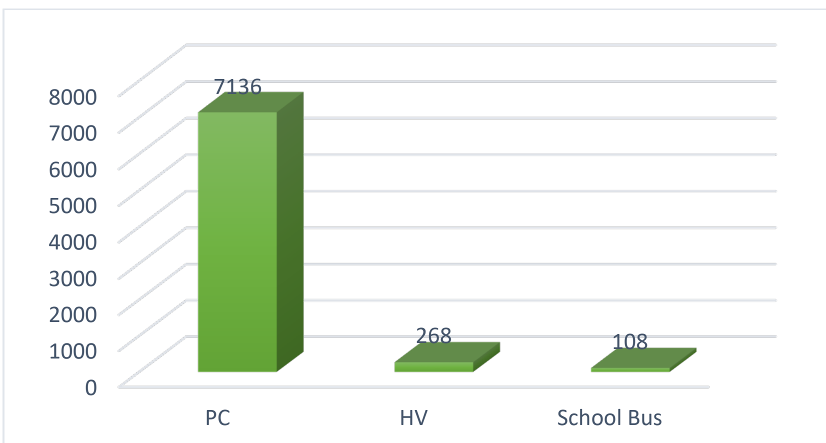


Figure 4.1 Vehicle composition in the morning and afternoon

From Figure 4.1, it has been seen that the total number of traffic volume in both directions on the roadway was 7,512 where the number of passenger car was significantly higher than the other two types. The percentage of the passenger car was around 95%, and those of heavy vehicles and school buses were 3% and 2%, respectively.

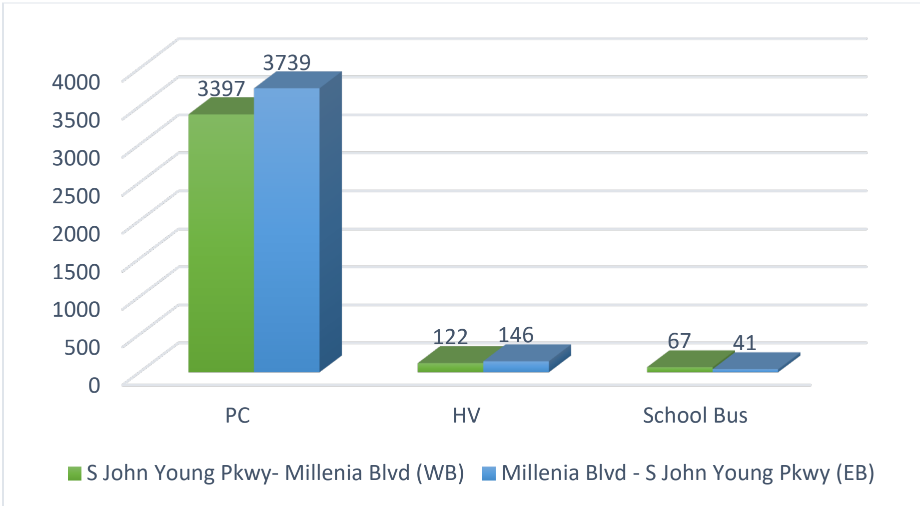


Figure 4.2 Vehicle composition EB and WB

Figure 4.2 presents the vehicle composition by direction (eastbound and westbound). From the figure, the total number of the passenger cars and heavy vehicles was larger for eastbound (Millenia Boulevard - South John Young Parkway) than westbound (South John Young Parkway - Millenia Boulevard) direction. On the other hand, the number of school buses was larger for westbound.

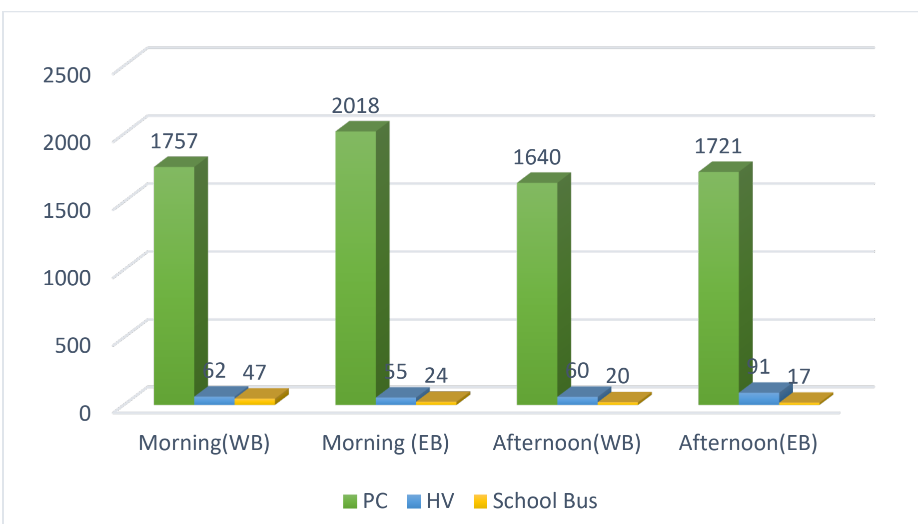


Figure 4.3 Vehicle composition by morning and afternoon both EB and WB

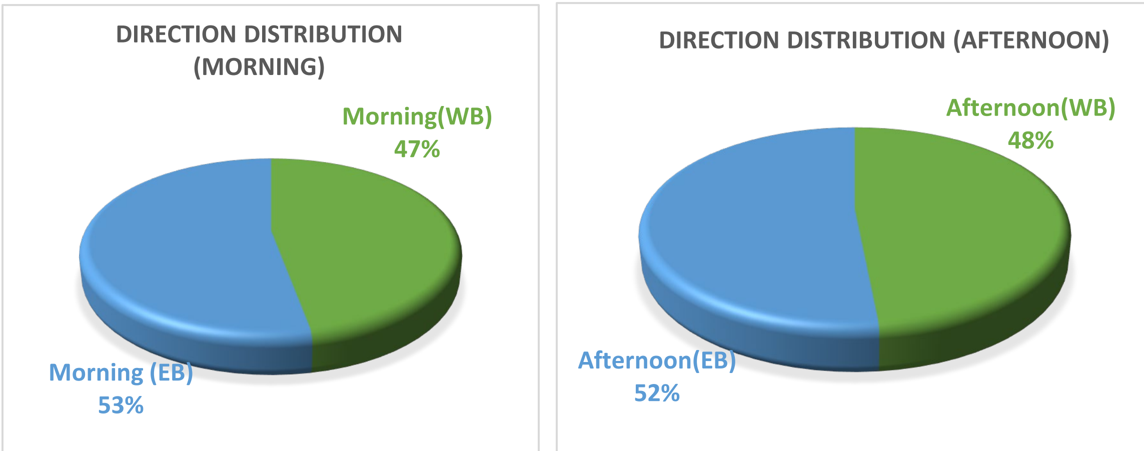


Figure 4.4 Directional distribution during morning and afternoon

In general, traffic volume would be much larger in one direction than other during morning peak hours and the reverse scenario will happen during afternoon peak hours. However, the above analysis shows that the directional distribution of traffic volume was almost same for both direction during morning and afternoon which means that flow was almost constant in both directions at morning and afternoon time (Figure 4.3 and Figure 4.4).

Also, the research team analyzed the percentage of traffic volume with respect to AADT and found that the percentage was varied from 4-6% of AADT during the morning and afternoon period.

4.2 Network Building in VISSIM

4.2.1 Microsimulation Area

In this study, a microsimulation network was built in VISSIM microsimulation environment for further analysis. As the main objective of this study is to improve school zone safety, therefore the research team selected the roadways (i.e., West Oak Ridge, Millenia Boulevard, South John Young Parkway, etc.) near school zone that might have a major impact on school zone safety. Hence, the team developed a network in VISSIM, which was about 3.21 miles long on West Oak Ridge Road connected with other road named South John Young Parkway (1.7 miles long). Moreover, the team considered around 29 driveway accesses and 7 intersections that might have impacts on the main roadway as well as school zone area. The proposed full network in VISSIM is shown in Figure 4.5.

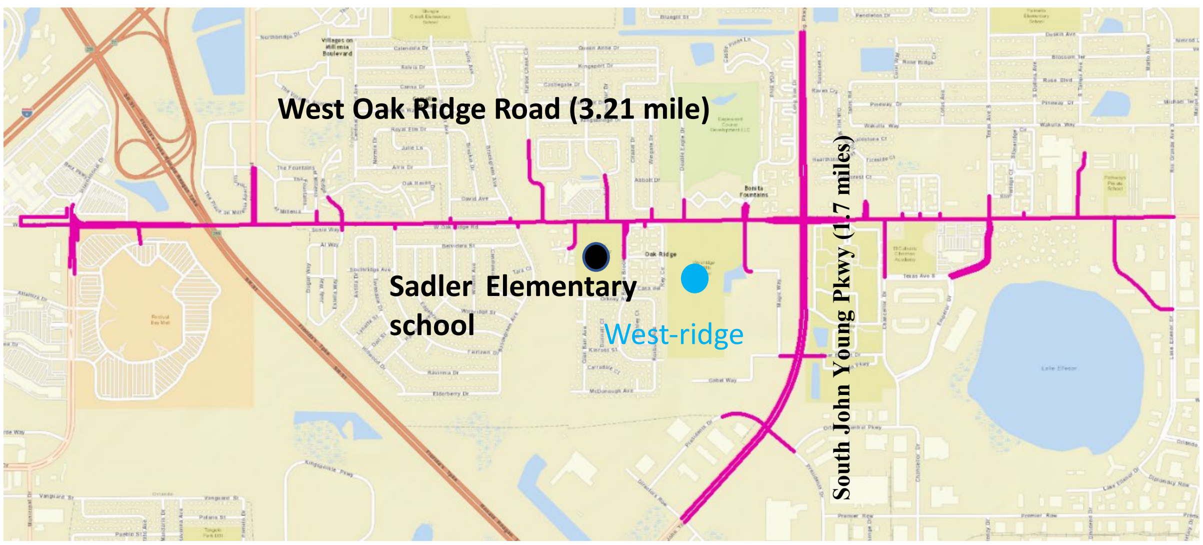


Figure 4.5 Microsimulation area

4.2.2 Network Coding

In VISSIM, there are two basic components of roadway network, which are links and connectors. The links represent roadway segments and are connected to other links by connectors. Thus, vehicles cannot travel from one link to another without connectors attached. There are several properties which must be specified for each link: (1) number of lanes for the segment; (2) behavior type—there are six types of behavior in total, and urban (Motorized) was selected in this project; (3) lane width which was set as 12.0 feet; and (4) gradient, set as 0% since the study segment is flat. Following the roadway shapes in the background Bing map, which is toggled in VISSIM, the research team adjusted the curvatures of the studied segment by coding through adjusting the shape of links and connectors. Finally, the model of the arterial segment could accurately represent the geometric characteristics of the studied arterial segment. Figure 4.6 displays the link description in VISSIM and Figure 4.7 shows the roadway segments coded in VISSIM with the background map where links indicate blue line and connectors indicate red.

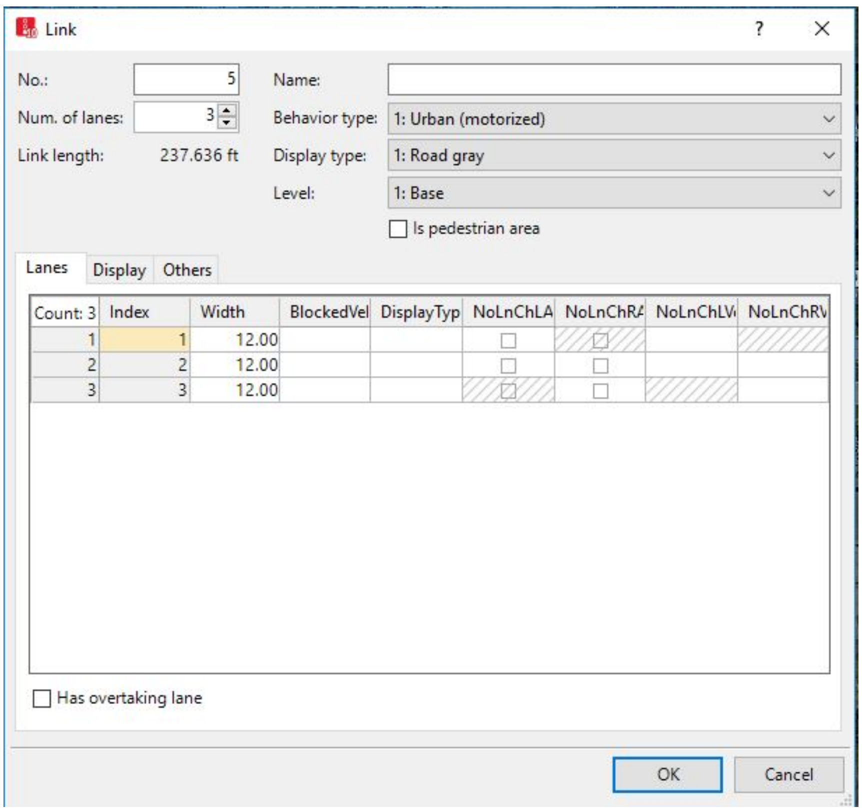


Figure 4.6 Description of link in VISSIM

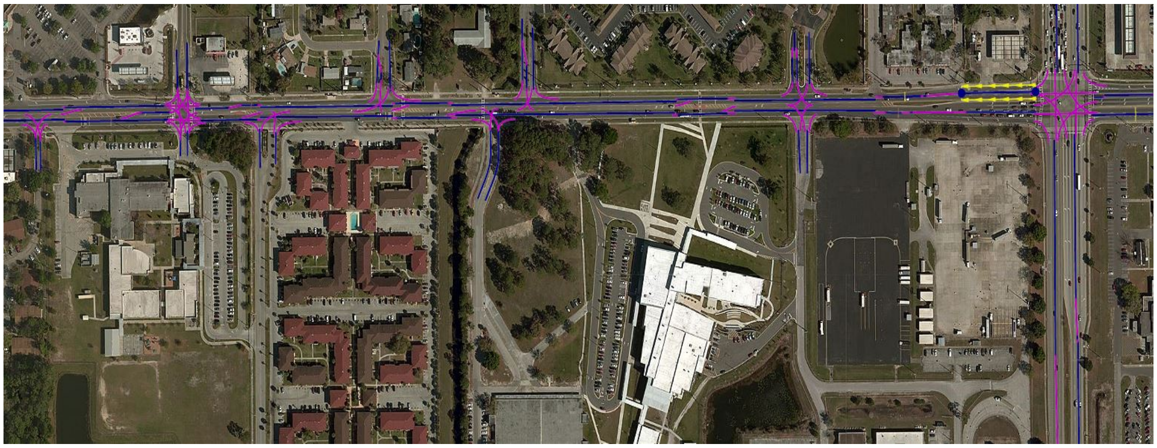


Figure 4.7 Roadway segments coded in VISSIM

Also, the research team used priority rules, stop signs, and conflict areas tools for coding TWLTL in VISSIM which is shown in Figure 4.8.

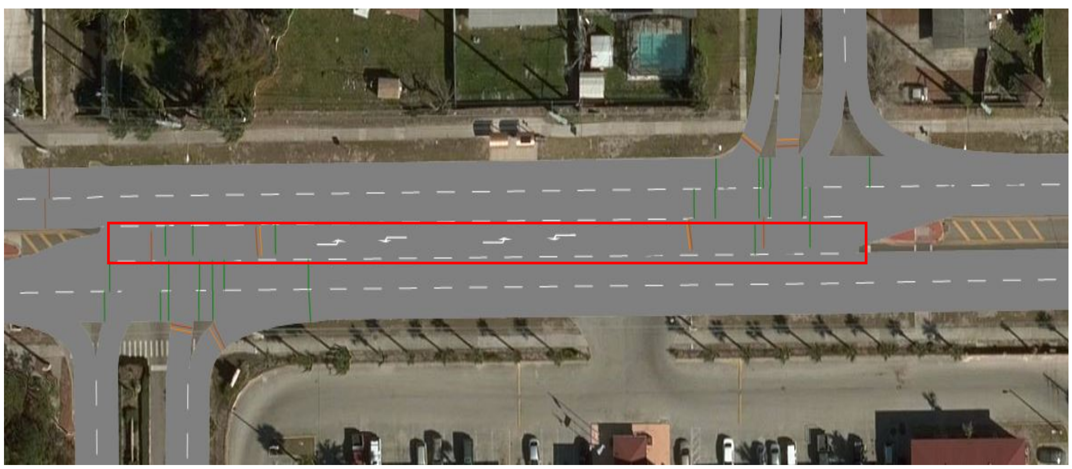


Figure 4.8 Two way left turn lane in VISSIM

4.2.3 Traffic Data Input

Traffic data i.e., volume, vehicle composition, and speed are needed in addition to the roadway geometric characteristics, link, and connectors. Nevertheless, there was no detector to collect real-time traffic volume data in the study area. Therefore, in order to input the traffic volume in each roadway in VISSIM, the research team used the traffic volume percentage with respect to AADT that was found for West Oak Ridge Road from volume study survey and multiplied this value with the AADT of other connecting roadways. As the team collected data from two different locations, thus two different traffic volume percentages with respect to AADT was estimated which were further used to calculate the hourly traffic volume of each roadway. Figure 4.9 displays which percentages were used for which roadways.

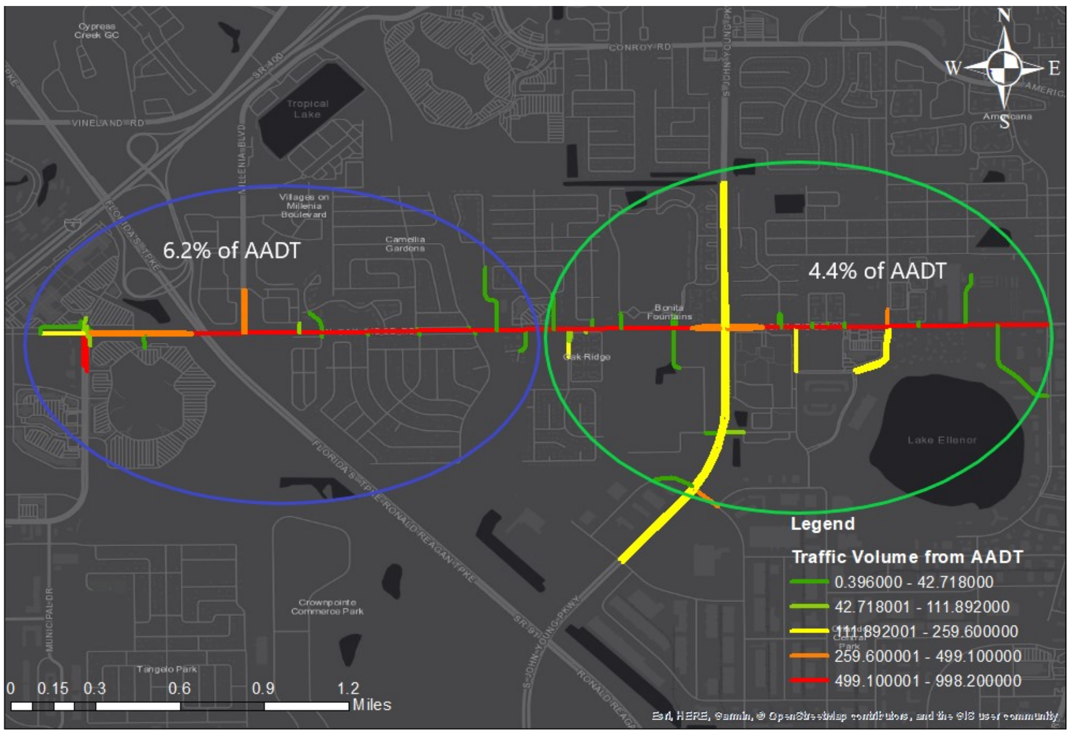


Figure 4.9 Hourly traffic volume

In the above Figure 4.9, blue circle represents the area where 6.2% of AADT was used for hourly traffic volume calculation and similarly for green circle, 4.4% of AADT was used. Moreover, hourly traffic volume variation for each roadway section is shown in the figure where green represents low volume and red represents high volume.

The simulation time was from 7.00 to 9.00 am where first and last 30 minutes were selected for warm-up and cool-down period. The traffic data was aggregated by 5 minutes intervals to input into the VISSIM and similar vehicle composition (95% passenger cars, 3% heavy vehicles, 2% school buses) was used for all roadways.

Desired speed is the speed when drivers are not hindered by other vehicles or network objects (PTV, 2016). Getting desired speed distribution information is difficult because vehicles are always hindered by other vehicles in the roadway. A better way to get desired speed is to find out the off-peak hours when traffic volume is low. Because at low volume, vehicles have less possibility to get hindered by other vehicles and are able to maintain their desired speed.

Because of unavailability of real-time traffic volume data, the research team was not able to differentiate peak and off-peak hours for our study area. Therefore, the team assumed off-peak period was 12.00 to 2.00 am. Hence, the team collected speed data from HERE, NPMRDS (National Performance Measure Research Data Set) which gives aggregated speed of vehicles per 1-minute interval which was further aggregated by 5 minutes interval for the analysis.

In order to formulate cumulative speed distribution, the research team used the coefficient of variation (CV), mean speed, and standard deviation of speed. Hjälmdahl and Várhelyi (2004) showed that in arterial, standard deviation of speed was around 5.31 when mean speed was about 50 mph. CV was estimated by using this value. Then the team calculated the standard deviation of speed for the dataset using the above CV and mean value of speed from HERE dataset.

Moreover, HERE data provided the average speed for all type of vehicles i.e., passenger car, heavy vehicles, and others. However, VISSIM had to specify desired speed distributions for different vehicle types. Therefore, one assumption was made to calculate the desired speed distributions:

the average speed of car was 6 mph higher than that of HV (Hallmark and Isebrands, 2005) and speed of HV and school buses was same.

From the field data, it was found that the percentage of passenger cars in the study segment was about 95%. Supposing x is the speed of passenger cars then the speed for HV or school buses is equal to (x-6), and the average speed provided by HERE is y. Then,

$$0.95\,x+0.05\,(x-6)=y \quad (4.1)$$

From Equation 4.1, the passenger car speed was found to be about (y+0.3), and the HV or school bus speed was around (y-5.7). Then the desired speed distribution of passenger cars (PC), and HV or school buses were acquired separately. Figure 4.10 gives an example of the desired speed distribution for PC and HV/SB of eastbound in South John Young Parkway. Also, the input of desired speed distribution in VISSIM is shown in Figure 4.11.

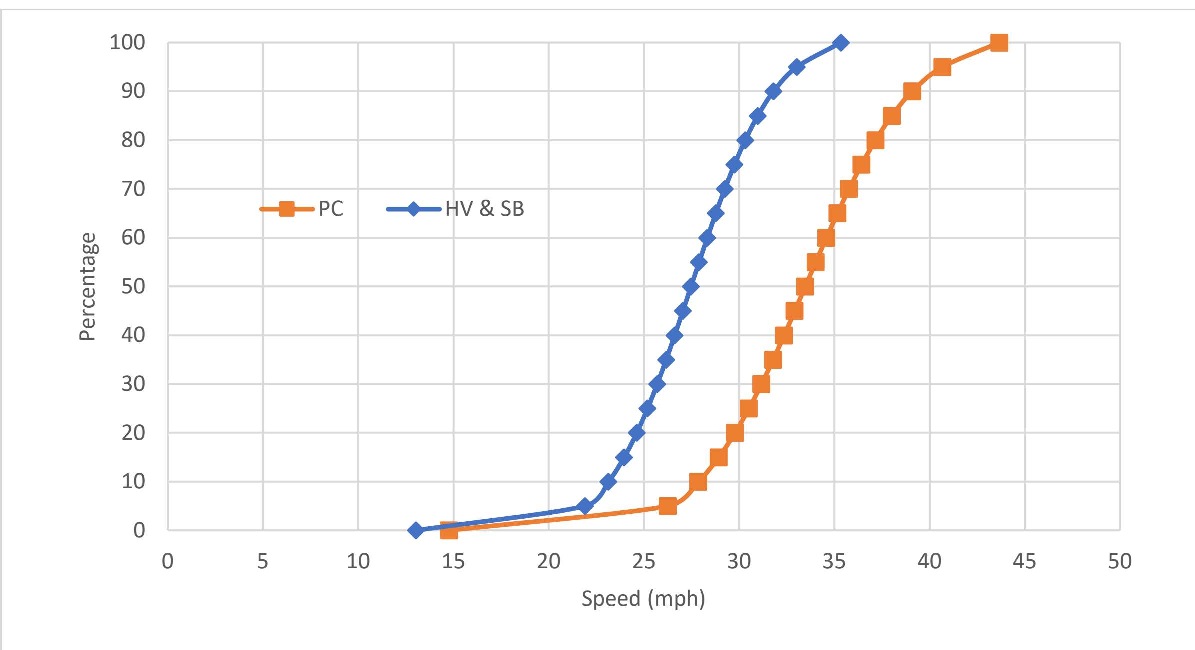


Figure 4.10 Speed distribution of PC, HV, and SB

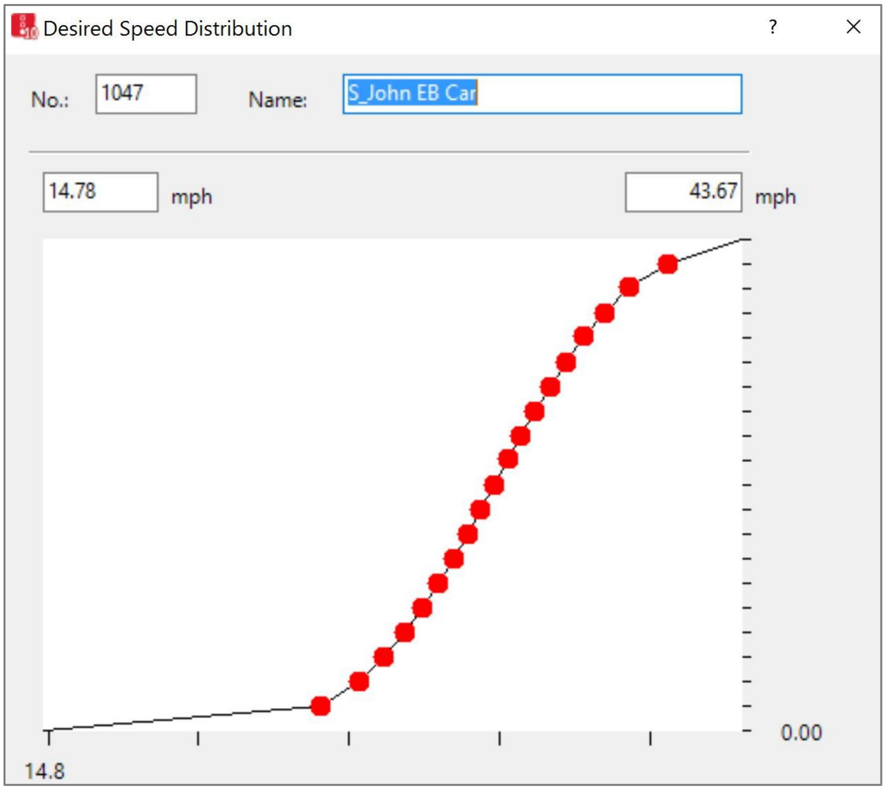


Figure 4.11 Desired speed distribution in VISSIM

Furthermore, data collection points were added to the simulation network in order to get traffic information data from VISSIM. To extract traffic data, they were installed near the intersections and sometimes in the middle of the roadway segments. Data collection points recorded both times when the front and rear of a car reaches and leaves the point respectively, vehicle type, speed, acceleration, etc. One data collection point can only record one lane traffic information. Therefore, if a roadway segment has multiple lanes then multiple detectors are needed. Figure 4.12 shows the detail of data collection points in VISSIM. The name indicates roadway segments (EB or WB direction) and the data collection points indicate how many points or lanes present in that segment.

Coun	No	Name	DataCollectionPoints
1	1	IN_Dr_EB	1,2
2	2	IN_Dr_NB	3,4
3	3	IN_Dr_SB	5,6
4	4	IN_Dr_WB	7,8
5	5	Millenia_EB	9,10
6	6	Milenia _SB	11,12
7	7	Millenia_WB	13,14
8	8	EB_After_Millenia	15,16
9	9	WB_after_Millenia	17,18
10	10	Harcout_EB	19,20

Figure 4.12 Data collection points in VISSIM

4.3 Calibration

According to the U.S. DOT microsimulation guideline for arterials (Dowling et al., 2004), the model network should include areas that might be impacted by the proposed improvement strategies and extend at least one intersection beyond those within the boundaries of the improvement. Thus, a network was built in VISSIM, which was about 3.21 miles long on West Oak Ridge Road connected with other roadways named South John Young Parkway (1.7 miles long), and Millenia Boulevard (0.3 miles). Moreover, around 19 driveway access points and 7 intersections near the school areas were included. For developing microsimulation network around the school zone, three types of vehicle compositions (PC, HV, and SB) were used which is mentioned above and their percentages were 95%, 3%, and 2% respectively. The location of the volume and travel time data collection points, location of selected schools, and roadways for microsimulation network are shown in Figure 4.13.

For calibration and validation, traffic data including traffic volume and travel time were aggregated into 5 minutes intervals. The simulation time was from 7:00 to 9:00 am, where first and last 30 minutes were selected for warm-up and cool-down periods. One of the major roadway geometry features in the school zone was two-way left turn lane (TWLTL) for accessing multiple driveways. The TWLTL was replicated in VISSIM as similar to the real field. In order to replicate the real field in the microsimulation model, calibration, defined as tweaking the value of different parameters to minimize the difference between field and simulated traffic measurement (i.e., volume, speed, travel time, etc.), is the most important part. In this study, for calibration with the traffic volume, the research team used GEH statistics, correlation coefficient (CC), and Theil's inequality coefficient.

There are two car following models i.e., Wiedemann-74 and Wiedemann-99, in VISSIM which were developed by Rainer Wiedemann. Wiedemann-74 car following model is suitable for urban traffic while Wiedemann-99 is suitable for freeway/expressway traffic state (Cai et al., 2018; Gong et al., 2019; Lee et al., n.d.; M. H. Rahman et al., 2019; Rahman and Abdel-Aty, 2018a; Saad et al., 2018b, 2018a). For good calibration result, different parameters (i.e., behavioral, lane changing, etc.) settings of Wiedemann-74 model were changed in VISSIM to replicate the real field as the study area was selected on arterial section. In this study, the objective function for calibration was to maximize the percentage of observations where GEH value is less than 5, maximize the value of CC and minimize the value of Theil's inequality coefficient by fine-tuning different parameters settings within a certain range specified in the VISSIM manual (PTV, 2016; M. H. Rahman et al., 2019; Md Sharikur Rahman et al., 2019).

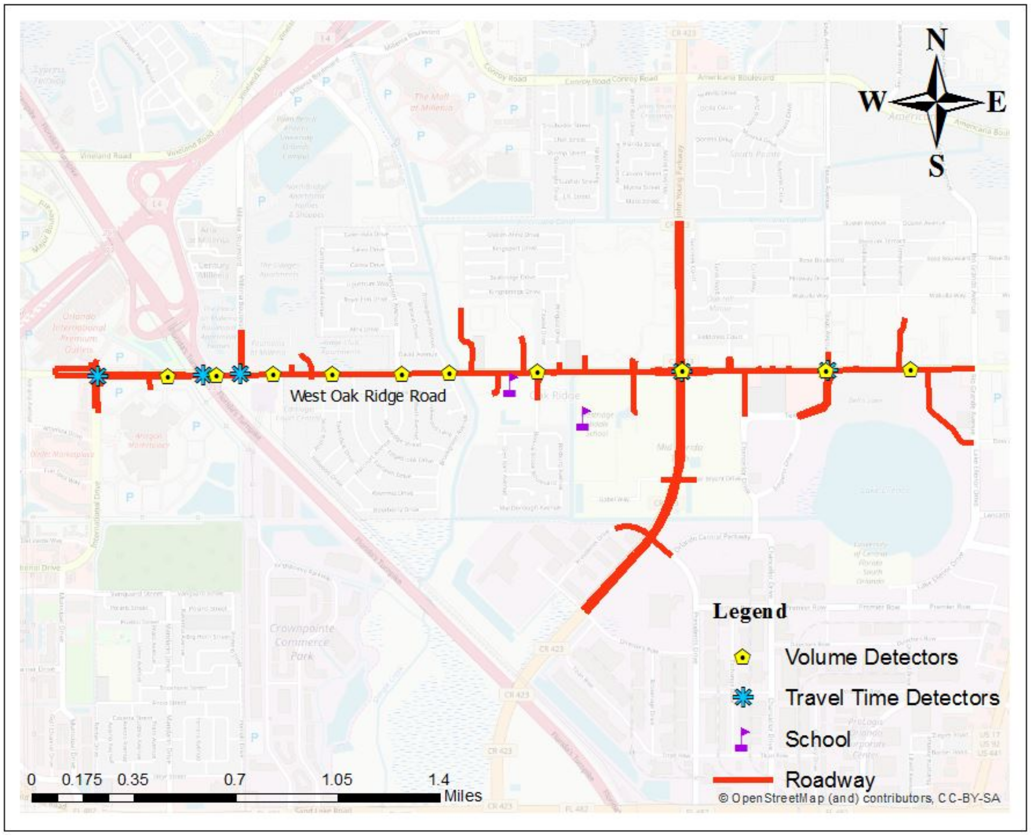


Figure 4.13 The study area showing School zone and Detectors Location

Geoffrey E. Heavers (GEH) statistic is a modified Chi-square statistic that incorporates both relative and absolute differences which was used to compare between field and simulated traffic volumes (A.-A. Ekram and Rahman, 2018; Rahman et al., 2018). The definition of GEH is as follows:

$$GEH = \sqrt{\frac{2\times(V_{obs}-V_{sim})^2}{(V_{obs}+V_{sim})}} \quad \text{.....(4.2)}$$

where V_{obs} is the hourly observed volume of field detectors and V_{sim} is the hourly simulated volume obtained from the simulation network. The simulated volume replicates the field volume perfectly if the GEH value is less than 5 for 85% of the cases (Abdel-Aty and Wang, 2017; A. A. Ekram and Rahman, 2018; M. S. Rahman et al., 2019; Rahman and Abdel-Aty, 2018b; Wu et al., 2019; Yu and Abdel-Aty, 2014). Also, to measure the goodness of fit, Correlation Coefficient (CC) was calculated which indicates the degree of linear association between field and simulated volume. The definition of CC is given below:

$$CC = \frac{1}{n-1} \sum_{i=1}^{n} \frac{(y_{i,sim} - \hat{y}_{sim})(y_{i,obs} - \hat{y}_{obs})}{S_{sim} S_{obs}} \quad \text{...(4.3)}$$

where n is the total number of observations in traffic measurement, $\hat{y}_{sim}$ and $\hat{y}_{obs}$ are means value of the simulation and observed measurements aggregated into 5 min interval, respectively. S_{sim} and S_{obs} are the standard deviations of the simulated and observed measurements, respectively. Correlation Coefficient value of 1 shows a perfect and direct correlation while -1 shows a perfect and inverse relationship (El Esawey and Sayed, 2011; FDOT Systems Planning Office, 2014; Hollander and Liu, 2008). CC value of 0.85 is considered acceptable for the model calibration (FDOT Systems Planning Office, 2014). Another measure that gives information on the relative error is Theil's inequality coefficient, given by:

$$U = \frac{\sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_{i,obs} - y_{i,sim})^2}}{\sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_{i,obs})^2} + \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_{i,sim})^2}} \quad \text{..(4.4)}$$

where n is the number of observations, $y_{i,obs}$ and $y_{i,sim}$ are the overserved and simulated value at time *i,* respectively. *U* is the Theil's inequality coefficient which is bounded between zero and one.

U=0 indicates perfect fit between observed and simulated measurements. (Hollander and Liu, 2008). To compare with the field condition, traffic volume was aggregated into 5-minute interval and ten simulations were run with different random seeds to capture the randomness effect. Finally, the average of the ten simulations was used for the analysis. The results showed that for more than 89% of the cases the GEH value were less than 5 and around 99% of the cases the GEH value were less than 10. Correlation coefficient value was 0.96 which means almost perfect and direct correlation. Also, Theil's inequality coefficient was found 0.08 which means the error is very small and there is a perfect fit between simulated and observed volumes. The calibrated values of the selected parameters such as average standstill distance (feet), Maximum deceleration – Own (ft/s^2), Waiting time before diffusion (s) and Maximum deceleration – Trailing (ft/s^2) were found to be 3.75, -12, 180 and -12 respectively whereas the VISSIM default values were 6.56, -13.12, 60, -9.84 respectively. (See Table 4.1).

For validating the network with travel time, the difference between field and simulated travel times should be within ±1 minute for routes with observed travel times less than seven minutes and within ±15% for routes with observed travel times greater than seven minutes for all routes identified in the data (FDOT Systems Planning Office, 2014). Though in this study, the travel time was less than seven minutes for all cases, both criteria were used for travel time validation. Hence, the result showed that 100% of the cases simulated travel time and the field travel time difference were less than 1 minute and 87.5% of the cases the difference between observed and simulated travel times was less than 15%.

Table 4.1 Parameter settings in VISSIM for calibration

Parameter Grouping	Parameter name	Default settings	Calibrated value
Car Following (Wiedemann 74 car following model)	Average standstill distance (feet)	6.56	3.75
	Additive part of safety distance (feet)	2.00	2.00
	Multiplicative Part of safety distance (feet)	3.00	3.00
Lane change	Maximum deceleration - Own (ft/s^2)	-13.12	-12.00
	Waiting time before diffusion (s)	60	180
	Maximum deceleration - Trailing(ft/s^2)	-9.84	-12.00

CHAPTER 5: PROPOSED METHODOLOGIES

In order to assess the safety performance of different roadway characteristics in school zones, this study tested three different countermeasures i.e., two-step speed reduction, decreasing the number of driveways and replacing two-way left turn lane (TWLTL) to the raised median. Also, the combination of best measures was tested to see the combined safety effect in the school zones.

5.1 **Two-step Speed Reduction (TSR)**

In the school zone area, vehicle speeds are often suddenly dropped because of the speed limit reduction, which results in a high standard deviation of speeds and increases the risk of rear-end crashes. Oh et al. (Oh et al., 2001) found that reducing the variation in speed generally reduces the likelihood of crashes. Also, Ellison et al. (Ellison et al., 2013) showed that if the speed of the previous segment is higher than 70 km/h (43.5 mph) then it is difficult to reduce the speed with the posted speed limit (40 km/h or 24.85 mph). Thus, in this study, an intermediate zone was provided for the smooth reduction of speed instead of sudden change from higher speed limit of upstream section to lower speed limit of the school zone area and captured how this change improves safety in the school zone.

In the first part of Figure 5.1 illustrates that the speed limit of the upstream section ahead of the school zone is 40 mph, which is reduced to 15 mph in the school zone area during school hours. This variation might result in a higher standard deviation of speed and increase the probability of rear-end crash occurrence. In order to address this problem, an advance speed reduction zone (see second part of Figure 4) was created between the high and low speed limit section so that drivers can reduce the speed slowly instead of sudden change from upstream section to the school zone area.

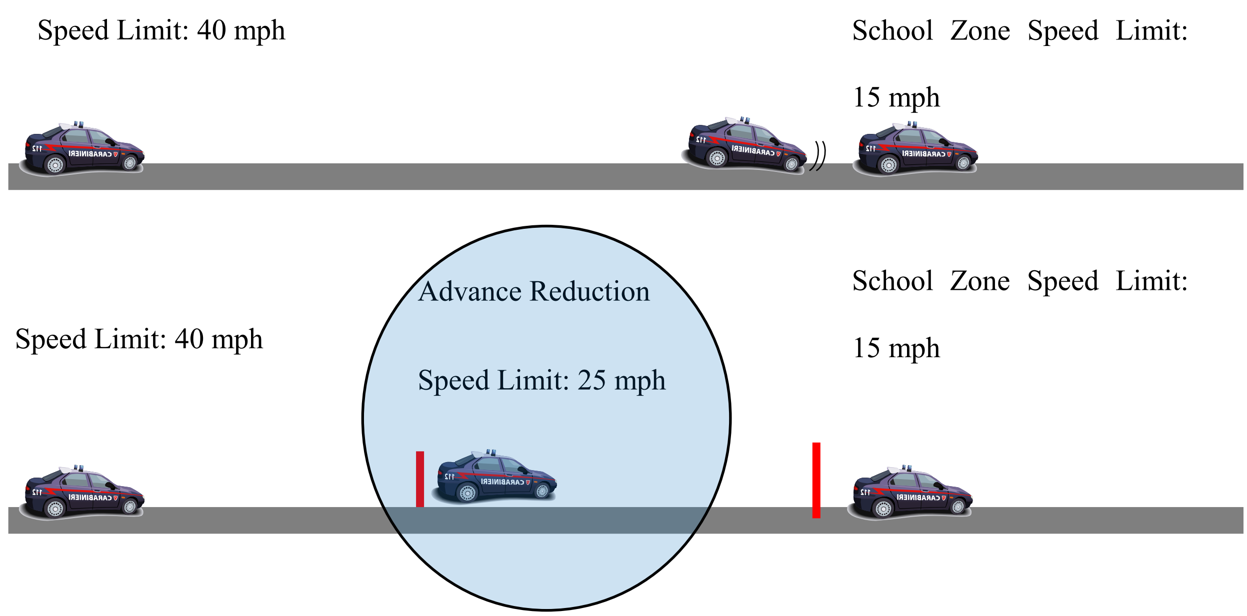


Figure 5.1 Two-step Speed Reduction procedure.

Depending on the maximum speed limit (40 mph) on the main roadway in the school zone, three different procedures (sub-scenario) of TSR was tested in microsimulation which are:

i. 40-25-15 (maximum speed limit 40 mph, advance reduction 25 mph and school zone speed limit 15 mph)

ii. 40-20-15 (maximum speed limit 40 mph, advance reduction 20 mph and school zone speed limit 15 mph)

iii. 40-30-15 (maximum speed limit 40 mph, advance reduction 30 mph and school zone speed limit 15 mph)

5.2 Decreasing the Number of Driveways (DD)

Since most of the land-use at the study area is residential, there are a number of driveway accesses that are directly connected to the main road. Such high density of driveways might create more conflicting traffic movement and increase the crash frequency near the school zone area (Dixon et al., 1999; Kesting et al., 2010; Mauga and Kaseko, 2010; Papayannoulis et al., 1999). Therefore, we suggested to reduce the number of driveway access by 25, 50, and 75 percent by connecting them with the main road through a collector road and tested how this change affects the safety in the school zone (Figure 5.2). We did not test 100% decrease of driveways as it is practically infeasible. So, three different sub-scenarios were introduced under this measure which is given by:

i. DD 25% (driveway reduction by 25%)
ii. DD 50% (driveway reduction by 50%)
iii. DD 75% (driveway reduction by 75%)

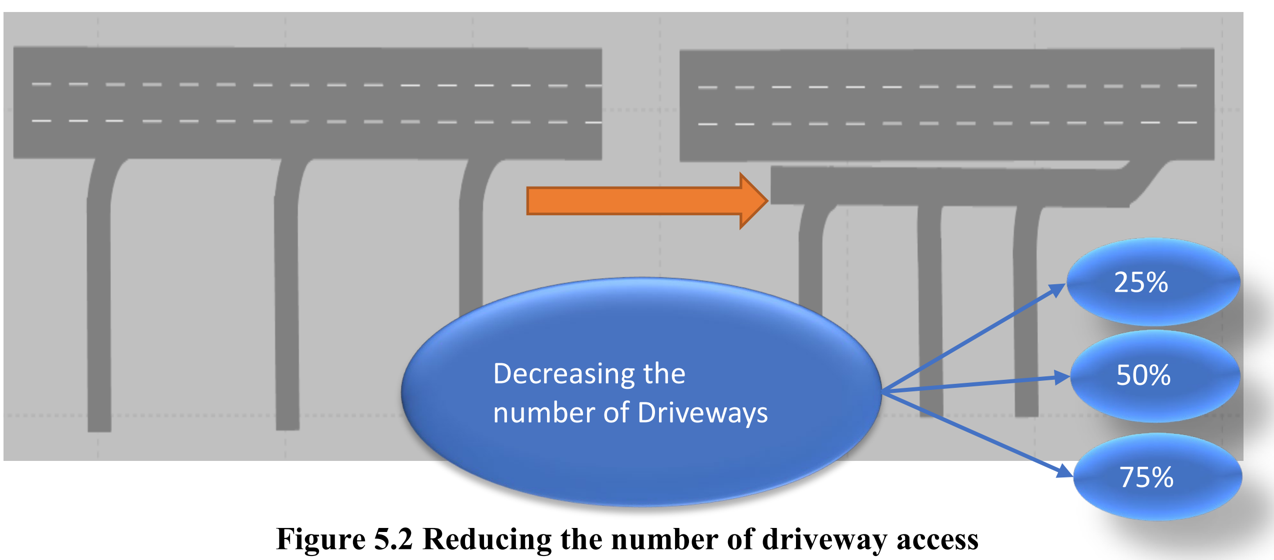


Figure 5.2 Reducing the number of driveway access

5.3 **Replace TWLTL with Raised Median (RM)**

There were too many TWLTL in the study area for accessing between the driveway and the main road which might create confusion to the drivers during turning movements and result in severe crashes. Previous studies (Alluri et al., 2016; Bonneson and McCoy, 1998; Parsonson et al., 2000) showed that raised median (RM) is more effective in reducing crashes than TWLTL but they only analyzed the segments that was changed from TWLTL to raised median. Hence, in this study TWLTL was replaced by the raised median and measured how this change improves safety not only in the raised median segments but also in the location of U-turn movements. Median and intersection U-turns were created so that the vehicle could move to their desired destination. Therefore, we tested two different sub-scenarios in this case i.e., 1. Intersection U-turn 2. Median U-turn.

CHAPTER 6: SURROGATE MEASURES OF SAFETY

The surrogate measures of safety are widely used as indicators to evaluate the crash risk in the microsimulation software as it cannot be directly used to measure crashes or traffic safety. Thus, the surrogate measures of safety are used as an alternative option to evaluate the crash risk in microsimulation. In previous studies (Abdel-Aty et al., 2007b; Peng et al., 2017) lots of surrogate safety measures i.e., time-to-collision, post-encroachment time, and rear-end crash risk index etc. were used. In this research project, three surrogate measures of safety were considered where two advanced surrogate safety measures are developed from Time to Collision (TTC) notations and denoted as time exposed time-to collision (TET) and time integrated time-to-collision (TIT) to evaluate the traffic safety in school zone area. The TTC concept was first introduced by Hayward (Hayward, 1972) and is defined as the time that remains until a collision between two vehicles (following and leading) would occur if the collision course and speed difference are maintained. A smaller TTC value indicates a higher risk of collision at a certain time instant because it represents the time required for two successive vehicles moving on the same lane and collide if they continue with the same speed where following vehicle n is moving faster than the leading vehicle (n-1) which is expressed by:

$$TTC_n(t) = \begin{cases} \frac{y_{n-1}(t)-y_n(t)-L_{n-1}}{v_n(t)-v_{n-1}(t)}, \ if\ v_n(t) > v_{n-1}(t) \\ \infty, \ if\ v_n(t) \leq v_{n-1}(t) \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.1)$$

where $TTC_n(t)$ = the TTC value of vehicle n at time t, y = the positions of vehicles, v= the velocities of vehicles, L_{n-1}= Length of leading vehicles.

Previously, many studies (Peng et al., 2017; Rahman and Abdel-Aty, 2018b) used two types of TTC for analyzing traffic safety where TTC1 denoted that the leading vehicle always maintains its current speed without any change while TTC2 explained the situation where leading vehicle stop suddenly. The later one is called TTC at brake (TTC_{brake}) and in this research project, we analyzed both TTC1 and TTC2 but TTC2 is more appropriate as traffic data was collected from several detectors in VISSIM. The TTC at brake is defined as follows:

$$TTC_{brake}(t) = \frac{y_{n-1}(t) - y_n(t) - L_{n-1}}{v_n(t)} \quad \text{……………………………………(6.2)}$$

The TET and TIT are used to evaluate the risks of collision aggregately which was developed by (Minderhoud and Bovy, 2001). The TET expresses the total time spent in safety critical situations, characterized by TTC_{brake} value below the threshold value TTC*:

$$TET\ (t) = \sum_{n=1}^{N} \delta_t \times \Delta t, \quad \delta_t = \begin{cases} 1, & 0 < TTC_{brake}(t) \le TTC^* \\ 0, & otherwise \end{cases} \quad \text{……………………..…..(6.3)}$$

$$TET = \sum_{t=1}^{Time} TET(t) \quad \text{…………………………………………………………..…..(6.4)}$$

where t = time ID, n = vehicle ID, N = total number of vehicles, δ = switching variable, Δt = time step, which was 0.1 s in simulation, Time = simulation period, and TTC^*= the threshold of TTC. In general, the values of TTC* threshold varies from 1 to 3 s which is used to differentiate between safe and unsafe car following condition (Li et al., 2016, 2018; Rahman and Abdel-Aty, 2018b).

The TIT is also defined by TTC_{brake} and TTC* which is given below:

$$TIT(t) = \sum_{n=1}^{N} \left[\frac{1}{TTC_{brake}(t)} - \frac{1}{TTC^*}\right] . \Delta t, 0 < TTC_{brake}(t) \le TTC^* \quad \text{……………………….(6.5)}$$

$$TIT = \sum_{t=1}^{Time} TIT(t) \quad \text{...(6.6)}$$

A rear-end crash risk index (RCRI) was first proposed by Oh et al. (2006). A rear end crash may occur when the two vehicles moving on the same lane and the leading vehicle stops suddenly but the following vehicle does not decelerate in time with the following vehicle. So, if the following distance between leading and the following vehicle plus the stopping distance of leading vehicle is smaller than the stopping distance of the following vehicle then rear-end crash may occur. In order to avoid the rear end crash, the following vehicle should follow its leading vehicle by making a sufficient gap between them. According to Oh. et al. (2006) the RCRI can be expressed as:

$$SD_F > SD_L$$

$$SD_L = v_L \times h + \frac{v_L^2}{2 \times a_L} + l_L \text{...(6.7)}$$

$$SD_F = v_F \times PRT + \frac{v_F^2}{2 \times a_F} \text{...(6.8)}$$

Where SD_L and SD_F are the stopping distance of the leading and the following vehicles, respectively. PRT is the perception-reaction time, h *is* the time headway, l_L is the length of the leading vehicle, v_L is the speed of the leading vehicle, v_F is the speed of the following vehicle, a_L is the deceleration rate of the leading vehicle and a_F is the deceleration rate of the following vehicle. Furthermore, (Rahman and Abdel-Aty, 2018b) proposed a new surrogate safety measures derived from RCRI and denoted as time exposed rear-end crash risk index (TERCRI) which is defined as:

$$TERCRI\ (t) = \sum_{n=1}^{N} RCRI_n(t) \times \Delta t, \quad RCRI_n\ (t) = \begin{cases} 1, & SD_F > SD_L \\ 0, & Otherwise \end{cases} \quad \text{.......................(6.9)}$$

$$TERCRI = \sum_{t=1}^{Time} TERCRI(t) \qquad \text{...(6.10)}$$

where SD_L and SD_F are the stopping distance of the leading and the following vehicles, respectively. PRT = perception-reaction time, h = time headway, l_L = length of the leading vehicle, v_L = speed of the leading vehicle, v_F = speed of the following vehicle, a_L = deceleration rate of the leading vehicle and a_F = deceleration rate of the following vehicle.

In VISSIM, we used three types of vehicle i.e. Car, Heavy Goods Vehicle (HGV) and School Bus (SB). Therefore, for estimating the reliable safe distance for the leading and following vehicles, different deceleration rates were employed in this research project. The deceleration rate of PC was selected as 3.42 m/s^2 where for both HGV and SB the rates were selected as 2.42 m/s^2. The value of PRT was used as 1.5 s which is accepted by AASHTO (2004).

In this study, we analyzed these three surrogate safety measures for all scenarios and compared between them.

CHAPTER 7: RESULT AND DISCUSSION

As mentioned earlier, we introduced three different countermeasures i.e., two-step speed reduction, decreasing the number of driveways, replacing TWLTL to RM and analyzed TET, TIT, and TERCRI for each measure which is further compared with the field condition (base scenario). Each sub-scenario was simulated repeatedly 30 times in order to consider the randomness effect of simulation. At first, the TTC threshold was considered 1.5 seconds and further sensitivity analysis was conducted for different values of TTC thresholds from 1 to 3 seconds. In this study, we wanted to show the possible maximum benefits of the countermeasures, so we used 100% compliance rate in TSR. Also, we used 820 ft. as look ahead distance in VISSIM.

The descriptive statistics of three surrogate safety measures (TET, TIT, and TERCRI) for all sub-scenarios are presented in Tables 4 and 5. Also, the average value of TET, TIT and TERCRI for all sub-scenarios and percentage change with respect to base scenario is shown in Figure 7.1.

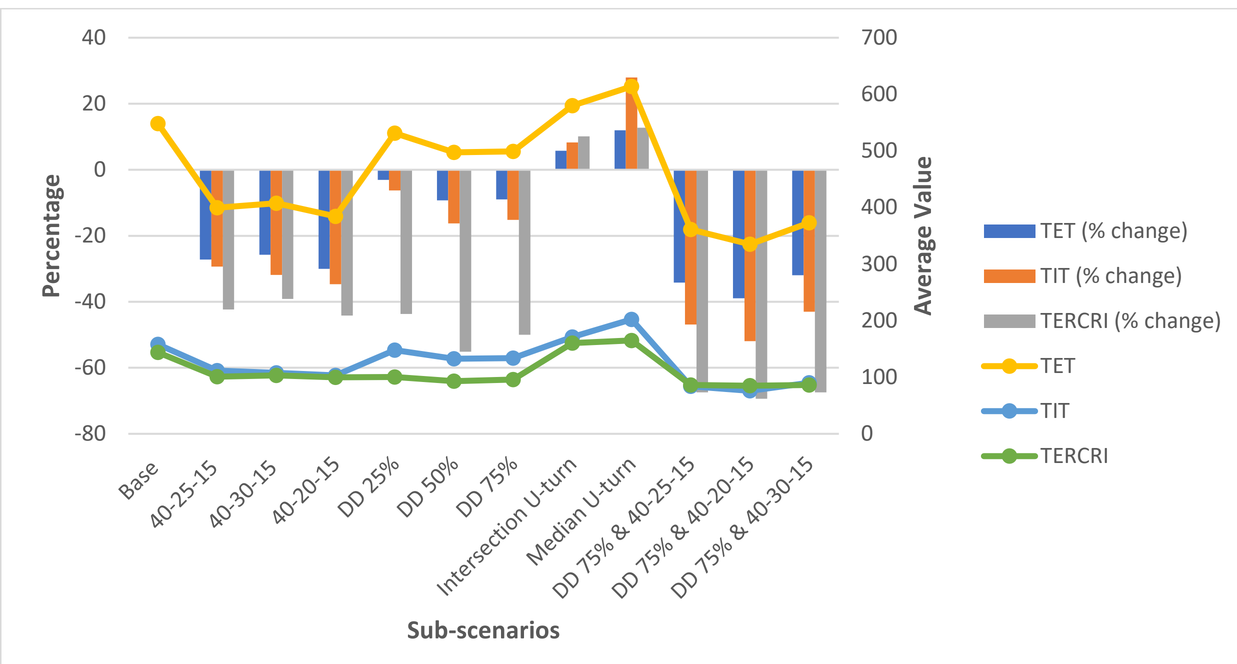


Figure 7.1 Percent change and average value of TET, TIT and TERCRI with respect to the Base

The higher values of TET, TIT and TERCRI imply more dangerous situations. The negative percentage change in Figure 5 indicates lower value of surrogate safety measures and vice versa. Thus, the result showed that the crash risk is higher for the base scenario compared to all other sub-scenarios, except converting TWLTL to RM. For TSR, both 40-25-15 and 40-20-15 sub-scenarios showed the best result among the three of them while for DD, the value of surrogate safety measures decreases with the increase of the reduction percentage of the number of driveways (Figure 7.1). Also, the standard deviation of speed for all sub-scenarios in TSR showed lower value compared with the base condition which is an indication of less crash risk (Figure 7.2).

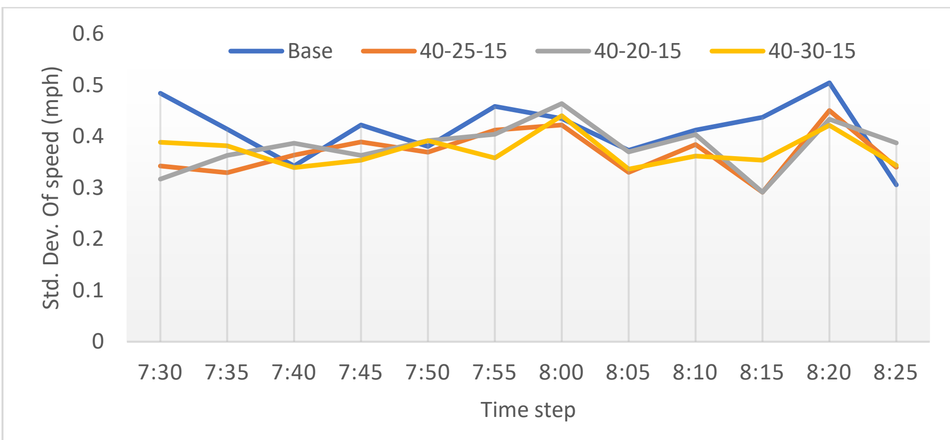


Figure 7.2 Standard Deviation of Speed for all sub-scenarios in TSR.

On the other hand, for replacing TWLTL with RM, the value of surrogate safety measures for both sub-scenarios were higher than the base scenario which means higher probability of crash risk than the field condition. Also, the standard deviation of TET, TIT, and TERCRI was high for base scenario compared to all other sub-scenarios of TSR and DD, which is presented in Table 7.1 and Table 7.2, respectively.

Moreover, we combined the best sub-scenarios (combinations of DD 75% with 40-25-15, 40-20-15, 40-30-15, separately) based on the above results for analyzing surrogate safety measures found that all three combined sub-scenarios outperformed than all other sub-scenarios (Figure 7.1). In addition, the minimum, maximum, mean and standard deviation of TET, TIT, TERCRI values for three combined sub-scenarios were very low than the base scenario which is shown in Tables 4 and 5.

Table 7.1 Summary Statistics of TET and TIT

TET					
Scenarios	**Sub-Scenario**	**Mean(s)**	**Std. Dev(s)**	**Minimum(s)**	**Maximum(s)**
Base	Base	548	43	444	620
Two-step speed Reduction (TSR)	40-25-15	399	31	332	448
	40-30-15	407	31	337	457
	40-20-15	384	30	321	437
Decreasing the number of Driveways (DD)	DD 25%	531	45	432	612
	DD 50%	498	39	416	569
	DD 75%	499	37	428	557
TWLTL to RM	Intersection U-turn	580	41	486	662
	Median U-turn	614	42	520	685
DD and TSR	DD 75 %& 40-25-15	361	29	286	443
	DD 75 %& 40-20-15	335	27	267	411
	DD 75 %& 40-30-15	373	28	309	440

TIT					
Scenarios	**Sub-Scenario**	**Mean(s)**	**Std. Dev(s)**	**Minimum(s)**	**Maximum(s)**
Base	Base	158	40	113	345
Two-step speed Reduction (TSR)	40-25-15	112	27	86	218
	40-30-15	108	10	91	130
	40-20-15	103	25	83	204
Decreasing the number of Driveways (DD)	DD 25%	148	16	117	200
	DD 50%	132	12	111	157
	DD 75%	134	10	117	153
TWLTL to RM	Intersection U-turn	171	15	138	206
	Median U-turn	202	104	156	735
DD and TSR	DD 75% & 40-25-15	84	7	68	91
	DD 75% & 40-20-15	76	6	62	95
	DD 75% & 40-30-15	90	7	73	112

The one-way ANOVA was also conducted among all twelve sub-scenarios. The F-values for TET, TIT and TERCRI were 265.89, 44.47 and 870.54, respectively, which are considerably higher than the critical F-values at 95% confidence level. Therefore, we can conclude that all the sub-scenarios are significantly different from each other. Furthermore, we tested ANOVA, separately for TSR, DD, replacing TWLTL with RM and combination of DD and TSR which indicated that the sub-scenarios for each countermeasure are also significantly different from each other.

Table 7.2 Summary Statistics of TERCRI

Scenarios	Sub-Scenario	Mean (s)	Std. Dev (s)	Minimum (s)	Maximum (s)
Base	Base	144	10	123	161
Two-step speed Reduction (TSR)	40-25-15	101	6	91	113
	40-30-15	103	6	91	115
	40-20-15	100	6	89	111
Decreasing the number of Driveways (DD)	DD 25%	88	6	77	103
	DD 50%	93	7	79	108
	DD 75%	99	7	86	113
TWLTL to RM	Intersection U-turn	160	9	143	176
	Median U-turn	165	9	147	183
DD and TSR	DD 75% & 40-25-15	86	9	68	108
	DD 75% & 40-20-15	85	9	66	111
	DD 75% & 40-30-15	86	10	63	117

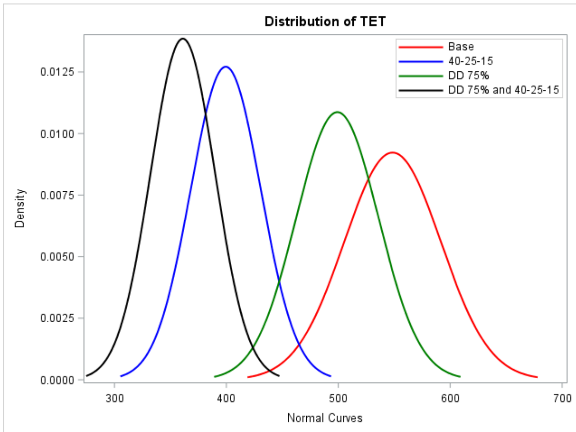
In addition, the distributions of TET, TIT and TERCRI for four sub-scenarios, i.e., base, 40-25-15, DD 75% and DD 75% & 40-25-15 are shown in Figure 7.3(a), 7.3(b), and 7.3(c), respectively.

Moreover, the mean value of TET, TIT, and TERCRI for these three sub-scenarios along with base condition were presented in Figure 7.3(d) which shows that all three sub-scenarios improve considerably compared to the base scenario but the combined sub-scenarios (DD 75% & 40-25-15) reduced TET, TIT, and TERCRI values more which is approximately by 34%, 47% and 40%, respectively, compared to the base scenario.

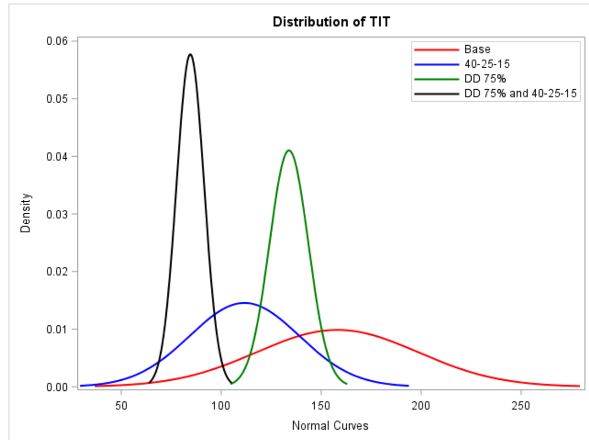
Table 7.3 Sensitivity Analysis of Different Values of TTC Threshold

TTC* (s)	Sub-Scenarios	Base		Sub-Scenarios 1 (DD 75%)		Sub-Scenarios 2 (40-25-15)		Sub-Scenarios 3 (DD 75% & 40-25-15)	
	Measures	TET(s)	TIT(s)	TET(s)	TIT(s)	TET(s)	TIT(s)	TET(s)	TIT(s)
1.5	Average value	548	158	499	134	399	112	361	84
	Reduction proportion	-	-	9%	15%	27%	29%	34%	47%
2.0	Average value	772	269	668	231	648	218	570	161
	Reduction proportion	-	-	13%	14%	16%	19%	26%	40%
3.0	Average value	1001	416	875	359	931	349	839	278
	Reduction proportion	-	-	13%	14%	7%	16%	16%	33%

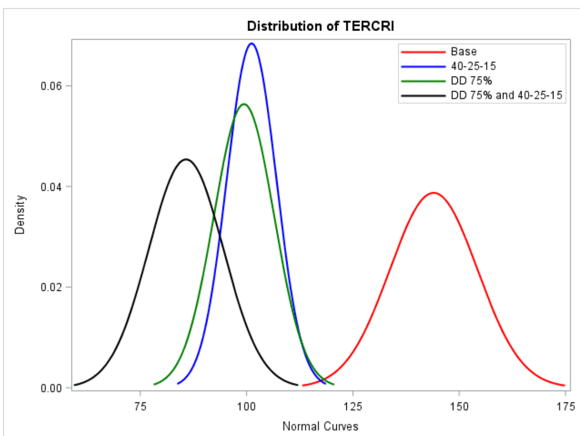
The above results of TET and TIT are mainly based on the same parameter setting of TTC threshold of 1.5 s. Sensitivity analysis of TTC thresholds was also conducted for all thirteen sub-scenarios but only the best three sub-scenarios were presented in Table 7.3. Result shows that compared with the base scenario, all the reductions of TET and TIT values maintain within 13% to 9% and 15% to 14%, respectively for the Scenario 1. For Scenario 2, those relative reductions of TET and TIT were 27% to 7% and 29% to 16%, respectively. Also, TET and TIT values were reduced higher for Scenario 3 (34% to 16% and 47% to 33%, respectively). Lastly, for each value of TTC threshold, TET and TIT reduction percentage increased from the sub-scenario 1 to the sub-scenario 3.



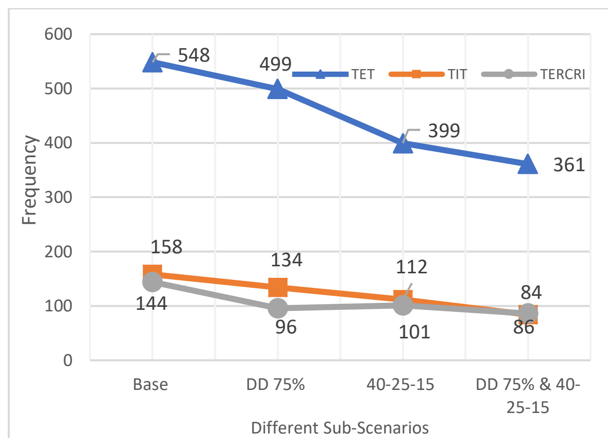
(a)



(b)



(c)



(d)

Figure 7.3 Distribution of TET (a), TIT (b), TERCRI (c) for the best three sub-scenarios with base scenarios and the value of TET, TIT, TERCRI for the best three sub-scenarios with base scenario (d).

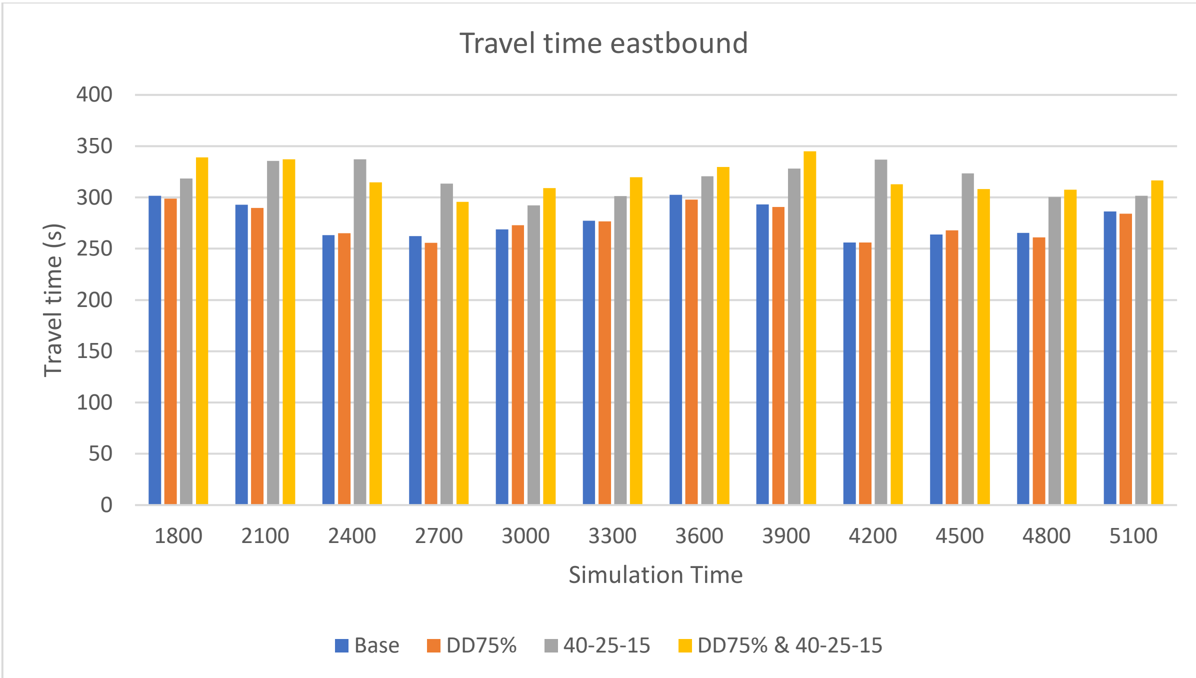
Also, we analyzed the acceleration and deceleration behavior of vehicles for the sub-scenario 40-25-15 and found that all the values are within the range of comfortable deceleration (see Figure 7.4) (Wang et al., 2005) .

Figure 7.4 Acceleration behavior of sub-scenarios 40-25-15

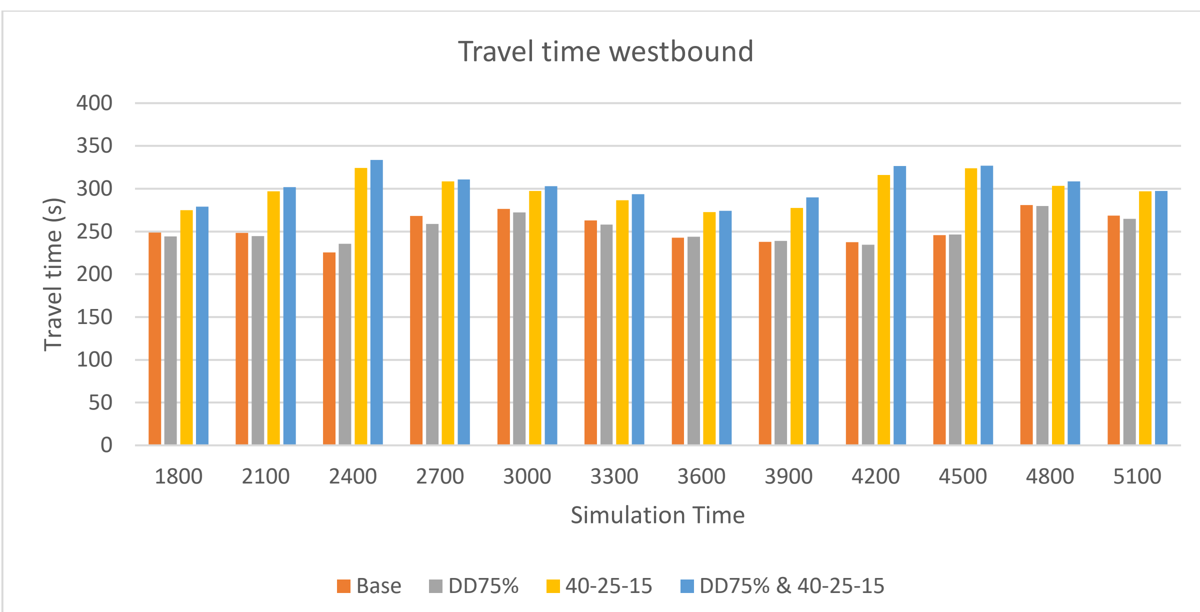
The main objective of this study was to improve safety in the school zone area rather than to improve mobility. Here, we analyzed the travel time after implementing the proposed countermeasures and found that the average maximum increase in travel time was about 50s compared with the base condition near the school zone area (Table 7.4). Figure 7.5 shows the travel time of east and westbound of some sub-scenarios for each time interval.

Table 7.4 Average Travel time before and after proposed strategy

Sub-scenarios	**Avg. Travel time (s) (Westbound)**	**Avg. Travel time (s) (Eastbound)**
Base	254	278
DD 75%	252	276
40-25-15	298	318
DD75% & 40-25-15	303	320



(a)



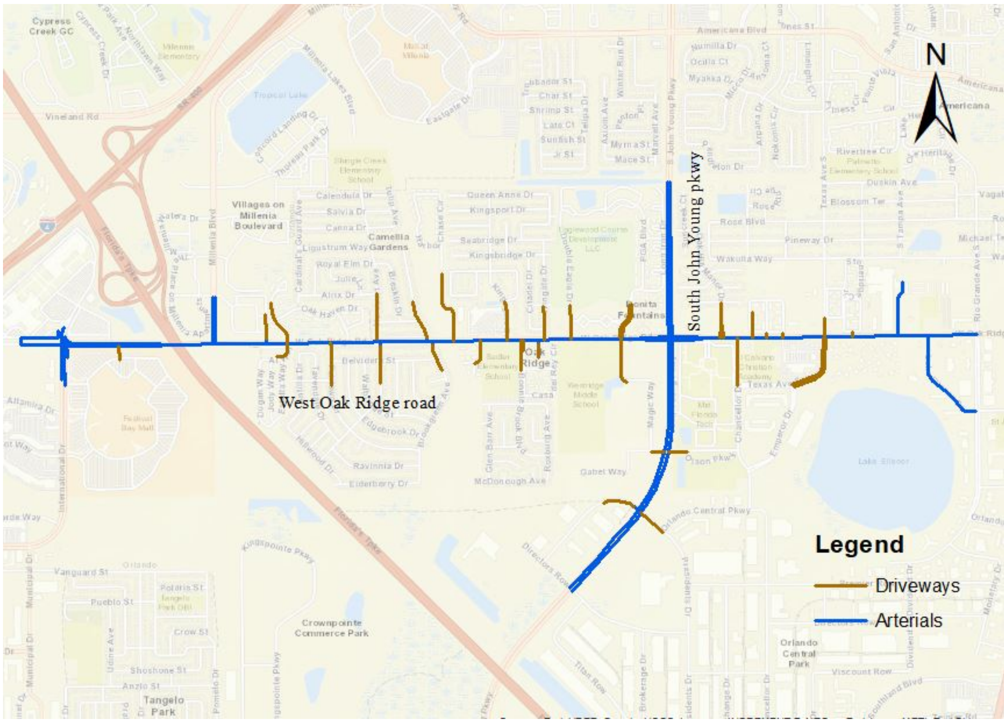
(b)

Figure 7.5 Travel time distribution before and after proposed strategy (a) Eastbound (b) Westbound

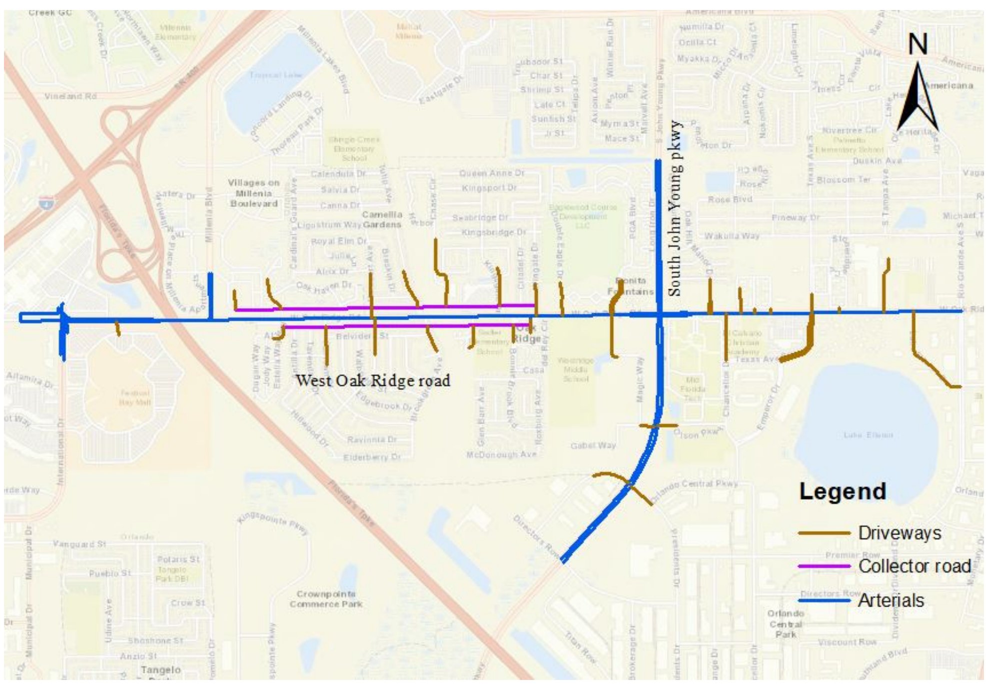
CHAPTER 8: SUMMARY AND CONCLUSIONS

The main objective of this study is to improve traffic safety by proposing different countermeasures for school zones and evaluate them by using microsimulation. At first, the most crash-prone school zone was identified based on crash rates, which was further analyzed by using VISSIM. The simulation experiments were designed by deploying sub-scenarios of three countermeasures i.e., two-step speed reduction (TSR), decresing the number of driveways (DD) and replacing two-way left turn lane (TWLTL) with raised median (RM). Three surrogate safety measures i.e. time exposed time to collision (TET), time integrated time to collision (TIT), and time exposed rear-end crash risk index (TERCRI) were analyzed for all sub-scenarios separately and also their combined effects.

The results indicated that the value of TET, TIT, and TERCRI is larger for base scenraio compared with the all sub-scenarios in TSR which means less traffic conflict for two-step speed reduction. Also, the standard deviation of speed is lower for all sub-scenarios in TSR than the base condition. For DD, we found that conflicts were decreased with the increase of driveway reduction percentages compared with the base scenario. Generally, driveway related crashes are result from conflict between vehicles either by conflicting turning movement at the access point or speed variation and vehicle queue at the access point. When the spacing between two driveways is very short or the density of driveways is very high then the conflict areas may overlap with each other and create more conflicts. Since we reduced the driveway access points by different percentages, it reduces conflicts or improve safety in the school zone area. The network topology of base condition and reduced driveway condition is shown in Figure 8.1.



(a)



(b)

Figure 8.1 Network topology (a) Base condition (b) DD75% sub-scenarios

In replacing TWLTL with RM , two sub-scenarios were tested which showed a larger value of surrogate safety measures than the base scenario because of the large number of traffic that made U-turn both at the intersection and median. Although preivous many studies (Alluri et al., 2016; Bonneson and McCoy, 1998; Parsonson et al., 2000) showed that raised median is more effective in reducing crashes than TWLTL but most of them only analyzed the crashes at those segments where roadway geometry was changed from TWLTL to raised-median. In our study, we found that TWLTL is more effective in reducing conflicts than the raised median because we analyzed conflicts not only at the segments with raised median but also at the location of turning movements (signalized intersection, median opening).

Moreover, the combined sub-scenarios of TSR and DD outperformed all other sub-scenarios. One-way ANOVA showed that there was a significant difference among all thirteen sub-scenarios. Futhermore, the sensitivity analysis indicated that different value of TTC thresholds does not affect the results of different sub-scenarios. Finally, the study evaluated the impact of different countermeasures in the school zone safety by using simulation modeling practice which could help the transportation planners and decision makers to know the effect of these countermeasures prior to implemention at school zones.

In this study, we calibrated the network with traffic volume and travel time but it could be more effective to calibrate with real traffic conflicts. Since video data was not available, we only used traffic volume and travel time. In the school zone area, speed profile of vehicles is very low. So, lower value of TTC threshold would be preferable to compare result for different scenarios. Since, around 49% of total crashes are rear end related crashes in the study area, we used surrogate safety measure related to rear-end crashes. Additional research could be evaluated by using other surrogate safety measures to represent different crash types.

REFERENCES

Abdel-Aty, M., Chundi, S.S., Lee, C., 2007a. Geo-spatial and log-linear analysis of pedestrian and bicyclist crashes involving school-aged children. J. Safety Res. 38, 571–579. https://doi.org/10.1016/j.jsr.2007.04.006

Abdel-Aty, M., Pande, A., Lee, C., Gayah, V., Santos, C. Dos, 2007b. Crash Risk Assessment Using Intelligent Transportation Systems Data and Real-Time Intervention Strategies to Improve Safety on Freeways. J. Intell. Transp. Syst. 11, 107–120. https://doi.org/10.1080/15472450701410395

Abdel-Aty, M., Wang, L., 2017. Implementation of Variable Speed Limits to Improve Safety of Congested Expressway Weaving Segments in Microsimulation. Transp. Res. Procedia 27, 577–584. https://doi.org/10.1016/j.trpro.2017.12.061

Alluri, P., Gan, A., Haleem, K., 2016. Safety Impacts of Converting Two-Way Left-Turn Lanes to Raised Medians and Associated Design Concerns, in: Journal of the Transportation Research Forum.

American Association of State Highway and Transportation Officials (AASHTO), 2004. A policy on geometric design of highways and streets. Washington, D.C.

Ash, K.G., Saito, M., 2006. Field Evaluation of the Effect of Speed Monitoring Displays on Speed Compliance in School Zones, in: Applications of Advanced Technology in Transportation. American Society of Civil Engineers, Reston, VA, pp. 780–786. https://doi.org/10.1061/40799(213)125

Ben-Bassat, T., Shinar, D., 2011. Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior. Accid. Anal. Prev. 43, 2142–52. https://doi.org/10.1016/j.aap.2011.06.004

Bonneson, J.A., McCoy, P.T., 1998. Median treatment selection for existing arterial streets. ITE J. 68, 26–35.

Burritt, B.E., Buchanan, R.C., Kalivoda, E.I., 1990. School zone flashers. Do they really slow traffic. ITE J. (Institute Transp. Eng. 60, 29–31.

Cai, Q., Saad, M., Abdel-Aty, M., Yuan, J., Lee, J., 2018. Safety impact of weaving distance on freeway facilities with managed lanes using both microscopic traffic and driving simulations. Transp. Res. Rec. 2672, 130–141.

Clifton, K.J., Kreamer-Fults, K., 2007. An examination of the environmental attributes associated with pedestrian-vehicular crashes near public schools. Accid. Anal. Prev. https://doi.org/10.1016/j.aap.2006.11.003

Dixon, K.K., Hibbard, J.L., Mroczka, C., 1999. Public perception of median treatment for developed urban roads, in: TRB Circular E-C019: Urban Street Symposium.

Dowling, R., Skabardonis, A., Alexiadis, V., 2004. Traffic Analysis Toolbox Volume III : Guidelines for Applying Traffic Microsimulation Modeling Software. Rep. No. FHWA-HRT-04-040, U.S. DOT, Fed. Highw. Adm. Washington, D.C III, 146.

Ekram, A.-A., Rahman, M.S., 2018. Effects of Connected and Autonomous Vehicles on Contraflow Operations for Emergency Evacuation: A Microsimulation Study. Proceeding 97th Annu. Meet. Transp. Res. Board.

Ekram, A.A., Rahman, M.S., 2018. Effects of Connected and Autonomous Vehicles on Contraflow Operations for Emergency Evacuation: A Microsimulation Study. Transp. Res. Board 97th Annu. Meet.

El Esawey, M., Sayed, T., 2011. Calibration and validation of micro-simulation models of medium-size networks. Adv. Transp. Stud. 57–76. https://doi.org/10.4399/97888548415126

Ellison, A.B., Greaves, S., Daniels, R., 2013. Capturing speeding behaviour in school zones using GPS technology. Road Transp. Res.

FDOT Systems Planning Office, 2014. Traffic Analysis Handbook. Florida Dep. Transp. 118.

Freedman, M., De Leonardis, D., Raisman, G., InyoSwan, D., Davis, A., Levi, S., Rogers, I., Bergeron, E., 2006. Demonstration of automated speed enforcement in school zones in Portland, Oregon. United States. National Highway Traffic Safety Administration.

Gong, Y., Abdel-Aty, M., Cai, Q., Rahman, M.S., 2019. A Decentralized Network Level Adaptive

Signal Control Algorithm By Deep Reinforcement Learning.

Gregory, B., Irwin, J.D., Faulks, I.J., Chekaluk, E., 2016. Differential effects of traffic sign stimuli upon speeding in school zones following a traffic light interruption. Accid. Anal. Prev. 86, 114–20. https://doi.org/10.1016/j.aap.2015.10.020

Hallmark, S.L., Isebrands, H., 2005. Evaluating speed differences between passenger vehicles and heavy trucks for transportation-related emissions modeling. J. Air Waste Manag. Assoc. https://doi.org/10.1080/10473289.2005.10464742

Hawkins, H.G., 2007. Rear-facing school speed limit beacons. ITE J. (Institute Transp. Eng. 77, 18–23.

Hayward, J.C., 1972. Near-miss determination through use of a scale of danger. Highw. Res. Rec. https://doi.org/TTSC 7115

Hjälmdahl, M., Várhelyi, A., 2004. Speed regulation by in-car active accelerator pedal. Transp. Res. Part F Traffic Psychol. Behav. 7, 77–94. https://doi.org/10.1016/j.trf.2004.02.002

Hollander, Y., Liu, R., 2008. The principles of calibrating traffic microsimulation models. Transportation (Amst). 35, 347–362. https://doi.org/10.1007/s11116-007-9156-2

Kattan, L., Tay, R., Acharjee, S., 2011. Managing speed at school and playground zones. Accid. Anal. Prev. 43, 1887–1891. https://doi.org/10.1016/j.aap.2011.04.009

Kesting, A., Treiber, M., Helbing, D., 2010. Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity. Philos. Trans. R. Soc. London A Math. Phys. Eng. Sci. 368, 4585–4605. https://doi.org/10.1098/rsta.2010.0084

Khan, M.M.I., Rahman, M.H., 2016. A prediction model for pedestrian fatalities based on explanatory factors.

Kirmizioglu, E., Tuydes-Yaman, H., 2012. Comprehensibility of traffic signs among urban drivers in Turkey. Accid. Anal. Prev. 45, 131–141. https://doi.org/10.1016/j.aap.2011.11.014

Lee, C., Lee, S., Choi, B., Oh, Y., 2006. Effectiveness of Speed-Monitoring Displays in Speed Reduction in School Zones. Transp. Res. Rec. J. Transp. Res. Board 1973, 27–35.

https://doi.org/10.3141/1973-06

Lee, J., Abdel-Aty, M., Rahman, M.H., n.d. Replication Data for: Enhancing School Zone and School Bus Safety. https://doi.org/10.7910/DVN/EVMA6J

Li, Y., Wang, H., Wang, W., Liu, S., Xiang, Y., 2016. Reducing the risk of rear-end collisions with infrastructure-to-vehicle (I2V) integration of variable speed limit control and adaptive cruise control system. Traffic Inj. Prev. 17, 597–603. https://doi.org/10.1080/15389588.2015.1121384

Li, Y., Wang, W., Xing, L., Fan, Q., Wang, H., 2018. Longitudinal safety evaluation of electric vehicles with the partial wireless charging lane on freeways. Accid. Anal. Prev. 111, 133–141. https://doi.org/10.1016/j.aap.2017.11.036

Mauga, T., Kaseko, M., 2010. Modeling and evaluating safety impacts of access management features in the Las Vegas, Nevada, Valley. Transp. Res. Rec. 2171, 57–65.

McCoy, P.T., Heimann, J.E., 1990. School Speed Limits and Speeds in School Zones. Transp. Res. Rec.

Minderhoud, M.M., Bovy, P.H.L., 2001. Extended time-to-collision measures for road traffic safety assessment. Accid. Anal. Prev. 33, 89–97.

Oh, C., Oh, J.-S., Ritchie, S., Chang, M., 2001. Real-time estimation of freeway accident likelihood, in: 80th Annual Meeting of the Transportation Research Board, Washington, DC.

Oh, C., Park, S., Ritchie, S.G., 2006. A method for identifying rear-end collision risks using inductive loop detectors. Accid. Anal. Prev. 38, 295–301. https://doi.org/10.1016/j.aap.2005.09.009

Papayannoulis, V., Gluck, J.S., Feeney, K., Levinson, H.S., 1999. Access spacing and traffic safety, in: Urban Street Symposium. pp. 28–30.

Parsonson, P.S., Waters III, M.G., Fincher, J.S., 2000. Georgia study confirms the continuing safety advantage of raised medians over two-way left-turn lanes, in: Fourth National Access Management ConferenceAccess Management Committee (TRB Committee AD107) of the

Transportation Research Board.

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A.A., Jarawan, E., Mathers, C., 2004. World report on road traffic injury prevention, World Health Organization. https://doi.org/10.1016/j.puhe.2005.09.003

Peng, Y., Abdel-Aty, M., Shi, Q., Yu, R., 2017. Assessing the impact of reduced visibility on traffic crash risk using microscopic data and surrogate safety measures. Transp. Res. Part C Emerg. Technol. 74, 295–305. https://doi.org/10.1016/j.trc.2016.11.022

PTV, 2016. PTV VISSIM 9 User Manual 1055.

Pucher, J., Renne, J.L., 2005. Rural mobility and mode choice: Evidence from the 2001 National Household Travel Survey. Transportation (Amst). https://doi.org/10.1007/s11116-004-5508-3

Rahman, M.H., Abdel-Aty, M., Lee, J., Rahman, M.S., 2019. Enhancing traffic safety at school zones by operation and engineering countermeasures: A microscopic simulation approach. Simul. Model. Pract. Theory. https://doi.org/10.1016/j.simpat.2019.04.001

Rahman, M.S., Abdel-Aty, M., 2018a. Longitudinal safety evaluation of connected vehicles' platooning on expressways. Accid. Anal. Prev. 117, 381–391.

Rahman, M.S., Abdel-Aty, M., 2018b. Longitudinal safety evaluation of connected vehicles' platooning on expressways. Accid. Anal. Prev. 117, 381–391. https://doi.org/10.1016/j.aap.2017.12.012

Rahman, M.S., Abdel-Aty, M., Lee, J., Rahman, M.H., 2019. Safety benefits of arterials' crash risk under connected and automated vehicles. Transp. Res. Part C Emerg. Technol. https://doi.org/10.1016/j.trc.2019.01.029

Rahman, M.S., Abdel-Aty, M., Lee, J., Rahman, M.H., 2019. Understanding the Safety Benefits of Connected and Automated Vehicles on Arterials' Intersections and Segments. Transp. Res. Board 98th Annu. Meet.

Rahman, M.S., Abdel-Aty, M., Wang, L., Lee, J., 2018. Understanding the Highway Safety

Benefits of Different Approaches of Connected Vehicles in Reduced Visibility Conditions. Transp. Res. Rec. J. Transp. Res. Board 036119811877611. https://doi.org/10.1177/0361198118776113

Roper, P., Thoresen, T., Tziotis, M., Imberger, K., 2006. Evaluation of flashing lights in 40 km/h school speed zones. Sydney, Aust. ARRB Consult.

Saad, M., Abdel-Aty, M., Lee, J., Wang, L., 2018b. Safety analysis of access zone design for managed toll lanes on freeways. J. Transp. Eng. Part A Syst. 144, 4018067.

Saad, M., Abdel-Aty, M., Lee, J., Wang, L., 2018a. Determining the optimal access design of managed lanes considering dynamic pricing, in: 18th International Conference Road Safety on Five Continents (RS5C 2018), Jeju Island, South Korea, May 16-18, 2018. Statens väg- och transportforskningsinstitut.

Saibel, C., Salzberg, P., Doane, R., Moffat, J., 1999. Vehicle speeds in school zones. ITE J. (Institute Transp. Eng. 69, 38–42.

Simpson, C.L., 2008. Evaluation of Effectiveness of School Zone Flashers in North Carolina. Transp. Res. Rec. J. Transp. Res. Board 2074, 21–28. https://doi.org/10.3141/2074-03

Strawderman, L., Rahman, M.M., Huang, Y., Nandi, A., 2015. Driver behavior and accident frequency in school zones: Assessing the impact of sign saturation. Accid. Anal. Prev. https://doi.org/10.1016/j.aap.2015.05.026

Tay, R., 2009. Speed Compliance in School and Playground Zones. Ite Journal-Institute Transp. Eng. 79, 36–38.

Ullman, G., Rose, E., 2005. Evaluation of Dynamic Speed Display Signs. Transp. Res. Rec. J. Transp. Res. Board 1918, 92–97. https://doi.org/10.3141/1918-12

Wang, J., Dixon, K., Li, H., Ogle, J., 2005. Normal deceleration behavior of passenger vehicles at stop sign-controlled intersections evaluated with in-vehicle global positioning system data. Transp. Res. Rec. J. Transp. Res. Board 120–127.

Warsh, J., Rothman, L., Slater, M., Steverango, C., Howard, A., 2009. Are school zones effective?

An examination of motor vehicle versus child pedestrian crashes near schools. Inj. Prev. 15, 226–229. https://doi.org/10.1136/ip.2008.020446

Wu, Y., Abdel-Aty, M., Wang, L., Rahman, M.S., 2019. Improving Flow and Safety in Low Visibility Conditions by Applying Connected Vehicles and Variable Speed Limits Technologies. Transp. Res. Board 98th Annu. Meet.

Yu, R., Abdel-Aty, M., 2014. An optimal variable speed limits system to ameliorate traffic safety risk. Transp. Res. Part C Emerg. Technol. 46, 235–246. https://doi.org/10.1016/j.trc.2014.05.016

Zhao, X., Li, J., Ma, J., Rong, J., 2016. Evaluation of the effects of school zone signs and markings on speed reduction: a driving simulator study. Springerplus 5, 789. https://doi.org/10.1186/s40064-016-2396-x