Accident Analysis and Prevention 82 (2015) 118–125

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Driver behavior and accident frequency in school zones: Assessing the impact of sign saturation

Lesley Strawderman*, Md Mahmudur Rahman, Yunchen Huang, Apurba Nandi

Department of Industrial and Systems Engineering, Mississippi State University, P.O. Box 9542, Mississippi State, MS 39762, USA

ARTICLE INFO

Article history:
Received 17 October 2014
Received in revised form 8 April 2015
Accepted 30 May 2015
Available online 10 June 2015

Keywords:
School zone
Sign saturation
Driver behavior
Compliance
Accident frequency

ABSTRACT

Based on the models of human information processing, if a driver observes too many of the same signs, he or she may no longer pay attention to those signs. In the case of school zones, this expected effect may lead to non-compliance to posted speeds, negatively impacting safety around nearby schools. This study aims to investigate the effect of the number of nearby school zones on driver behavior (vehicle speed and compliance) and accident frequency. As a measure of the density of school zones, this study introduced and defined a new term sign saturation and presented a methodology to calculate sign saturation for school zones. Results found a significant effect of sign saturation on vehicle speed, compliance, and accident frequency. This study also examined the speeding behavior in school zones for different time of the day and day of the week. Results found that speeding was more prevalent in the early mornings and during the weekends.

1. Introduction

School zones are often viewed as an effective way to reduce driving speeds and thereby improve safety near our nation's schools. The effect of school zones on reducing driving speeds, however, is minimal at best. Studies have shown that over 90% of drivers exceed speed limits posted in school zones (Trinkaus, 1996, 1998). Another study conducted in Atlanta found no effect of school zones on vehicle speed (Young and Dixon, 2003). Furthermore, similar studies done in Canadian cities Edmonton (Ash and Saito, 2006) and Saskatoon (Lazic, 2003) reported similar statistics of non-compliance in school zones. These findings imply that school zones are proven mostly ineffective in changing drivers' speeding behavior. A field survey study done by Reiss and Robertson (1976) reported that only 22% of the drivers complied with posted speed while passing through a school zone. Many drivers report that their lack of speed reduction was based on the fact that they were unaware that they were in a school zone (Ash, 2006).

1.1. Driver speed compliance

Speeding in general is influenced by a number of factors (Ellison and Greaves, 2010). For school zones, these factors include types of school zones (school zone compared to playground) (Tay, 2009; Kattan et al., 2011), number of lanes (2-lane roads vs. 4-lane roads) (Tay, 2009; Kattan et al., 2011), presence of children (Kattan et al., 2011), length of the speed zone (Strawderman et al., 2013; Kattan et al., 2011), approach speed (Saibel et al., 1999; McCoy and Heimann, 1990), types of schools (elementary school vs. high school) (Day, 2007), presence of fencing (Tay, 2009; Kattan et al., 2011) etc. Kattan, et al., (2011) found that in the situation when there is 2-lane roads, roads with fencing, traffic control devices and the presence of speed display device or children, and zones that were longer, drivers' mean speeds were lower, and the rate of compliance was higher. Drivers' speeding behaviors changes for different time of the day and day of the week. Many researchers reported that speeding on weekends is more likely than on weekdays (Wundersitz et al., 2009; Ellison and Greaves, 2010; Familar et al., 2011). To be more specific, speeding is reported to be prevalent on weekend late evenings/nights and in early mornings during the weekdays (Ogle, 2005; Ellison and Greaves, 2010). Studies that involve school zones also investigated the effects of the time of day and the day of the week on speeding. Lazic (2003) reported that there was no significant change in speed outside the restricted hours (school hours) and on weekend. Day (2007) studied the school zone speed variation for morning and afternoon peak hours and found no significant difference.

Researchers have investigated methods used to increase driver compliance for some time (McCoy et al., 1981). Based on the results of empirical studies, effective methods include increased enforcement (Dumbaugh and Frank, 2007; Cedar Rapids, 2006),

* Corresponding author. Tel.: +1 662 325 7214.
E-mail address: strawderman@ise.msstate.edu (L. Strawderman).

http://dx.doi.org/10.1016/j.aap.2015.05.026

appropriate speed zone settings (Day, 2007; McCoy and Heimann, 1990), visual placement of school buildings and play equipment (Clifton and Kreamer-Fults, 2007), and speed monitoring devices (Ash, 2006; Lee et al., 2006; Cedar Rapids, 2006). Traffic engineers and city planners have utilized a variety of school zone signage in an attempt to improve compliance. Signs, flashers, and roadway markings have all been implemented. While some studies have shown a positive effect from utilizing signs on reducing speed (Schrader, 1999; Aggarwal and Mortensen, 1993; Hawkins, 1993), others argue that signs have no effect on driver compliance with posted speed limits (Simpson, 2008; Burritt et al., 1990), leading to a lack of conclusive evidence on the value of school zone signage (Dumbaugh and Frank, 2007; Lee and Bullock, 2003).

1.2. School zone sign saturation

In many municipalities, school zone signs are often placed based on public requests or by political pressure. There is a clear lack of empirical evidence to demonstrate that the addition of such signs reduces driver speed. Furthermore, the addition of too many signs in a given area may actually reduce driver compliance. Based on models of human information processing, if a driver observes too many of the same stimulus, he or she no longer attends to the stimulus with a great deal of attention (Wickens et al., 2004). This overwhelming presence of stimuli (school zone signs) leads to a driver not noticing a particular stimulus.

In the case of school zone signs, the presence of too many signs in a compact area could lead to the same phenomenon. The presence of multiple school zones on a driver's route may lead the driver to ignore the zones altogether. The effectiveness of additional zones can be questioned, particularly if oversaturation of the signage leads to inattention. A balance between novelty and oversaturation of a stimulus must be reached to maximize a school zone's effectiveness at reducing driver speeds.

Adding a new school zone would be beneficial if it led to a reduction in crashes (in a previously unsafe location) or to an increase in compliance with posted speeds. The addition of a new school zone would be detrimental if it would lead to oversaturation, thereby diverting driver attention from multiple school zones in the municipality. This study aimed to quantify the impact of increasing number of school zones on driver speeding behavior and accident frequency, by this means allowing transportation officials the ability to make informed decisions on the expected benefits of adding school zone signage.

2. Methodology

To explain the impact of increasing the number of school zones, this paper introduced and defined the term sign saturation and presented a methodology to measure sign saturation for school zones. The study was conducted in the state of Mississippi, United States. Using the sign inventory provided by the Mississippi Department of Transportation (MDOT), sign saturation was calculated for each school zone in the state. The calculation of sign saturation was a prerequisite of this research.

This paper presents findings of two studies. Table 1 summarizes the study methods. In study 1, driver behavior (vehicle speed and speed limit compliance) in school zones was studied. For this study, four school zones were selected for data collection. In selecting the school zones sign saturation level, road type (number of lanes) and few control variables (Table 1) were taken into consideration. The complete dataset for this study included 168 h (7 days × 24 h) of vehicle speed for four school zones. Study 2 investigated the effect of sign saturation on accident frequency in school zones. Data for this study included the number of traffic accidents for a year of each school zone ($n = 79$) in Northeast Mississippi (MDOT district 1). The following sections provide details on the calculation of sign saturation, as well as data collection methods for the two studies.

2.1. Sign saturation

Sign saturation can be defined as the density of school zones around a reference school zone. For this study, sign saturation was quantified as the total number of other school zones within a 10 mile radius of the school zone being studied. To be able to calculate distances between school zones, multiple signs in the same school zone were needed to be converted into a single sign location. The methodology followed the below steps:

1. For each of the individual signs, the distance to all other signs situated in close proximity was calculated. Latitudes and longitudes of a pair of signs was used to calculate their distance. If the distance was less than a pre-specified (750 yard or 0.426 mile) value, this two signs were considered to be in the same school zone.
2. For each of the individual school zones, the number of the school zones located within a pre-specified radius (10 miles) was counted. The number of school zones within the 10 miles radius of the reference school zone was the measure of sign saturation.

Ideally the number of school zones should be half of the number of school zone signs as there are two signs per school zone. The pre-specified value mentioned above was taken as 750 yards as it gave the number of school zones equal to about half of the total number of signs. The choice of the two pre-specified distances (750 yards and 10 miles) mentioned above is arbitrary; these distances may be different for different states in the United States or other countries in the world.

Table 1
Summary of study methods.

Study objective		Dependent variable	Independent variable	Control variable	Data characteristics
Study 1:	Objective 1: Investigating the effect of time of the day and day of the week variable on driver behavior	Vehicle speed, speed limit compliance	Time of the day, day of the week	Accident frequency, sign type, and required speed reduction	7 days × 24 h of vehicle speed
	Objective 2: Investigating the effect of sign saturation on driver behavior	Vehicle speed, speed limit compliance	Sign saturation, road type	Same as study 1 objective 1	5 days × 2 h of vehicle speed
Study 2:	Objective 1: Investigating the effect of sign saturation on accident frequency	Accident frequency	Sign saturation, lane number	None	1 year of accident frequency

2.2. Study 1: the study of driver behavior

2.2.1. Variables

Two dependent variables: vehicle speed and vehicle compliance were used for study 1. Vehicle speed was measured as a continuous variable. It is the speed of vehicles when they pass the measure point (100 feet downstream from the school zone speed limit sigh) within the school zone. Vehicle compliance was measured as a binary variable. It was coded as either '1' (the vehicle complied with the speed limit posted in school zone) or '0' (the vehicle failed to comply with the speed limit posted in school zone).

There were four independent variables for this study: time of the day, day of the week, sign saturation, and road type. The time of the day variable had four levels: midnight to 6 am, 6 am to noon, noon to 6 pm, 6 pm to midnight. The day of the week variable had seven levels for the seven days of the week. Sign saturation had two levels: high saturation and low saturation. School zones with a saturation of at least 10 were categorized as high saturation. School zones with a saturation of less than 2 were categorized as low saturation. The cutoffs for the categories were selected with the intention of keeping the low density and high density categories as far apart as possible to be able to estimate the impact of sign saturation on speed compliance with high clarity. The category cutoffs provided an approximation to the 10th and 90th percentiles for saturation levels and were adjusted slightly due to rounding. The road type variable, is defined as the number of lanes on the road, excluding any shared or turn lanes. In this study, the road type variable had two levels: 2-lane and 4-lane.

Several control variables were included in an attempt to isolate the effect of the independent variables. Control variables included accident frequency, sign type, and required speed reduction. All data collection sites had the same values for all of these measures (accident frequency = low, sign type = static with no flashers, required speed reduction = 10 mph from 45 mph to 35 mph).

2.2.2. Site selection

There are a total of 489 school zones in the state of Mississippi. According to the categorization scheme mentioned in Section 2.2.1 (*Variables*), the state of Mississippi contains 37 high saturation school zones and 68 low saturation school zones. The rest of the school zones were considered medium density and were not considered candidates for data collection for study 1. Among the high and low saturation school zones, four school zones were selected for data collection (Table 2). The school zones also represent 2-lane and 4-lane roadways. When selecting the four school zones, it was aimed to minimize arterial roadways and traffic signals that would impact driver speed within the school zone. To further minimize the impact of these factors, the magnetic traffic sensors were placed within the school zone, 100 feet downstream from the school zone speed limit sign.

2.2.3. Equipment

Data was collected using magnetic traffic sensors (Vaisala Nu-Metrics Portable Traffic Analyzer NC200). The device utilizes Vehicle Magnetic Imaging (VMI) technology to detect vehicle count, speed and classification (Vaisala Nu-Metrics Portable Traffic Analyzer NC200, 2010). After data collection, the data is easily exported to Highway Data Management (HDM) software that comes with the device. The traffic sensors record data in a time-stamped format. This organized data collection allows analysis based on time of data and traffic density. For this study, a single device was installed in each lane of the study site. The devices continuously recorded data throughout the data collection period.

Table 2
Selected school zone information.

School zone	Location	Saturation level	Number of lanes
A	Shannon, MS	High	2
B	Tupelo, MS	High	4
C	Amory, MS	Low	2
D	Belzoni, MS	Low	4

2.2.4. Data collection

The traffic sensors were programmed so that the data collection was continuous for a complete seven days. The data collection in school zones A and B (Table 2) was started on Wednesday at 4:00 pm and stopped on the next Wednesday at 4:00 pm. The data collection in school zone C was started on Tuesday at 4:00 pm and stopped on the next Tuesday at 4:00 pm. The data collection in school zone D was started on Thursday at 4:00 pm and stopped on the next Thursday at 4:00 pm. Data collection occurred during the first half of October, therefore the weather condition in the four school zones were about the same. The mean temperature, for the school zones, ranged from 58.4 °F to 64.8 °F during the data collection period. Each school zone experienced one day of rain.

For all four data collection sites, the research team was on site together with MDOT (Mississippi Department of Transportation) personnel. The research team was responsible for programming the traffic sensors and determining the exact location to install the traffic sensors. MDOT personnel were responsible for traffic control and installing the traffic sensors on the road. MDOT personnel were also responsible for retrieving the traffic sensors after the data collection period was complete.

2.2.5. Data processing

Data with low speed values (less than 10 mph) was removed from the data set as the vehicle was likely turning and not acting as through traffic. To study the effect of time of the day and day of the week variables on driver behavior, complete dataset (168 h of vehicle speed data) was used. To study the effect of sign saturation on driver behavior, the data set was truncated based on school days and times (5 weekday × 2 h of vehicle speed data). The data was truncated due to the fact that in many school zones, special speed limits are active during school start and dismissal times only, as children are most likely to be present at those times. One hour of morning data (30 min prior to and 30 min after school start time) and one hour of afternoon data (30 min prior to and 30 min after school dismissal time) were included in the data set for analysis. Any data outside of this time window was removed.

2.3. Study 2: the study of accident frequency

2.3.1. Variables

Study 2 considered one dependent variable: accident frequency. The accident frequency variable represents the number of crash-related accidents in the school zones for a year. There were two independent variables: sign saturation and road type. The definition and calculation method of the independent variables for this study was similar to study 1.

2.3.2. Data collection

The number of crash-related traffic accidents for a year of each school zone in Northeast, Mississippi was extracted from the traffic accident database. The sample size for this data was 79 school zones. Out of these school zones 19 were low, 52 were medium, and 8 were high saturation school zones. To investigate the effect of sign saturation on accident frequency only the low and high saturation school zones were included in the data set. However, to investigate the effect of road type on accident frequency data from all 79 school zones were included in the analysis as these school zones were either 2-lane or 4-lane school zones.

2.4. Statistical analysis

To analyze the vehicle speed data one-way ANOVA (study 1 objective 1) and factorial ANOVA (study 1 objective 2) were performed. Post-hoc analysis involved the Tukey–Kramer approach. The Chi-square test was used to analyze the vehicle compliance variable. The analysis on accident frequency data involved the Mann–Whitney test as the dataset was highly skewed and did not meet the assumptions of analysis of variance. Results were considered significant at $\alpha = 0.05$. In addition, appropriate descriptive statistics were generated for the dependent variables. Data analysis was done using SAS 9.4.

3. Results

3.1. Study 1: the study of driver behavior results

3.1.1. Effect of time of the day and day of the week variable

3.1.1.1. Descriptive statistics of driver behavior. Descriptive statistics of vehicle speed and vehicle compliance for all four locations are presented in Table 3. Table 3 presents statistics of the complete data set ($n = 253{,}868$). The overall compliance with the posted speed limit was 19.27%. Considering the confidence intervals of mean vehicle speed, it is apparent that for location C and location D (low sign saturation locations) the mean vehicle speed is higher than the posted speed limit (45 mph) of the road before entering the school zone, let alone the reduced speed limit of the school zone. Again for these two locations compliance of the school zone speed limit was very low. Table 3 also reports traffic density for all four locations. Weighted average of traffic density for high and low saturation locations was calculated as 2.76 and 1.77 vehicles/lane/min respectively, and for 2-lane and 4-lane roads, it was calculated as 1.84 and 2.55 vehicles/lane/min respectively.

3.1.1.2. Effect of time of the day on vehicle speed. One-way ANOVA results (F (3, 253864) = 1415.41, p-value < 0.0001) show that vehicle speed varies significantly for different levels of the time of the day variable. Table 4 presents the descriptive statistics of vehicle speed and compliance by different levels of the time of the day variable. Fig. 1 illustrates the differences in the mean vehicle speeds for the four levels of the variable. Post-hoc comparison using the Tukey–Kramer test indicated that the mean vehicle speeds for all four levels of time of the day variable are significantly different from each other. From the graph, it is apparent that from noon to 6 pm the mean vehicle speed was lowest among the time slots with highest percentage of compliance. Chi-square test was done to identify any effect of the time of the day variable on vehicle compliance. Results ($\chi^2(3) = 3144.86$, p-value < 0.0001) indicate a strong effect of the variable on compliance.

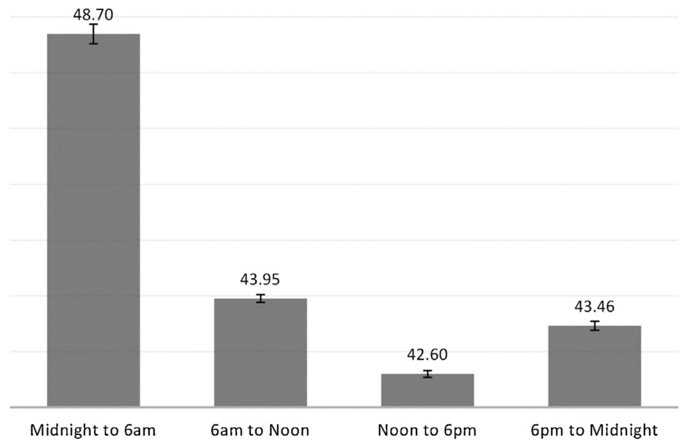

Fig. 1. The mean vehicle speeds for different levels of the time of the day variable (error bars presents the 95% confidence interval limits).

3.1.1.3. Effect of the day of the week variable on vehicle speed. Descriptive statistics of vehicle speed and compliance by different levels of the day of the week variable are presented in Table 5. One-way ANOVA results (F (6, 253861) = 210.32, p-value < 0.0001) show a strong effect of the days of the week variable on vehicle speed. Fig. 2 illustrates the differences in the mean vehicle speeds for different levels of the variable. Post-hoc comparison indicated that the mean vehicle speeds for Saturday and Sunday are the two highest values among the seven days and are statistically different from each other and the other five days. The mean vehicle speed on Friday was the lowest and statistically different from the mean speed of all the other days. Like the time of the day variable, higher mean vehicle speed was associated with lower vehicle compliance for the days of the week variable. Chi-

Table 3
Descriptive statistics of driver behavior of complete data set.

Location	Number of lanes	Saturation level	Number of observations	Traffic density (number of vehicles/lane/min)	Mean vehicle speed (SD)	95% confidence interval (mean speed)	Compliance (%) with posted speed limit (35 mph)
A	2	High	26,305	1.30	47.42 (9.65)	(47.31, 47.54)	9.15
B	4	High	123,957	3.07	37.34 (7.01)	(37.30, 37.38)	33.34
C	2	Low	43,636	2.16	51.72 (7.64)	(51.65, 51.79)	1.33
D	4	Low	59,970	1.48	48.48 (9.56)	(48.41, 48.56)	7.68

Table 4
Vehicle speed and compliance by different levels of the time of the day variable.

Time of the day	Number of observations	Mean vehicle speed (SD)	Compliance (%) with posted speed limit (35 mph)
Midnight–6 am	11,985	48.70 (9.95)	7.93
6 am–Noon	80,997	43.95 (10.19)	20.79
Noon–6 pm	110,400	42.60 (10.29)	26.92
6 pm–Midnight	50,486	43.46 (9.33)	19.19

Table 5
Vehicle speed and compliance by different levels of the days of the week variable.

Day of the week	Number of observations	Mean vehicle speed (SD)	Compliance (%) with posted speed limit (35 mph)
Monday	37,225	43.24 (10.33)	23.6
Tuesday	37,302	43.14 (10.15)	23.6
Wednesday	37,950	43.32 (10.22)	23.4
Thursday	38,642	43.23 (10.09)	23.3
Friday	44,398	42.88 (10.14)	24.7
Saturday	33,796	44.02 (9.82)	19.9
Sunday	24,555	45.43 (9.99)	16.3

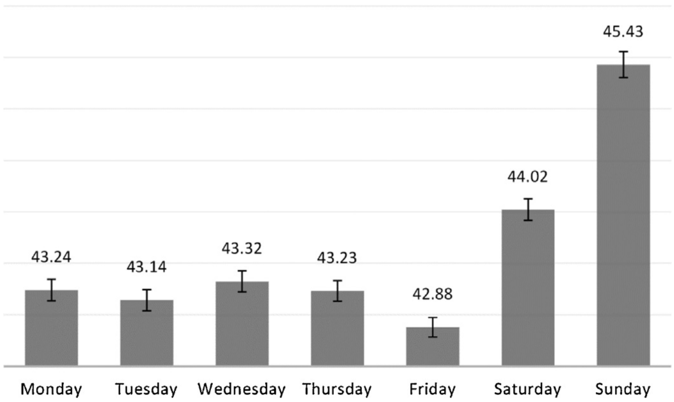

Fig. 2. The mean vehicle speeds for different levels of the days of the week variable (error bars presents the 95% confidence interval limits).

square test ($\chi^2(6) = 882.61$, p-value < 0.0001) found a significant effect of the days of the week variable on vehicle compliance.

3.1.2. Sign saturation and driver behavior

3.1.2.1. Descriptive statistics of driver behavior. Descriptive statistics of vehicle speed and vehicle compliance for all four locations are presented in Table 6. Table 6 presents statistics of the truncated dataset ($n = 28{,}644$). Compared to the complete data set, the mean vehicle speeds were found to be lower, and traffic densities were found to be higher for this data set. The overall compliance with the posted speed limit was 26.33%. Mean vehicle speed for low sign saturation locations (C and D) were found to be higher compared to high sign saturation locations, and compliance was lower for these locations as well. The weighted average of traffic density for high and low sign saturation locations was calculated as 4.97 and 3.40 vehicles/lane/min respectively, and for 2-lane and 4-lane roads, it was calculated as 3.82 and 4.57 vehicles/lane/min respectively.

3.1.2.2. Effect of sign saturation and road type. A 2×2 factorial ANOVA was performed to investigate the effects of the sign saturation and road type variable on vehicle speed. Results showed

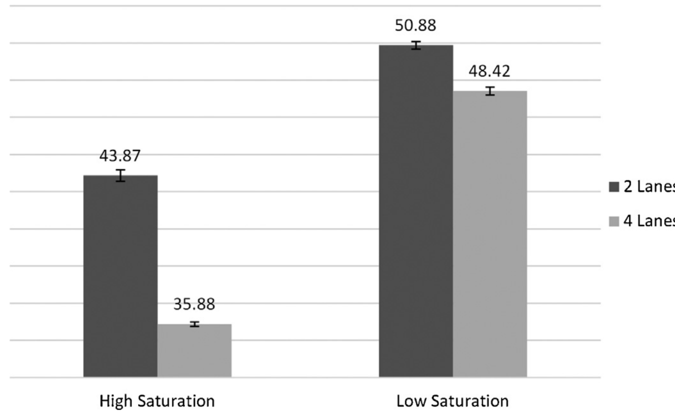

Fig. 3. Differences in the mean vehicle speed for different levels of the sign saturation and road type variable (error bars presents the 95% confidence interval limits).

that both main effects of sign saturation (F (1, 28640) = 8955.22, p-value < 0.0001) and road type (F (1, 28640) = 2557.28, p-value < 0.0001) were significant. In addition, the interaction effect was also found to be significant (F (1, 28640) = 714.58, p-value < 0.0001). Fig. 3 illustrates the differences in mean vehicle speed for the levels of the sign saturation and road type variables. Post-hoc analysis using the Tukey–Kramer approach showed that all four means are statistically different. However, the difference in mean vehicle speeds for 2-lane roads for high and low saturation was smaller than that of 4-lane roads (Fig. 3), indicating a greater impact of sign saturation with 4-lane roads when compared to 2-lane roads.

The Chi-square test results showed that the vehicle compliance to school zone speed limit was significantly higher for high saturation school zones ($\chi^2(1) = 4525.67$, p-value < 0.0001). School zones with high saturation exhibited vehicle compliance of 40.81% compared to school zones with low saturation with 5.17%. For the road type variable, the Chi-square test results showed that 4-lane roads exhibited significantly higher vehicle compliance rates compared to 2-lane roads ($\chi^2(1) = 1779.92$, p-value < 0.0001). Vehicle compliance for 4-lane roads was 33.75% compared to 2-lane roads with 10.07%. An interaction plot for compliance is

Table 6
Descriptive statistics of driver behavior of truncated data set.

Location	Number of lanes	Saturation level	Number of observations	Traffic density (number of vehicles/lane/min)	Mean vehicle speed (SD)	95% confidence interval	Compliance (%) with posted speed limit (35 mph)
A	2	High	3824	3.18	43.87 (9.94)	(43.55, 44.18)	20.19
B	4	High	13,184	5.49	35.88 (6.98)	(35.76, 36.00)	46.79
C	2	Low	5149	4.29	50.88 (7.41)	(50.68, 51.08)	2.56
D	4	Low	6487	2.70	48.42 (8.56)	(48.21, 48.63)	7.23

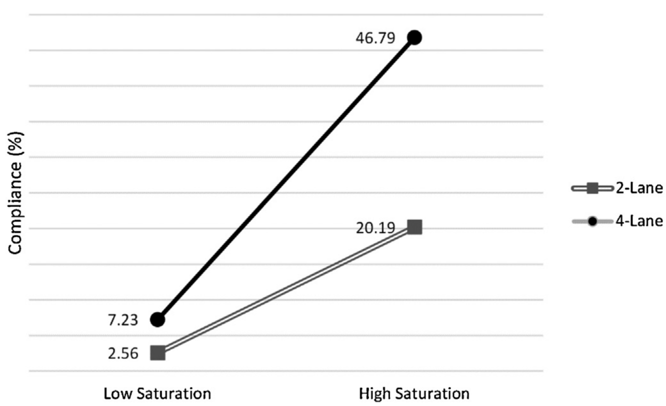

Fig. 4. Interaction plot of vehicle compliance percentage.

provided in Fig. 4. It shows that 4-lane roads exhibited higher compliance compared to 2-lane roads, and this effect is much greater for high saturation roads.

3.2. Study 2: the study of accident frequency results

The average accident frequency per school zone for different levels of the sign saturation and road type variables is presented in Table 7. A big difference in accident frequency for urban (ranging from 144 to 330) and rural (ranging from 0 to 75) locations was observed. For that reason, accident frequency within this sample of school zones was characterized with large standard deviation. The average accident frequency for high saturation school zones was found to be greater than that of low saturation school zones; this difference was found to be statistically significant (Mann–Whitney $U = 20.500$, $Z = -2.958$, p-value = 0.002). Similarly, the difference in accident frequency for 2-lane and 4-lane roads was also found to be statistically significant (Mann–Whitney $U = 320.500$, $Z = -3.356$, p-value < 0.001).

4. Discussion

Overall compliance was recorded as 19.27% for the complete data set (Table 3) and 26.33% for the truncated data set that represents morning and afternoon rush hours during weekdays (Table 6). This result of non-compliance supports the findings of the previous studies (Trinkaus, 1996, 1998; Young and Dixon, 2003; Lazic, 2003; Ash and Saito, 2006; Reiss and Robertson, 1976). Analyses of both data sets revealed that the mean vehicle speed in all four school zones were greater than the posted speed limit of 35 mph (Tables 2 and 5). The situation was worse for low saturation school zones; as for these school zones, the mean vehicle speed was found to be greater than 45 mph: the speed limit of approaching road. With this result, it would be reasonable to conclude that school zones have no effect on vehicle speed and on compliance for low saturation locations and very minimal effect for high saturation locations.

4.1. Effect of time of the day and day of the week variables

The analysis of the complete data set found that vehicle speed in the school zones significantly varies for different time of the day (Table 4, Fig. 1). Though this result supports the findings of previous studies (Ogle, 2005; Ellison and Greaves, 2010) that investigated speeding in general, it differs from the findings of the studies (Lazic, 2003; Day, 2007) that include school zones. Speeding was found more prevalent from midnight to 6 am with the lowest compliance to the posted school zone speed limit. Generally, school zone speed limits are enforced when children are going to and from school. Therefore, the higher vehicle speed outside school hours is understandable. However, mean vehicle speed from 6 am to noon and from noon to 6 pm were found higher than posted school zone speed limits (35 mph) with a compliance rate lower than 27% (Table 4). The National Highway Traffic Safety Administration (2008) reported that from 1998 to 2008, there have been 132 (out of 267 total) fatalities recorded due to school transportation-related crashes from 2 to 5 pm. Despite the higher number of fatalities during afternoon school hours, this study found that from noon to 6 pm mean vehicle speed was the lowest among other intervals with the highest rate of compliance. Perhaps, the higher number of fatalities (and thus accidents) can be explained by the larger volume of vehicles during that interval of the day, and it is also likely that this higher volume of vehicles is also regulating the vehicle speed and compliance.

The mean vehicle speed in school zones was found to be significantly higher during weekends than on weekdays. This finding is supported by previous studies (Wundersitz et al., 2009; Ellison and Greaves, 2010; Familar et al., 2011) except one study (Lazic, 2003) that considered school zones. Again, this type of speeding behavior is understandable as generally school zones are not in effect during weekends. As discussed earlier, a large volume of vehicles in this case was also found to be associated with a decreased vehicle speed and increased compliance rate (Table 5). On the other hand, lower levels of traffic density would allow vehicles to travel at higher speeds, thus decreasing compliance with posted speeds.

4.2. Sign saturation and driver behavior

The analysis of the truncated data set proved the significant effect of sign saturation and road type variables. It was found that the mean vehicle speed in high saturation school zones was abated with an increased compliance rate, this result is contradictory to our hypothesis that drivers will comply more with the posted speed in low saturation school zones. The hypothesis about high saturation negatively affecting driver behavior was primarily based on the assumption that drivers actually pay attention to school zone signs. Having an opposite result questions the validity of the initial assumption. Perhaps, the results of this study indirectly support the findings of the previous studies about school zones having very little or no effect on vehicle speed (Trinkaus, 1996, 1998; Lazic, 2003; Young and Dixon, 2003; Ash and Saito, 2006). With an increased number of school zones present within a certain area makes the drivers notice the signs and actually obey the speed limit.

Table 7
Average accident frequency per school zone.

	Low saturation	High saturation	2-lane roads	4-lane roads
Number of school zones (n)	19	8	57	22
Accident frequency (Mean (SD))	26.05 (64.28)	105.88 (112.31)	18.49 (37.19)	73.55 (86.63)

The effect of sign saturation was observed considerably for 4-lane roads. The mean vehicle speed was found to be the lowest with the highest rate of compliance for high-sign-saturation-4-lane school zones among that of all 2 × 2 (sign saturation × road type) levels. Overall, 2-lane school zones exhibited higher mean vehicle speed compared to the 4-lane school zones. This result differs from the findings of previous studies (Tay, 2009; Kattan et al., 2011). This type of result may be due to the difference in road geometry or the surroundings of school zones. 4-lane school zones, especially school zone B, has more complicated surroundings (more cross roads, more traffic lights, more nearby businesses and parking lots, etc.) than 2-lane school zones. These surroundings may greatly influence driver behavior on the roads. It is possible that drivers have to slow down because they are ready to make a right turn on the next crossroad. Although the data was trimmed to remove cars that were turning, drivers could have been slowing for an upcoming turn or another maneuver. This information is unknown and was not taken into consideration during data analysis.

4.3. Sign saturation and accident frequency

The impact of sign saturation and road type was also observed on accident frequency for school zones. The mean accident frequency was found to be higher for high saturation and 4-lane school zones compared to low saturation and 2-lane school zones. Previous analyses identified that high saturation and 4-lane school zones exhibit lower mean vehicle speed with higher rate of compliance than of other levels of those variables. This type of safe driver behavior makes the explanation of higher accident frequency in those school zones difficult. Perhaps, the higher accident frequency can be attributed to a large volume of vehicles. High saturation and 4-lane school zones were characterized with higher traffic density compared to low saturation and 2-lane school zones (Tables 3 and 6). With high traffic volume, it is likely that those school zones would have a higher accident frequency compared to low saturation and 2-lane school zones. The effect of high traffic density can also be traced back to regulating driver behavior (vehicle speed and compliance) (Fig. 5). With high traffic density, drivers are forced to drive slowly which leads to low mean vehicle speed and high compliance in school zones. Since this study did not plan to include traffic density in the analysis, the effect of traffic density on driver behavior cannot be confirmed. However, the association of high traffic density with high saturation, 4-lane road type, low mean vehicle speed, high compliance, and high accident frequency and was apparent (Tables 3–7).

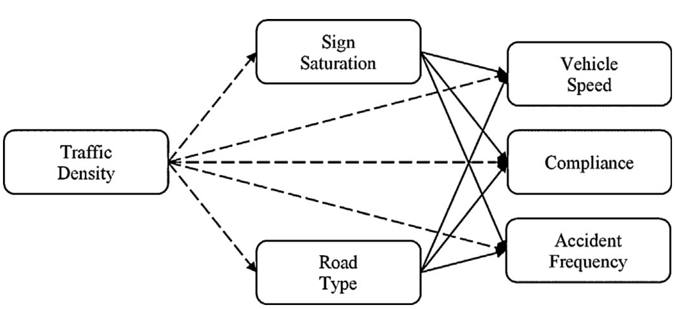

Fig. 5. Factors that affect driver behavior and accident frequency in school zones. (Dashed lines represent unconfirmed association).

5. Limitations of the study

Sampling procedure of the study could have been better. For example, the data collected in school zone B greatly skewed the final results. School zone B alone accounts for more than 46% of the total data points (for both data sets). Any significant effect could be due to the fact that school zone B is different from any of the other three locations of school zones. Furthermore, there are many confounding variables that were not controlled or eliminated in the study. These confounding variables may have impacted the final results. For example, school zone B was identified as a metropolitan area while the other three school zones were located in rural areas. There is likely more law enforcement in school zone B compared to the other three school zones, which may skew the drivers' behavior. These effects could be minimized by including the same number of data points from each school zone. Another way to handle this between-school-zone variability could be including school zones as blocks in the analysis. To do so, there should be more than one school zone for each 2 × 2 (sign saturation × road type) level.

6. Conclusions and future study

The ineffectiveness of school zones on reducing vehicle speed has been shown in this study. Additionally, this study confirmed the effect of the time of the day, the day of the week, the sign saturation, and the road type variable on vehicle speed and compliance. Based on current data, drivers had the highest average speed during the overnight and morning hours. In school zones, therefore, additional interventions (e.g., law enforcement, crossing guards) appear to be more important for school arrival, as compared to school dismissal times. One possible explanation for this difference in driver behavior is an assumed hurriedness in the morning commutes, compared to a less hectic afternoon commute.

Additionally, vehicles in high saturation and 4-lane school zones exhibited lower speeds and higher compliance compared to low saturation and 2-lane school zones. It was also observed that rural school zones exhibited higher vehicle speeds. Based on these results, there is not enough actionable information to inform standard policies for the placement of school zone signs. Further work is needed. However, these initial findings can be used to guide sign placement as follows:

- There is no evidence of a negative impact of sign saturation. Place school zone signs as needed.
- Road type (number of lanes) has an impact on driver compliance in a school zone. A school zone located on a 4-lane road is more effective than a school zone located on a 2-lane road. Place school zone signs in 4-lane roads as needed.
- There is evidence to suggest that drivers are more compliant to school zone signage in an urban setting. Place school zone signs in urban settings as needed.

The effects of sign saturation and road type were also observed on accident frequency. However, this result indicates association of traffic density with driver behavior and accident frequency as a regulating factor. Increased traffic density, possibly due to a higher population in the surrounding area, leads to a higher number of schools and thus high saturation. Therefore, it can be argued that traffic density impacts sign saturation and road type as well as vehicle speed, compliance, and accident frequency. Confirmation of this argument could explain the ineffectiveness of school zones and other speed zones. Future research is needed to quantify the effect of traffic density on driver behavior. Additionally, the impact of sign design on driver behavior was not assessed in this project.

While the signage used at all data collection sites was identical and based on Federal Highway Administration's guidelines (FHWA, 2009), there could be other school zone locations that do not use the fixed, static signage. The influence of sign design on driver behavior, specifically the trend towards digital or dynamic message signs should be further investigated.

Acknowledgement

This project was funded by the Mississippi Department of Transportation (MDOT State Study #253).

References

Aggarwal, G.C., Mortensen, S.L., 1993. Do advance school flashers reduce speed? ITE J. 63 (10), 24–30.
Ash, K.G., 2006. Increasing Speed Limit Compliance in Reduced-speed School Zones (Master's Thesis). Brigham Young University, Provo, UT.
Ash, K.G., Saito, M., 2006. Field evaluation of the effect of speed monitoring displays on speed compliance in school zones. Applications of Advanced Technology in Transportation. The Ninth International Conference .
Burritt, B.E., Buchanan, R.C., Kalivoda, E.I., 1990. School zone flashers—do they really work? ITE J. 60 (1), 29–31.
Cedar Rapids uses speed-monitoring trailer in its safety program (2006, April). Technology News—Center for Transportation Research and Education, IOWA State University, p. 8.
Clifton, K.J., Kreamer-Fults, K., 2007. An examination of the environmental attributes associated with pedestrian–vehicular crashes near public schools. Accid. Anal. Prev. 39, 708–715.
Day, S.W., 2007. Assessment of Driver Speed Compliance in Rural School Zones: Comparison of Speed by School Level and Time of Day (Master's Thesis). Clemson University, Clemson, SC.
Dumbaugh, E., Frank, L., 2007. Traffic safety and safe routes to school. Transp. Res. Rec. 2009, 89–97.
Ellison, A.B., Greaves, S., (2010, September). Driver characteristics and speeding behaviour. In Australasian Transport Research Forum (ATRF), 33rd, 2010, Canberra, ACT, Australia.
Familar, R., Greaves, S., Ellison, A., 2011. Analysis of speeding behavior multilevel. Transp. Res. Rec. 2237 (1), 67–77.
Federal Highway Administration (FHWA), 2009. Manual on Uniform Traffic Control Devices. http://mutcd.fhwa.dot.gov/.
Hawkins, N., 1993. Modified signs, flashing beacons and school zone speeds. ITE J. 63 (6), 41–44.
Kattan, L., Tay, R., Acharjee, S., 2011. Managing speed at school and playground zones. Accid. Anal. Prev. 43 (5), 1887–1891.
Lazic, G., 2003. School speed zones: before and after study for city of saskatoon. The Transportation Factor 2003, Annual Conference and Exhibition of the Transportation Association of Canada.
Lee, K.S., Bullock, D.M., 2003. Traffic signals in school zones. Publication FHWA/IN/JTRP-2002/32. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana.
Lee, C., Lee, S., Choi, B., Oh, Y., 2006. Effectiveness of speed-monitoring displays in speed reduction in school zones. Transp. Res. Rec. 1973, 27–35.
McCoy, P.T., Mohaddes, A.K., Haden, R.J., 1981. Effectiveness of school speed zones and their enforcement. Transp. Res. Rec. 811, 1–7.
McCoy, P.T., Heimann, J.E., 1990. School speed limits and speeds in school zones. Transp. Res. Rec. 1254, 1–7.
National Highway Traffic Safety Administration, 2008. School Transportation-Related Crashes. Department of Transportation, Washington, D.C.
Ogle J.H., 2005. Quantitative assessment of driver speeding behavior using instrumented vehicles. Dissertation. https://smartech.gatech.edu/handle/1853/6950.
Reiss, M.L., Robertson, H.D., 1976. Driver perception of school traffic control devices (abridgment). Transp. Res. Rec. (600), 36–39.
Saibel, C., Salzberg, P., Doane, R., Moffat, J., 1999. Vehicle speeds in school zones. ITE J. 69 (11), 38–43.
Schrader, M.H., 1999. Study of effectiveness of selected school zone traffic control devices. Transp. Res. Rec. 1692, 24–29.
Simpson, C.L., 2008. Evaluation of effectiveness of school zone flashers in north carolina. Transp. Res. Rec. 2074, 21–28.
Strawderman, L., Huang, Y., Garrison, T., 2013. The effect of design and placement of work-zone warnings signs on driver speed compliance: a simulator-based study. IIE Trans. Occup. Ergon. Hum. Factors 1 (1), 66–75.
Tay, R., 2009. Speed compliance in school and playground zones. ITE J. 79 (3), 36–38.
Trinkaus, J., 1996. Compliance with a school zone speed limit: an informal look. Percept. Mot. Skills 82, 433–434.
Trinkaus, J., 1998. Compliance with a school zone speed limit: another look. Percept. Mot. Skills 87, 673–674.
Vaisala Nu-Metrics Portable Traffic Analyzer NC200, 2010. http://www.vaisala.com/en/tabcontentadmin/Pages/NC200.aspx (accessed 09.10.14.)
Wickens, C.D., Liu, Y., Becker, S.E.G., Lee, J.D., 2004. An Introduction to Human Factors Engineering, 2nd ed. Prentice-Hall, Upper Saddle River, NJ.
Wundersitz, L.N., Hiranandani, K., Baldock, M.R., 2009. Annual Performance Indicators of Enforced Driver Behaviours in South Australia, 2007. Centre for Automotive Safety Research, University of Adelaide.
Young, E., Dixon, K., 2003. The effects of school zones on driver behavior. 2nd Urban Streets Symposium, Anaheim, California.