School zones

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Please note: The studies included in this synopsis were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides a *quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1 Summary

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1.1 COLOUR CODE: LIGHT GREEN

There is some indication that the installation of school zones can help to reduce speeds and improve road safety near schools. However, despite some improvements, there are still indications of frequent speeding and enhanced traffic risk in school zones.

1.2 KEYWORDS

School zone, speed limit, speeding, safety, intervention, crash

1.3 ABSTRACT

A school zone refers to a road area near a road traffic network around a school that has a likely presence of (young) pedestrians. In general, school zones have a reduced speed limit during certain hours. Most studies on the road safety impact of school zones used before and after measurements of vehicle speeds in these zones as the safety relevant indicator. There is evidence that a lowered speed limit in a school zone can substantially reduce vehicle speeds, but nevertheless vehicle speeds tend to remain far above the posted speed limit. There is evidence that speeds in school zones may be reduced by the application of speed monitoring displays and fiber-optic signs. The speed-reducing effects of speed monitoring displays have also been found to remain stable at long term. Studies have not consistently demonstrated that flashing beacon signs or pavement marking significantly reduce vehicle speeds in school zones. The presence of specific elements in the physical road environment (sidewalk, crosswalk, pedestrian fencing) may contribute to lower speeds in school zones. The research evidence is not clear on how the length of school zones and number of lanes affect vehicle speeds: opposing results have been found.

1.4 BACKGROUND

1.4.1 What is a school zone?

A school zone refers to a road traffic network around a school that has a likely presence of (younger) pedestrians. In general school zones have a reduced speed limit during certain hours. School zone speed limits are often only applicable during posted weekday hours near the beginning and ending of school when children are likely to cross roads. The school zone speed limit might also be effective at all times when school is in session. School zones can be indicated by signs, flashers, and roadway markings. In many European countries it is common practice to introduce changes to the road infrastructure itself, e.g. road humps.

1.4.2 Why are school zones necessary?

School zones are essential around primary schools. During school opening and closing hours and traffic peaks there are increased risks for conflicts between young, often inexperienced and poorly disciplined child-pedestrians and high speed cars. For example, in Canada it was found that collisions between motor vehicle and child pedestrians occurred more frequently during the hours and months of travel to and from school (Warsh et al., 2009). The rate of collisions per school travel hour was three times the rate of collisions at other times.

1.4.3 How does a school zone lead to road safety?

School zones are expected to lead to improved road safety by decreasing vehicle speeds near schools and by raising awareness of car drivers that young children or students may cross the road.

1.4.4 Which measures can support school zone limits?

Setting a reduced speed limit in a school zone is unlikely to produce the desired speed reduction on its own. Additional measures used to assist in reducing vehicle speeds in school zones may include police enforcement, public awareness campaigns, and engineering countermeasures. Traffic engineering tools include school speed limit zones and traffic calming (such as curb extensions or raised crosswalks).

1.4.5 Which factors influence speeding in a school zone?

For school zones, various factors concerning the road and the physical and social environment of the road may influence speeding namely:

- types of school zones (school zone compared to playground)
- the road class and number of lanes (2-lane roads vs. 4-lane roads)
- the visible presence of children
- the length of the school zone
- the approach speed
- the type of school (elementary school vs. high school) and
- the presence of fencing

1.4.6 How is the effect of school zones on road safety measured?

Most studies have measured the effect of school zones on vehicle speeds. These studies predominantly focus on specific measures such as school zone limit change, or the installation of flashers, beacons, or speed monitoring displays at the beginning of the school zone.

1.5 OVERVIEW OF RESULTS

For this synopsis 8 studies were coded, 5 of which from USA. Most studies used a before-after design, and most studies were restricted to one or a small number of school locations. A few studies presented long term results.

- There is evidence that speeds in school zones may be reduced by the application of speed monitoring displays and fiber-optic signs
- There is evidence that speed limit change alone may substantially reduce vehicle speed in school zones even though speeds may still remain above the posted speed limit
- Studies have not consistently demonstrated that flashing beacon signs or pavement marking will substantially reduce vehicle speeds in school zones.
- The presence of specific elements in the physical road environment (sidewalk, crosswalk, fencing) may contribute to lower speeds in school zones.
- The visible social environment of school zones and the presence of school children lower vehicle speeds.
- School zone speeds on local, and urban roads tend to be lower than school zone speeds on non-local and rural roads.

- The evidence for how the length of school zones affects vehicle speeds is unclear, as studies find opposing results
- The evidence is not clear regarding the effect of the number of lanes of roads in school zones on vehicle speeds. Studies find opposing results. A higher density of school zones and higher school zone signage around a reference school zone leads to lower vehicle speeds in a school zone.

1.6 TRANSFERABILITY OF RESULTS

Of the 8 studies on school zones 5 were done in the USA and have concentrated on the effects of school zone signs (flashers, beacons, marking) and general zone characteristics on speeding. Very little or no recent and relevant European literature on the subject could be found or was suitable for inclusion into this analysis.

The general dynamic occurring both in Europe and outside Europe seems to be that marking areas as school zone will tend to bring vehicle speeds down but nowhere enough near the safe speed limit. Additional measures such as flashing beacons, speed monitoring displays or traffic calming measures are then needed to further bring down vehicle speeds. Increasing the visibility of schools and school children would also tend to bring down speeds.

2 Scientific Overview

This scientific overview on the safety effects of school zones first describes individual studies (Section 2.1), it then presents study results (Section 2.2), and it ends with major conclusions (Section 2.3).

2.1 DESCRIPTION OF STUDIES

2.1.1 USA studies

Traffic control devices

In Springfield, USA, Schrader (1999) examined the speed reducing effectiveness of five different school zone traffic control devices. The tested speed control devices were Fiber-optic signs, two types of flashing yellow beacons and two types of pavement markings. The study used a before-after control group design, where each control device was tested at one site and one additional site without device was used as a control condition. Speed data were obtained at each site before the devices were added and again 1 month and 6 months after the devices were installed.

Three criteria were used for the selection of sites. The first criterion was that the school zone selected was to be marked only with signs that read "Speed Limit 20 on School Days When Children Are Present". The second criterion was that the site should be located on a collector road. The rationale behind this criterion was that pedestrian volumes on roads without specific crossing facilities are higher on collectors than on arterials because of lower vehicular volumes. Local streets were considered not to have enough vehicular traffic to create many vehicle-pedestrian conflicts. In other words, sites that were selected had vehicular volumes that were high enough to create numerous potential vehicle-pedestrian conflicts but not high enough to discourage a significant number of pedestrian crossing movements. The third criterion was that the site had a high number of "walkers" (students who walk to school). Sites with a high number of walkers also have more potential for vehicle-pedestrian conflicts and therefore a higher chance of pedestrian injury.

Vehicular speed data were collected with radar before any traffic devices were introduced at the sites. Vehicular speed data were also collected 1 month after traffic device installation and again 6 months after installation. (Six-month data were not gathered for one of the sites, which was added several months after the changes to the other sites.)

In a North Carolina study, Simpson (2008) set out to:

- determine if flashing beacons located in reduced-speed school zones decrease speeds and increase speed compliance when compared with reduced-speed school zones without flashers
- examine differences in vehicle speeds and compliance rates in school zones during reduced-speed school zone hours of operation (school time) versus hours outside the reduced-speed school zone hours of operation (non-school time)

From December 2006 through March 2007, speed data were collected with a Lidar gun on typical weekdays (Tuesday, Wednesday, or Thursday) when school was in session. All data collection was done under favourable, dry weather conditions. Speed data were collected at each site for the morning and afternoon school times for the entire duration (approximately 1 h) that the reduced speed limit was in effect. At least 100 speed samples or 1 h of data collection were also obtained at each site in the morning and afternoon during non-school-time hours. Non-school-time data collection began (ended) at least 30 min after (before) the school time. Data collectors targeted only unimpeded vehicles that were setting their own speed. In the study, various characteristics of the distribution of speeds were calculated and analysed, including the percentage of vehicles exceeding the speed limit, average speed, standard deviation, 85th percentile speed, and pace speed.

Sign saturation
In 2 studies, Strawderman et al. (2015) examined the impact of school sign saturation on speed and accident frequency. Sign saturation can be defined as the density of school zones around a reference school zone. For these studies, sign saturation was quantified as the total number of other school zones within a 10 mile radius of the school zone being studied. 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 cut-offs 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.

In study 1, 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 the sign saturation level, the road type (number of lanes) and a few control variables were taken into consideration. The complete dataset for this study included 168 h (7 days x 24 h) of vehicle speeds for four school zones (1 high saturation and 2 lanes, 1 high saturation and 4 lanes; 1 low saturation and 2 lanes, 1 low saturation and 4 lanes). The quasi-experimental design allowed to test the effects of low versus high saturation and number of lanes in a 2 x 2 factorial design.

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 researchers mention the following study limitations:
- The sampling procedure of the study could have been better. The data collected in one school zone greatly skewed the final results. This school zone alone accounted for more than 46% of the total data points (for both data sets).
- There were many confounding variables that were not controlled for or eliminated in the study. These confounding variables may have impacted the final results. One school zone was identified as a metropolitan area while the other three school zones were located in rural areas. There is likely more law enforcement in the urban school zone compared to the other three school zones, which may affect the drivers' behaviour.
- The accident results were probably primarily influenced by traffic volume as an explanatory variable. 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 volume impacts sign saturation and road type as well as vehicle speed, compliance, and accident frequency.

2.1.2 Studies outside USA

Speed zones - Canada
In Canada, Lazic (2003) examined the speed effects of school speed zones in the City of Saskatoon that were implemented prior to the 2002/2003 school year. The speed limit in the school zones was 30 km/h. The reduced speed zones were in effect from 8.00 to 5.00 pm, Monday to Friday from September 1st 2002 to June 30th 2002. Speed and traffic volume data were gathered at 15 school locations throughout the city. The speed data were averaged over 15 school locations throughout

the city; to eliminate the possibility of higher volume locations governing the percentile speeds and shapes of curves, vehicle percentages for each speed group were averaged instead of the actual values.

School zone characteristics - Canada
In *Canada, Alberta*, Kattan et al. (2011) examined the influence of various characteristics of school zones on speeding. The studied characteristics were the type of zone (school zone, playground), presence of children, number of lanes (2 or 4), presence of fencing, presence of a speed monitoring device, road classification (local, collector road), length of the zone, distance from road, (next to, ≤ 50 meter, > 50 meter) and traffic control device near the study location.

The study area was the City of Calgary in the Province of Alberta in Canada. The City of Calgary has implemented a reduced speed limit of 30 km/h on roads around both school and playground zones. These zones are clearly marked by a traffic sign at the beginning and end of the zone. A school zone is in effect between 8:00 a.m. and 4:30 p.m. during school days and a playground zone is in effect starting at 8:30 a.m. and ending 1 h after sunset. A sample of 11 schools and 16 playgrounds randomly located in the four quadrants of the City were selected for this study.

Data collection took place during daytime off-peak periods to ensure that a reasonable sample of observed vehicles with adequate head-way and tail-way was taken. Data on vehicle speed were collected by the research team using Ultralyte 20–20 laser speed guns. To reduce the influence of researchers on driver behaviour, the research team was stationed unobtrusively upstream from the zone. The speeds of the vehicles were measured while they were moving in the school or playground zones. To ensure free flow speed, impeded or rushed drivers who had been influenced by traffic were not included in the sample. Moreover, since weather and road surface conditions would affect traffic speed, measurements were only taken under dry conditions. The speed of 4580 vehicles was measured and recorded.

Speed monitoring displays – South Korea and USA
In *South Korea*, Lee et al. (2006) investigated the performance of a Speed Monitoring Display (SMD) in reducing speed in school zones in Gwacheon City. Two after measurements were conducted to assess both the short-term and the long-term effectiveness of the SMD. The SMD showed a school zone sign (upper), a 30 km/h limit sign (middle), and a display of vehicle speed (below).

Several variables were used to compare the performance characteristics, including the average speed, the 85th percentile speed, and the distribution of speeds.

In a USA, North Carolina-study on speed monitoring displays, O'Brien et al. (2012) investigated the speed reducing effects of a "Your Speed" sign. This sign displays amber-lighted steady numerals for speeds below and up to 5 mph above the posted speed limit and flashing numerals for speeds between 6 and 20 mph above as well as a pattern (no numeral) for speeds of 21 mph or more above.

The study location was the C. M. Eppes Middle School located in Greenville, North Carolina, near the campus of East Carolina University. The school sits on South Elm Street, a four-lane road divided by a tree-lined median with unmarked bike lanes, on-street parking, and a sidewalk on both sides through the school zone. South Elm Street's average daily traffic is 11,000 vehicles , and the speed limit is 35 mph during non–school time. The designated school zone along South Elm Street extends for approximately 1,500 ft. (457.5 m) in front of the school. From 8:00 to 9:00 a.m. and 3:25 to 4:45 p.m. (i.e., school time) the speed limit was reduced from 35 mph to 25 mph.

Speed data were collected before the signs were installed and at 1-, 3-, 6-, and 12-month intervals post-installation from November 2009 through October 2010. The speed data were organized by school time and non–school time sets for analysis. Various speed characteristics were calculated for each group analysed, including the percentage of vehicles exceeding the speed limit, average speed, 85th percentile speed, standard deviation, and pace speed. Average speeds before and after installation of the "Your Speed" signs were compared by using two-sided unpaired t-tests.

2.2 RESULTS

2.2.1 Results per study

In Springfield, USA, Schrader (1999) examined the speed reducing effectiveness of five different school zone traffic control devices. Of the five traffic control devices tested, only the fiber-optic signs, significantly decreased speeds. The effect was both immediate (i.e., within 1 month after the signs were installed) and long lasting (i.e., 6 months after the signs were installed). The other four devices — the two types of flashing yellow beacons and the two types of pavement markings — did not significantly reduce speeds in short or long term, although the site with the post-mounted flashing beacons did experience a modest decrease in speeds. However, it cannot be determined whether these decreases were a direct result of the beacons or a random sample variation. Because of the very limited scope of this study, these results cannot be considered conclusive. The tested devices should be tested at other locations to determine whether the effectiveness or non-effectiveness of a particular device can be attributed to the device itself or to some other site-specific influence.

In North Carolina, Simpson (2008) examined the effects of flashing beacons on vehicle speeds in school zones. She found that the average speeds at flashing beacons sites compared to non-flasher sites was 1.5 mph less for 25-mph school-time speed limits and 1.8 mph less for 35-mph or greater school-time speed limits. Although these results are significant, Simpson concludes that these changes in speed have only a minor effect on road safety.

The above two studies raise some doubt about the effectiveness of flashing beacons. More recently, however, some experts tend to have a more positive judgment. Based on empirical evidence and expert judgment , the iRAP assessment of pedestrian risk near school zones and possible countermeasures suggests to adopt a 10% reduction (or CMF of 0.90) for school zone flashing beacons . The use of school zone static signs or road markings was judged to be half as effective as the flashing beacons estimated as being a 5% reduction (or CMF of 0.95) (iRAP, 2013). It should be noted that the iRAP assessment only mentions one empirical study and it does not refer to either the Schrader or Simpson study.

In another study in North Carolina, O'Brien et al. (2012) investigated the speed reducing effects of a speed monitoring display sign ("Your Speed" signs). The main findings were:

- During school time, the average speed significantly decreased by at least 2.9 mph (4.6 km/h) and at most 4.5 mph (7.2 km/h). Indeed, 12 months after the installation, average speeds maintained a 3.4 mph (5.5 km/h) ($p < .0001$) to 4.1 mph (6.6 km/h) ($p < .0001$) decrease for southbound and northbound travel, respectively.
- The 85th percentile speed decreased by at least 3.8 mph (6.1 km/h) and at most 6.4 mph (10.3 km/h) after installation when either direction of travel was considered, and 85th percentile speeds maintained a 4.5 to 6.4 mph (7.2 km/h to 10.3 km/hr) decrease at 12 months after installation.
- When direction of travel is not considered, at school times the average speed was about 3.8 mph (6.1 km/h) (or 12%) lower 12 months after the signs were installed.
- During non–school time the average speed results varied by direction of travel. In the northbound direction, average speed decreased between 0.6 mph (1 km/h) ($p = .12$) and 2.4 mph (3.9 km/h) ($p < .0001$), but non-school time southbound speeds increased over time. At 1 and 3 months after installation, the modest increase in average speeds going southbound were

insignificant (p = .09 and p = .88, respectively). However, the largest increase of 1.7 mph (2.7 km/h) in average speed was extremely significant with a p-value less than .0001, and it occurred 12 months after the "Your Speed" signs were installed.

In Mississippi, Strawderman et al. (2015) examined the impact of school sign saturation on speed and accident frequency. In this study, sign saturation was defined as the density of school zones around a reference school zone. They found the following:

- Vehicles in high saturation and 4-lane school zones exhibited lower speeds and higher compliance compared to low saturation and 2-lane school zones.
- The effect of high saturation on vehicle speeds was larger for 4 lane roads than for 2 lane roads
- High sign saturation was also associated with lower accident frequency
- Two-lane roads were associated with lower accident frequency than 4 lane roads
- Rural school zones exhibited higher vehicle speeds (not coded)

In Canada, Lazic (2003) examined the speed effects of school speed zones in the City of Saskatoon. He found the following:

- The percentage of drivers driving at speeds less or equal to 30 km/h increased from 8.1% (Before Spring 2002) to 23.3% (After Fall 2002) and 21.7% (After Spring 2003)
- The median speed decreased from 46.0 km/h (Before Spring 2002) to 34.5 km/h (After fall 2002) and 35.0 km/h (After Spring 2003)
- The 85th percentile speed decreased from 54.5 km/hr (Before Spring 2002) to 45.5 km/hr (After Fall 2002) and 44.5 km/hr (After Spring 2003).
- The weekday traffic volume decreased by 14% (Before Spring 2002 vs. After Fall 2002) and 12% (Before Spring 2002 and after Spring 2003)

The researcher concluded that the general compliance with the 30 km/h limit in school zones was relatively low (23% complying drivers). However, it could be argued that the overall speed reduction of 10 km/h represents an improvement to child pedestrian safety. The reduction in weekday traffic volume near schools suggests that motorist prefer to avoid school zones.

In another Canadian study, Alberta, Kattan et al. (2011) examined the influence of various characteristics of school zones on speeding. This study found that the mean (and 85th percentile speeds) were:

- lower in school zones than in playground zones
- lower on roads with 2 lanes than on roads with 4 lanes
- lower for roads with pedestrian fencing than roads without pedestrian fencing
- lower on roads with speed display devices
- lower on controlled intersections than on sites with uncontrolled intersections.

These findings were supported by findings from previous research (Lazic, 2003; Lee et al., 2006; Tay, 2009; mentioned in Kattan et al., 2001)

In addition to the above results, this study also investigated several other potential contributing factors. The researchers found that the mean and 85th percentile speeds were:

- lower at zones that are closely joined with the road ($p < 0.0001$),
- lower with the presence of children compared to absence of children ($p = 0.003$)
- lower at local roads compared to collector roads ($p < 0.0001$)
- lower in longer zones of 200 m or more compared to zones less than 200 metres ($p < 0001$).

In addition to the series of univariate analyses, a multivariate analysis using a linear regression model was conducted to determine the effects of different site characteristics on vehicle speed. All estimated coefficients were statistically significant (p-value < 0.05) and had the expected signs.

In conclusion, the study found that the mean and 85th percentile speeds in both school (31.4 km/h, 38.0 km/h) and playground (32 km/h, 39.1 km/h) zones were considerably lower than the default speed limit on urban roads (50 km/h), although they were slightly higher than the posted speed limit of 30 km/h in these zones. The researchers note the following qualifications:
1. the study only collected data during the off-peak period and under free flow conditions; therefore the effect of the school and playground zones would likely be underestimated;
2. the study only collected data after the school and playground zones were in effect. Therefore, an assumption that the mean and 85th percentile speeds were around or above the default limit of 50 km/h before implementation had to be made in order to conclude that there was a reduction in speed.

In South Korea, Lee et al. (2006) investigated the performance of an Speed Monitoring Display (SMD) in reducing speed in school zones in Gwacheon City. The application of the SMD had a significant impact in reducing vehicle speeds. The short-term results in the after period showed that average speed dropped by 17.5% (8.2 km/h) at the SMD location. Although there was a slight difference in the magnitude of the speed reductions by the time of day, this speed reduction trend was observed throughout the day. From the long-term after study results, the trends were similar to those detected in the short-term study, but the (assumed) level of attention of the drivers to the existence of the SMD appeared to be reduced. The researchers derived the reduced attention from the finding that the reference point of the speed reduction was shifted downstream of the study site, and average speed there were found to be reduced by 12.4% (5.8 km/h) at the SMD location (significant difference).

The analysis of the results of the speed distribution indicated that the application of an SMD in school zones could reduce the number of speeding vehicles. About 26.5% of all vehicles used to drive at speeds over 50 km/h. The SMD reduced that to 9.9% and 5.4% in respectively the short-term and the long-term after studies. In addition, the 85th percentile speed was reduced from 54.3 km/h to 46.3 km/h and 45.0 km/h in the short-term and the long-term after studies, respectively. The variability of the speed data decreased from the application of the SMD. It was concluded that the use of the SMD in a school zone produced a positive impact on driver behaviour, and a significant speed reduction could be obtained for a longer period of time. The use of a SMD in school zones does not need be limited to only the active period of the day in school zones but may be applied throughout the day if necessary.

All in all the results of both the O'Brien et al. and Lee et al. study on speed monitoring displays show promising speed reducing effects, both in the short- and the long-term. At the same time these results should be interpreted with some caution as in both studies these are based on one location only.

2.2.2 Results summary

The major results of coded studies are listed in Table 1. The results can be summarised as follows:

- There is evidence that speeds in school zones may be reduced by the application of speed monitoring displays and fiber-optic signs (Schrader, 1999; Lee et al., 2006; Kattan et al., 2011).
- There is evidence that speed limit change alone may substantially reduce vehicle speed in school zones even though speeds may still remain above the posted speed limit (Lazic, 2003)

- Studies have not consistently demonstrated that flashing beacon signs or pavement marking may reduce vehicle speeds in school zones (Schrader, 1999; Simpson, 2008)
- The presence of specific elements in the physical road environment (sidewalk, crosswalk, fencing) may contribute to lower speeds in school zones (Fitzpatrick et al., 2010; Kattan et al., 2011))
- The visible social environment of school zones and the presence of school children lower vehicle speeds (Kattan et al., 2011)
- School zone speeds on local, and urban roads tend to be lower than speeds on non-local and rural roads (Fitzpatrick et al., 2010; Kattan et al., 2011; Strawderman et al., 2015).
- The evidence is not clear on how the length of school zones affect vehicle speeds. Studies find opposing results (Fitzpatrick et al., 2010; Kattan et al., 2011).
- The evidence is not clear about how number of lanes in school zones affect speeds. Studies find conflicting results (Fitzpatrick et al., 2010; Kattan et al., 2011 vs. Strawderman et al. 2015).
- A higher density of school zones and higher school zones signage around a reference school zone lead to lower vehicle speeds in a school zone (Strawderman et al., 2016).

Table 1: Overview of coded studies and their (simplified) main outcomes

Study	Method	Evaluated school zone characteristic	Indicator	Recorded change	Expected safety effect	Description of main outcomes
Schrader, 1999, USA, Illinois	Before-after	Flashing yellow beacons	Speed	—	—	No significant change in speeds
		Pavement markings	Speed	—	—	No significant change in speeds
		Fiber-optic sign	Speed	↙	↗	1 month after the changes, the mean speed decreased from 53.3 km/h to 47.9 km/h. 6 months after the changes, the mean speed was 48.7 km/h, 4.6 km/h less than the initial mean speed.
Lazic, 2003, Canada	Before-after	Reduction speed limit from 50 to 30 at school zones	Median Speed	↙	↗	The median speed decreased from 46 km/r (Before Spring 2002) to 34.5 km/hr (After fall 2002) and 35.0 (After Spring 2003)
			V85 speed	↙	↗	The 85th percentile speed decreased from 54.5 (Before Spring 2002) to 45.5 (After Fall 2002) and 44.5 (After Spring 2003).
Lee, 2006, South Korea	Before-after with 2 after measurements	Speed monitoring display	% vehicles > 50 km/h	↙	↗	At before measurement 26.5% of vehicles drove at speeds over 50 km/h, but the percentages were reduced to 9.9% (short-term) and 5.4% (long-term)
		Speed monitoring display	V85 speed	↙	↗	The 85th percentile speed was changed from 54.3 (before) to 46.3 (short term) and 45.0 km/h (long term)
Simpson, 2008, USA, North Carolina	Cross-sectional design	Flashing beacons	Speed	↙	↗	the average speeds at flashing beacons sites compared to non-flasher sites was 1.5 mph less for 25-mph school-time speed limits and 1.8 mph less for 35-mph or greater school-time speed limits
	Cross-sectional design, both	Longer school zones	Speed	↗	↙	Speeds increased app. 0.9 mph for every 500 ft. in school zone length.

Study	Method	Evaluated school zone characteristic	Indicator	Recorded change	Expected safety effect	Description of main outcomes
Fitzpatrick, 2010, USA, Texas	univariate and multivariate analysis	Presence of sidewalk or cross walk	Speed	↙	↗	The presence of either sidewalk or cross walk decreased speed
		Rural (vs urban)	Speed	↗	↙	Rural areas went together with increase speed (versus urban)
		Time increment from start or end of school	Speed	↗	↙	Speeds were higher for greater time increments from the start or the end of school.
Kattan, 2011, Canada	Cross-sectional design, both univariate and multivariate analysis	Presence speed display devices	Speed	↙	↗	Lower speeds when speed display devices present
		Presence children	Speed	↙	↗	Lower speeds when children present
		Presence fencing	Speed	↙	↗	Lower speeds when fencing present
		Local roads	Speed	↙	↗	Lower speeds at local roads
		Longer zones	Speed	↙	↗	Lower speeds at longer school zones of 200 m or more
		2-lanes (vs. 4 lanes)	Speed	↙	↗	Lower speeds at 2-lane roads
O'Brien, 2012, USA	Before-after with multiple after measurements	Speed monitoring display	Speed	↙	↗	After installation sign speeds during school times lowered. After 12 months the speed were still 5.5 to 6.5 km/hour lower than pre-installation.
Strawder-man, 2015, USA, Missisippi	Cross-sectional, quasi-experimental	High school zone sign saturation	Speed	↙	↗	Vehicles in high saturation school zones exhibited lower speeds and higher compliance
		High school zone sign saturation	Accident frequency	↗	?	High school zone sign saturation was associated with higher accident frequency (however no correction for traffic density)
		2-lane vs. 4-lane school zones	Speed	↗	↙	2-lane school zones exhibited higher mean vehicle speed compared to the 4-lane school zones
		Urban vs. rural	Speed	↙	↗	urban school zones exhibited lower vehicle speeds

2.3 CONCLUSIONS

The general dynamic occurring worldwide is that marking areas as school zone will tend to bring vehicle speeds down but nowhere enough near the safe speed limit.

Additional measures such as speed monitoring displays, flashing beacons or traffic calming measures seem needed for further reduction of speeds. However, not all studies on effects of flashing beacons show speed reduction effects.

Specific social or physical elements in the school road environment may either act as speed accelerators or decelerators. The physical presence of school and school children decelerates speed. Higher order roads with more lanes tend to accelerate speeds.

A higher density of school zones contributes to lower speeding in a school zone.

3 Supporting document

This Supporting Document on school zones describes the literature search strategy (Section 3.1), it presents a schematic overview of study characteristics (Section 3.2) and it presents references on coded studies and general literature (Section 3.3).

3.1 LITERATURE SEARCH STRATEGY

The literature on school zones and traffic risk was searched for in the international database Scopus on March 14th 2017. Scopus is the largest international peer-reviewed database. Table 2 describes the search terms and logical operators and the number of hits for the search on school zones.

Table 2: Used search terms and logical operators

No	Search terms/logical operators/combined queries	hits
1	(TITLE-ABS-KEY ("school zone") AND TITLE-ABS-KEY ("road safety" OR "accident" OR "crash" OR "speeding" OR "speed")) 69 hits	69

The search resulted in 69 hits. In a first screening round, these 69 references were screened on potential relevance for coding based on title and abstract information. Also references were screened for further references. Criteria for selecting publications in the first round were:

- The study is concerned with the behaviour or safety effects of school zone measures
- written in English
- better or more complete results were not published earlier or later in another publication (duplication).
- Not a general review-like text

Table 3 shows that 47 studies had to be rejected after this first round of screening, because the publication was not concerned with the effect of school zone on speeding or accidents. For example, several studies that were found by the search focused on pedestrian behavior near school zones.

Table 3: Initial selection of studies after the first screening round

Selection steps	Not selected first round	Selected first round
Excluded: School zones not evaluated in terms of speed or accident data	47	
Selected after initial screening		22
Added after screening references		0
Total selected		22

Of the 69 publications 22 studies were directly concerned with the evaluation of crash or speed data in school zones. These 22 selected studies were further screened on relevance for coding in a second screening round. In the second round the same criteria were used but were checked on full-text copies of the papers. Table 4 presents the results of this second screening round and describes the final decisions.

Table 4: Selection of studies to be coded in second screening round

	Reference	Relevant	To be coded
1	Schrader, M. H. (1999). Study of effectiveness of selected school zone traffic control devices . Transportation Research Record, 1692, 24-29.	Yes The effectiveness of five different school zone traffic control devices was tested. Each was tested at a unique site. Speed data were obtained at each site before the devices were added and again 1 month and 6 months after the devices were installed. The five devices tested in the study were fiber-optic signs, spanwire-mounted flashing yellow beacons, post-mounted flashing yellow beacons, transverse lavender stripes, and large painted legends.	Yes
2	Trinkaus, J. (1999). School zone speed limit dissenters: An informal look. Perceptual and Motor Skills, 88, 1057-1058	Only speed data at on location, not before after.	No to limited in scope
3	Lazic, G. (2003). School speed zones: Before and after study city of Saskatoon.	Yes	Yes
4	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 - Proceedings of the Ninth International Conference on Applications of Advanced Technology in Transportation, 780-785	Yes	No, could not be retrieved
5	Lee, C., Lee, S., Choi, B., & Oh, Y. (2006). Effective-ness of speed-monitoring displays in speed reduction in school zones . Transportation Research Record, 1973, 27-35	Yes	Yes
6	Chang, K., Nolan, M. (2007). School zones and radar speed signs: A winning combination when children are present? Institute of Transportation Engineers Annual Meeting and Exhibit 2007, 2, 875-881.	The King County Department of Transportation tested the effectiveness of a flashing beacon against a radar speed sign, also known as a dynamic speed display sign, as part of a school zone safety pilot project.	No, too limited
7	Isebrands, H.N., Hallmark, S.L. (2007). School zone safety and operational problems at existing elementary schools . ITE Journal (Institute of Transportation Engineers), 77, 26-31	The growing number of schoolchildren being dropped off or picked up in private vehicles poses significant challenges related to student safety and traffic operations in school zones. These private vehicles must compete for space at schools with buses, bicycles, and pedestrians. This study uses on-site observations, traffic data collection, and interviews with schools, law enforcement and traffic engineers to identify transportation safety issues at elementary school sites in Iowa	No
8	Simpson, C.L. (2008). Evaluation of effectiveness of school zone flashers in North Carolina . Transportation Research Record,2074, 21-28	Yes	Yes

9	Brewer, M.A., & Fitzpatrick, K. (2009). Characteristics of operating speeds in school speed zones in Texas. Institute of Transportation Engineers Annual Meeting and Exhibit 2009, 1, 168-183	Yes, researchers conducted a study on characteristics of operating speeds within school zones in Texas to determine possible relationships between speed and other school zone-related factors. The research team conducted a field study to collect data at school zones in 17 locations across the state, and they analysed the data based on school speed limit, length of school zone, and duration of school zone, among other factors	No, the Fitzpatrick et al 2010 (same study) is coded
10	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. Injury Prevention, 15, 226-229.	Yes	Yes
11	Fitzpatrick, K., Brewer, M.A., & Park, E.S. (2010). Suggestions concerning school traffic control devices. Transportation Research Record, 2149, 1-10	Yes, researchers collected speed data at 24 school zones, focusing the analysis on unique characteristics of reduced-speed school zones, such as length, duration, and time of day relative to the start and end of school. Of particular interest was the finding that longer school zones do not result in lower speeds for a longer distance; speeds increased approximately 0.9 mph for every 500 ft of school zone length. Findings from the analysis and discussions with practitioners were used to develop guidelines for traffic control devices, including school speed zones, near schools in Texas.	Yes
12	Kattan, L., Tay, R., & Acharjee, S. (2011). Managing speed at school and playground zones . Accident Analysis and Prevention, 43, 1887-1891.	Yes	Yes
13	O'Brien, S., & Simpson, C. (2012). Use of your speed changeable message signs in school zones. Transportation Research Record, 2318, 128-136	The Safe Routes to School (SRTS) program, through a variety of tools, seeks to enable children to walk and bicycle safely to school. One such tool recently implemented through a program of the North Carolina Department of Transportation (DOT) is the use of speed feedback signs ("Your Speed" signs) to reduce vehicle speeds in school zones. The North Carolina DOT has no policy or standard for the use of these signs within school zones, and research illustrating the value of using permanently installed "Your Speed" signs in school zones is sparse. The Eastern Carolina Injury Prevention Program (ECIPP) applied for SRTS funding to install these signs as part of its education, encouragement, and enforcement project. The North Carolina DOT therefore initiated a study on the use of the signs in conjunction with ECIPP's larger SRTS project. Significant findings of this study include a 3.0 mph ($p < .0001$) to 4.5 mph ($p < .0001$) reduction in speed sustained over a 12-month post-installation period, suggesting that responses to "Your Speed" signs may not diminish as drivers become accustomed to the signs' presence.	Yes
14	Ebrahim, Z.,& Nikraz, H. (2012). Harm minimisation in a school zone: A strategy for sustaining pedestrian safety. WIT Transactions on the Built Environment, 128, 165-172	Focuses on enforcement actions around school zones (Australian study), but method and analysis are not very clearly described.	No
15	Ratanavaraha, V., & Watthanaklang, D. (2013) The effectiveness of temporary traffic calming devices on reducing speeds of traffic flow in school zones. Indian Journal of Science and Technology, 6, 4478-4484	Indian	No

16	Gregory, B., Irwin, J.D., Faulks, I.J., & Chekaluk, E. (2014). Speeding in school zones: Violation or lapse in prospective memory? Journal of Experimental Psychology: Applied, 20, 191-198	Two studies are reported which show that an interruption to a journey, caused by stopping at a red traffic light, can result in failure to resume the speed of travel prior to the interruption (Study 1). In Study 2 we showed that the addition of a reminder cue could offset this interruption. These studies were conducted in a number of Australian school zone sites subject to a 40 km/h speed limit, requiring a reduction of between 20 km/h and 40 km/h. Motorists who had stopped at a red traffic signal sped on average, 8.27 km/h over the speed limit compared with only 1.76 km/h over the limit for those who had not been required to stop. In the second study a flashing "check speed" reminder cue, placed 70 m after the traffic lights, in the same school zones as those in Study 1 eliminated the interruptive effect of stopping with drivers resuming their journey at the legal speed.	No
17	Rohani, M.M., Daniel, B.D., Aman, M.Y., Prasetijo, J., & Mustafa, A.A. (2014). The effect of speed camera warning sign on vehicle speed in school zones . Research Journal of Applied Sciences, Engineering and Technology, 8, 2315-2319	Malaysian study	No
18	Rahman, M.M., & Strawderman, L. (2015). The effect of sign saturation on driver speed limit compliance in school zones. Proceedings of the Human Factors and Ergonomics Society, 2015-January	This study investigated the effect of school zone sign saturation on vehicle speed and compliance to school zone speed limit	No
19	Strawderman, L., Rahman, M.M., Huang, Y., & Nandi, A. (2015). Driver behavior and accident frequency in school zones: Assessing the impact of sign saturation . Accident Analysis and Prevention, 82, 118-125	Yes	Yes
20	Zhao, X.-H., Li, J.-H., Li, J.-F., Rong, J. (2014). Experimental research on optimal design of school zone traffic safety facilities. Jiaotong Yunshu Xitong Gongcheng Yu Xinxi/Journal of Transportation Systems Engineering and Information Technology, 14, 207-212.	In Chinese language	No
21	Zhao, X., Li, J., Ding, H., Zhang, G., & Rong, J. (2015). A generic approach for examining the effectiveness of traffic control devices in school zones. Accident Analysis and Prevention, 82, 134-142.	Simulator study A Traffic Control Device Selection Model (TCDSM) is developed and two representative school zones are selected as the testbed in Beijing for driving simulation implementation to enhance its applicability. Statistical analyses are conducted to extract the knowledge from test data recorded by a driving simulator. Multiple measures of effectiveness (MOEs) are developed and adopted including average speed, relative speed difference, and standard deviation of acceleration for traffic control device performance quantification.	No, study is about developing a method
22	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 (1), art. no. 789	Yes This research conducted a driving simulator experiment to assess the effects of school zone signs and markings for two different types of schools. The efficiency of these traffic control devices was evaluated using four variables derived from the driving simulation, including average speed, relative speed difference, standard deviation of acceleration, and 85th percentile speed. Results showed that traffic control devices such as the Flashing Beacon and School Crossing Ahead Warning Assembly, the Reduce Speed and School Crossing	No, simulator study within Chinese context

		Warning Assembly, and the School Crossing Ahead Pavement Markings were recommended for school zones adjacent to a major multilane roadway, which is characterized by a median strip, high traffic volume, high-speed traffic and the presence of pedestrian crossing signals. The School Crossing Ahead Pavement Markings were recommended for school zones on a minor two-lane roadway, which is characterized by low traffic volume, low speed, and no pedestrian crossing signals	

3.2 DESCRIPTIPON OF CODED STUDIES

Table 5 presents background characteristics of the coded studies.

Table 5: Overview of main characteristics of coded studies

Author(s), Year, Country	Study type	Measure/feature studied	Sample/Measurement	Analysis
Schrader, 1999	The effectiveness of 5 different school zone traffic control devices was tested. Each was tested at a unique site. Speed data were obtained at each site before the devices were added and again 1 month and 6 months after the devices were installed.	The 5 devices tested in the study were fiberoptic signs, spanwire-mounted flashing yellow beacons, post-mounted flashing yellow beacons, transverse lavender stripes, and large painted legends.	3 criteria were used for the selection of sites: 1. the site should be an unprotected crossing 2. the site should be located on a collector (these streets have vehicular volumes that were high enough to create numerous potential vehicle-pedestrian conflicts but not high enough to discourage a significant number of pedestrian crossings) - the site has a high number of students who walk to school. Vehicular speed data were collected with radar before any traffic devices were changed at the sites. Vehicular speed data were also collected 1 month after traffic device changes at the sites were implemented and again 6 months after the changes were implemented	a t-test was used to statistically analyse the data. for this analysis, the test hypothesis was that speeds decreased after the changes to the sites.
Lee, 2006, South Korea	This study investigated the performance of a Speed Monitoring Display (SMD) in reducing speed in school zones in Gwacheon City South Korea.	The Speed Monitoring Display (SMD) showed a school zone sign (upper), a 30 km/h limit sign (middle), and a display of vehicle speed (below).	A before and two after measurement, short term and long term, were conducted to assess the effectiveness of the SMD. The before measurement took place 1 day before installation. The after measurements were done 2 weeks and 12 months after	Several dependent variables were calculated, including the average speed, the 85th percentile speed, and the coefficient of variation.
Simpson, 2008, USA, North Carolina	The study objectives were to: - determine if flashers located in reduced-speed school zones	In an attempt to provide more awareness of the school zone speed limit and at the request of schools, the North Carolina	From December 2006 through March 2007, speed data collection was done with a Lidar gun, in both directions of travel, on typical weekdays (Tuesday,	Various characteristics of the distribution of speeds were calculated and analysed, including the percentage of vehicles exceeding the speed

Author(s), Year, Country	Study type	Measure/feature studied	Sample/Measurement	Analysis
	decrease speeds and increase speed compliance when compared with reduced-speed school zones without flashers - examine differences in vehicle speeds and compliance rates in school zones during reduced-speed school zone hours of operation (school time) versus hours outside the reduced-speed school zone hours of operation (non-school time).	Department of Transportation (NCDOT placed flashing beacons on school zone signs where the North Carolina Administrative Code allowed. The flashers operated during the school zone hours of operation to provide an additional reminder of the reduced speed limit.	Wednesday, or Thursday) when school was in session. All data collection was done under favourable, dry weather conditions. Speed data were collected at each site for the morning and afternoon school times for the entire duration (approximately 1 h) that the reduced speed limit was in effect. At least 100 speed samples or 1 h of data collection were also obtained at each site in the morning and afternoon during non-school-time hours. Non-school-time data collection began (ended) at least 30 min after (before) the school time. Data collectors targeted only unimpeded vehicles that were setting their own speed.	limit, average speed, standard deviation, 85th percentile speed, and pace speed.
Fitzpatrick, 2010, USA, Texas	The main study aim was to determine how school zone characteristics affect vehicle speeds when the School Speed Limit was in effect.	School zone characteristics studied were: - length of school zone - presence of crosswalk - presence of sidewalk - rural vs. urban - access density and school driveway density - number of lanes - the time increment from the start or end of the school	The research team collected speed data in school speed zones to determine the predominant speed patterns when the zones were active. Studies were conducted at 24 school sites in Texas. Elementary and middle schools located on higher-speed roadways were emphasized in the selection of study sites	3 speed types speed data were analysed: - Average speeds of vehicles in an active school zone obtained from 30 data sets (laser data sites and counter data sites, subdivided by direction of travel at six sites in which data were collected in both directions), number of observations (n) = 30. - Spot-speed data obtained from individual vehicle speeds for vehicles in an active school zone, n = 24,829. - Speed–distance data obtained from individual vehicle speeds along the entire active school zone distance measured when beacon is on, n = 59,966.
O'Brien, 2012, USA, North Carolina	This study investigated if "Your Speed" signs located in the school zone decreased speeds, and whether speed changes differed between school time and non-school time	The features of the "Your Speed" sign included : - Displaying amber-lighted steady numerals for speeds below and up to 5 mph above the posted speed limit and flashing numerals for speeds between 6 and 20 mph above and a pattern (no numeral) for speeds 21 mph or more above. - Operating only during the designated times.	A lidar gun was used to collect speed data in both directions of travel. Data were collected before the signs were installed and at 1-, 3-, 6-, and 12-month intervals post-installation from November 2009 through October 2010.	Speed data were organized by school time and non–school time sets for analysis. Various speed characteristics were calculated for each group analysed, including the percentage of vehicles exceeding the speed limit, average speed, 85th percentile speed, standard deviation, and pace speed. Average speeds before and after installation of the "Your Speed" signs were compared by using two-sided unpaired t-tests.

Author(s), Year, Country	Study type	Measure/feature studied	Sample/Measurement	Analysis
		- Using a strong yellow–green colour for the sign backing		
Strawder-man, 2015, USA, Mississipi	This study examined the impact of school sign saturation on speed and accident frequency.	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. Sign saturation had two levels: high saturation and low saturation	In study 1, driver behaviour (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 x 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).	A 2 x 2 factorial ANOVA was performed to investigate the effects of the sign saturation and road type variable (2/4lane road) on vehicle speed. Mann–Whitney U test were used to test differences in accident frequencies for high/low sign saturation and for 2-lane vs. 4-lane roads.

4 References

Coded studies

O'Brien, S.W. & Simpson, C.L. (2012). Use of "Your Speed" changeable message signs in school zones. *Transportation Research Record*, *2318*, 128-136.

Fitzpatrick, K., Brewer, M.A., and Park, E.S.(2010). Suggestions Concerning School Traffic Control Devices. *Transportation Research Record*, *2149*, 1-10.

Kattan, L., Tay, R., & Acharjee, S. (2011). Managing speed at school and playground zones . *Accident Analysis and Prevention*, *43*, 1887-1891.

Lazic, G. (2003). School speed zones: Before and after study city of Saskatoon. St John's, Newfoundland and Labrador, Canada: Transportation Association of Canada (TAC) Annual Conference and Exhibition, 2003.

Lee, C., Lee, S., Choi, B., & Oh, Y. (2006). Effectiveness of speed-monitoring displays in speed reduction in school zones . *Transportation Research Record*, *1973*, 27-35

Schrader, M. H. (1999). Study of effectiveness of selected school zone traffic control devices . *Transportation Research Record*, *1692*, 24-29.

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

General references

iRAP (2013). iRAP Road Attribute Risk Factors. School Zone Warning. International Road Assessment Programme (iRAP).

Tay, R. (2009). Speed compliance in school and playground zones. Institute of Transportation Engineers, ITE Journal, 36.

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. *Injury Prevention*, *15*, 226-229.