Evidence Base Associated with Safety Effects of Roadway Features for Pedestrians and Bicyclists

By Charles V. Zegeer, Pedestrian and Bicycle Information Center

June, 2013

The purpose of this paper is to provide a summary of what is known from international safety research with respect to the safety effects of various traffic and roadway features and countermeasures on the risk of pedestrian crashes.

Therefore, this summary attempted to address the following questions:

1. What is known from the safety literature about the relationship between roadway features and pedestrian crashes?
2. What is known from the safety research regarding the crash effects (i.e., Crash Modification Factors, or CMF's) of various types of engineering and roadway treatments on pedestrian-related crashes?
3. What is known about potential safety effects associated with various roadway and infrastructure treatments; that is, what is the effect of behavioral, speed, and/or conflict measures, where no CMF information exists?
4. What is known about the specific safety effects of roadway features and countermeasures on child pedestrian safety and/or safety for child pedestrians and bicyclists in school areas?

Relationships between Roadway Variables and Pedestrian Crash Risk

Several studies have been conducted in recent years which have developed crash-based models between pedestrian crashes and roadway and traffic variables.

FHWA Study of Marked vs. Unmarked Crosswalks

A 2005 study by Zegeer, et. al. conducted an analysis to quantify the effect of marked vs. unmarked pedestrian crossings on pedestrian crashes. The study collected roadway, traffic, and pedestrian crash data for 1,000 marked crosswalks and 1,000 matching unmarked crosswalks from 30 U.S. cities. Crash prediction models (Poison and negative binomial regression models were fit to pedestrian crash data for marked and also unmarked crossing sites, and the models included all significant variables. The following roadway and traffic factors were found to have a significant relationship with increased pedestrian crash risk:

- Higher pedestrian volume
- Higher motor vehicle volume (e.g., particularly for ADT's exceeding 12,000 vehicles per day)
- Greater number of lanes
- Lack of a raised median or raised median island for muli-lane roads
- Presence of a marked vs. unmarked crosswalk (particularly on multi-lane roads)

Variables that were NOT found to have a significant effect on pedestrian crashes included: speed limit (although this was nearly significant), area type, one-way vs. two-way, and crosswalk marking condition.

Because of the greater pedestrian crash risk when marked crosswalks are used on the higher-volume multi-lane roads, the authors recommend considering "more substantial" crossing enhancements where pedestrians need to cross at such locations. Treatments such as raised medians, enhanced overhead lighting, improved signs and markings, reducing the number of lanes (e.g., restriping 4-lane undivided roads to 2 or 3 lanes (i.e., road diet treatment), and/or adding traff and pedestrian signals was suggested to minimize pedestrian crash risk.

Pedestrian and Bicyclist Intersection Safety Indices (ISI)

This study was conducted by the UNC Highway Safety Research Center for FHWA in 2006, was intended to develop a methodology for rating intersections based on their relative risk to pedestrians and bicyclists based on observable roadway characteristics. The reason for developing such a method was that agencies should not have to wait for pedestrian or bicycle crashes to occur at a "high-risk" intersection before considering it for needed safety improvements.

Roadway and traffic variables were identified which were found to be associated with increased risk for pedestrians and bicyclists. The high-risk factors were identified based on an analysis of hundreds of hours of pedestrian and bicyclist behaviors, conflicts with motor vehicles, and driver behaviors at 68 pedestrian crossings and 67 bicycle approaches at intersections in seven U.S. cities. Subjective ratings were also obtained from selected pedestrian and bicycle professions who were asked to rate the relative safety of pedestrians and bicyclists from video clips and site diagrams for a variety of condition.

Pedestrian and bicycle crash information was also used at the sample sites. A 6-point Intersection Safety Index (ISI) rating scale was developed based on the roadway features found to be important risk factors, where a 1 or 2 rating represented a very low risk crossing (e.g., 2-lane road with low vehicle speeds and volumes) and a 5 or 6 was considered a high risk situation (e.g., multi-lane road with high vehicle speeds and volumes). The factors which were included in the pedestrian index as being associated with GREATER risk of a pedestrian crash included:

- An intersection does not have a traffic signal (with pedestrian signals)
- The intersection does not have a stop sign
- There are a greater number of lanes
- There is a higher vehicle speed limit
- The traffic volume is high
- The land use is in a predominately commercial area

A separate ISI model was developed for bicycle safety considerations. The factors found to associated with GREATER risk to bicyclist safety included:

- Lack of a separate bike lane
- Higher cross street traffic volume
- Greater number of through lanes on the cross street
- Greater number of lanes on the main street for bicyclists to have to cross to make a left turn

- Greater main street traffic volume
- Speed limit of 35 mph or greater
- Presence of on-street parking on the main street
- Greater number of lanes that bicyclists must cross to make a right turn
- Greater number of right-turn traffic lanes on the main street approach
- Presence of a traffic signal at the intersection
- Presence of turning vehicle traffic across the path of through cyclists

Pedestrian Safety Prediction Methodology

This 2008 study (NCHRP 17-26) by Harwood, et. al. (which included HSRC as a subcontractor) involved developing pedestrian crash prediction models (termed "safety performance functions) for use in the Highway Safety Manual. The study dealt only with 3-and 4-leg signalized intersections, and no models were developed for roadway sections or unsignalized intersections.

Based on several hundred signalized intersections from Charlotte, N.C. and Toronto, Canada, pedestrian crash prediction models were developed using 20 different traffic and roadway variables. The roadway and traffic variables found to have a significant effect on pedestrian crashes included:

- Traffic volume
- Ratio of minor road ADT to major road ADT
- Pedestrian volume
- Maximum number of traffic lanes crossed by pedestrians in any one crossing
- Presence of bus stops within 300 m of the intersection
- Presence of schools (public or private) within 300 m of the intersection
- Number of alcohol establishments within 300 m of the intersection

Summary of Crash Modification Factors (CMF's) from Safety Research

An update of the publication entitled "Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes" was completed in February, 2013 for the Federal Highway Administration by the UNC Highway Safety Research Center. Essentially, that publication involved a review of crash-based evaluations of a wide range of roadway and engineering countermeasures related to enhancing pedestrian safety. The signal-related measures that were found to have safety benefits, i.e., a known CMF's included:

- Exclusive pedestrian signal phasing
- Improved signal timing, including increasing pedestrian walking period
- Replacing traditional pedestrian signals with the pedestrian signals with countdown timers
- Modify signal phasing to a leading pedestrian interval
- Removing unwarranted signals on one-way streets
- Converting permissive left-turn signal timing to protected or protected/permissive
- Use of the pedestrian hybrid (HAWK) signal
- Installing traffic and pedestrian signals when warranted

Geometric treatments which were found to have a significant benefit to pedestrian crashes includes:

- Convert unsignalized intersection to a roundabout
- Install pedestrian underpass or overpass
- Install raised medians at unsignalized crossings
- Install a raised pedestrian crossing
- Install raised refuge islands
- Install sidewalks or paved shoulders
- Narrow the roadway cross-section from four lanes to three lanes (two through lanes with a center turn lane)

Sign, marking and operational improvements having beneficial crash effects (positive CMF's) include:

- Install intersection lighting
- Add roadway section lighting
- Improve pavement friction
- Increase enforcement
- Prohibit right-turn-on-red
- Prohibit left-turns
- Restrict parking near intersections Provide high-visibility crosswalks
- Provide high-visibility crosswalks in school zones

Review of Pedestrian Safety Literature Related to Roadway Measures

A detailed review of pedestrian safety research was developed in a February 2013 report for FHWA entitled: Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research (Draft Final Report) by Mead, Zegeer, and Bushell of the UNC Highway Safety Research Center. The report reviewed more than 100 research studies and articles which used rigorous research methods to quantify the safety and/or operational effects of a wide variety of roadway design, intersection design, traffic calming and other pedestrian roadway treatments which have been implemented, primarily from the U.S., Canada, Europe, and Australia. This review included not only studies which attempted to develop crash effects (i.e., Crash Modification Factors), but also studies which used such measures as pedestrian and motorist behaviors, pedestrian/motorist conflicts, vehicle speeds, and other measures.

Roadway and engineering treatments found to be associated with improved pedestrian safety include:

- Sidewalks, which are associated with a significant reduction in pedestrian crashes
- Marked crosswalks, which are associated with an increase in pedestrian crash risk when used alone (i.e., without other substantial measures) on multi-lane roads having vehicle ADT's of approximately 12,000 or more
- High-visibility crosswalks, which have a significant pedestrian safety benefit and CMF
- Flashing yellow beacons have been found to result in significant increases in motorist yielding to pedestrians and a reduction in motorist/pedestrian conflicts, as well as an improvement in pedestrian behavior

- In-pavement flashing lights have had very mixed results in terms of motorist and pedestrian behavior and interactions
- Zig-zag pavement markings were found in one study to result in lower vehicle speeds but were not well understood by drivers
- Curb extensions have not been evaluated in any known crash-based studies, but they were found in one study to be associated with decreased wait times to cross, decreased the number of vehicles that pass before yielding, and increased the distance that vehicles yield in advance of the crosswalk
- Crossing islands were found in several studies to be associated with reductions in pedestrian crashes, particularly on multi-lane roads. Also the "Danish offset" (i.e., where the median is designed for pedestrians to cross to the median and then walk to the right before crossing the second half of the street) resulted in a significant increase proportion of drivers who yielded to pedestrians and an increase in driver yield distance
- Raised pedestrian crossings were evaluated in one study and found to significantly reduce vehicle speeds, and significantly increase the percentage of pedestrians crossing in the crosswalk, while there was a small (non-significant) increase in driver yielding to pedestrians in the crosswalk
- Roadway lighting has been found at night to increase the percentage of motorists yielding to pedestrians and increase the percentage of pedestrians who use the crosswalk.
- Pedestrian overpasses significantly reduce pedestrian street-crossing crashes.
- Automated pedestrian detection has been found in one study to significantly reduce pedestrian/vehicle conflicts and reduce the percentage of pedestrians who began walking during the DON'T WALK interval. Another study found a significant reduction in the percentage of pedestrians who were trapped in the roadway.
- Leading pedestrian intervals have been found to decrease the number and severity of collisions, particularly at intersections with a heavy flow of turning vehicles. Another study found the LPI's to reduce the incidence of pedestrians having to yield to turning vehicles
- Lane reduction (i.e., road diets) has been found to reduce total vehicle crashes significantly based on several U.S. studies. Other studies have found pedestrian crashes to be lower for fewer numbers of lanes
- Modern roundabouts were found in one Swedish study to result in an increase in motorist yielding to pedestrians and a reduction in children running across the road, while two U.S. studies showed problems with motorists yielding to pedestrians in roundabouts, particularly while exiting the roundabout. Questions have been raised concerning how visually-impaired people would cross safely, particularly at multi-lane roundabouts, and one study recommended raised pedestrian crossings or use of a pedestrian hybrid beacon at splitter islands at multi-lane road roundabout crossings.
- Traffic calming measures (speed humps, speed tables, raised intersections, traffic mini-circles, and street narrowing, one-lane slow points, half street closures, diagonal diverters) have been found to slow vehicles speeds significantly
- Traffic (and pedestrian) signals have an unclear effect on pedestrian crashes and may depend on site conditions. There is some research from the U.S., Canada, and Australia that shows safety impacts (and conflicts analysis) of pedestrian countdown timers and also pedestrian signal phasing

- Advanced stop lines placed before the marked crosswalk in improve driver sight distance along with signing ("Stop here for Pedestrians") resulted in a significant decrease in vehicle/pedestrian conflicts and increased motorist yielding for pedestrians in several Canadian studies.
- Adding a separate left-turn signal phasing was found to significantly reduce the pedestrian crash rate based on a study in New York City
- Installing push buttons (and illuminated push buttons) have been found to increase the percent of pedestrians who wait for the WALK signal and decrease the number of pedestrians trapped in the intersection
- Accessible pedestrian signals have been found in several studies to improvements in the ability of pedestrians with visual impairments to accurately identify the direction of the crossing, reduce their delay in crossing the street, and an improvement in determining a safe time to cross the street
- Pedestrian hybrid beacon (HAWK signal) was found to significantly reduce pedestrian and motor vehicle crashes and also improved motorist yielding to pedestrians
- Rectangular Rapid Flashing Beacons (RRFB's) have been found to dramatically increase the proportion of motorists who yield to pedestrians, to reduce the percentage of pedestrians who are trapped in the roadway, and to reduce the number of conflicts between pedestrians and motorists
- Puffin crossing or Pedestrian User Friendly INtersection (as used in the U.K. and is a midblock crossing signal which may automatically provide more time for pedestrians to finish crossing the street if needed) has been studied in the U.K. and found to provide safety benefits to pedestrians
- In-street ("Yield or Stop for pedestrians) signing has been found to increase motorist yielding to pedestrians and to reduce vehicle speeds
- Other signing had unclear or mixed relationship to pedestrian safety. The advance yield line with the "Yield here for pedestrians was found to increase motorist yielding to pedestrians and decrease pedestrian/motorist conflicts. The florescent yellow-green pedestrian warnings sign was found to increase the number of cars that slowed or stopped for pedestrians, but there was no change in pedestrian/vehicle conflicts.
- Right turn on Red (RTOR) is an issues that may have an effect on pedestrian (and bicycle) safety at some locations, and various types of devices (e.g., illuminated NTOR signs, time restricted NTOR) have been evaluated with some increase in motorist compliance to the sign.
- School Zone "25 mph When Flashing" devices has been found to reduce average vehicle speeds significantly during flashing periods
- School Zone High-visibility crosswalks have been shown to significantly reduce collisions.
- Police enforcement programs to target motorist yielding to pedestrians was found to increase motorist yielding, a decrease in motorist violations.
-

Bicycle-Related Roadway and Engineering Features

Based on critical reviews of both crash- and observational-based studies, there are many different types of roadway treatments that can improve the safety for bicyclists. These treatments include signs, markings, traffic control, and delineation measures used at both intersections and roadway segments. The following is a list of bicycle treatments that have been shown to generally have a crash reduction for bicyclists.

Bicycle treatments on roadway segments:

- Bike lanes: Research evaluating the provision of dedicated bike lanes found a reduction in crashes after bike lanes were been installed. However, the research is less conclusive about the safety of bike lanes at intersections, where there may be little safety benefit. According to observational studies, when bike lanes are placed adjacent to parking lanes, bicyclists tend ride further from the parked cars than when no bike lane is provided.
- Wide curb lanes: The provision of wide curb/outside lanes greater than 4.0m appears to provide some safety benefit to bicyclists as found in observational studies.
- Paved highway shoulders: Studies have found that the expected number of bicycle-motor vehicle crashes is greatly reduced when cyclists ride on paved highway shoulders instead of sharing a lane with motorists.
- Bike paths: The provision of paths physically separated from the roadway results in lower bicycle crashes along the roadway segments. However, this design may result in an increase in intersection crashes.
- Traffic calming: In Germany and other countries, the use of traffic-calming techniques like these has increased bicycling, walking, and other kinds of street activity. In some cases, both fatal and injury crashes among all road users have been lowered as much as 60%.
- Lighting: Improved illumination has been found to reduce bicycle crashes.
- Access points: As the number of access points (i.e., signalized/unsignalized intersections and driveways) increases, so does the number of crashes.
- Drainage grates: Drainage grates may pose a crash risk to bicyclists, particularly when the grate runs parallel with the bicyclist's path.

Bicycle treatments at intersections

- Bike lanes at intersections: A Danish study noted that bike lanes increased the number of crashes at some busier intersections but that the total number of crashes along a corridor was reduced after the installation of bike lanes.
- Grade separation: Grade separation can effectively reduce the potential for conflicts between bicycles and motor vehicles at intersections.
- Raised, painted bicycle crossings: European studies have found great safety benefits to raised crossings for bicyclists at intersections.
- Colored bicycle crossings: Observational studies in the United States and Canada have found an increase in motorists yielding to bicyclists when color is used to designate bicycle path crossing points.
- Advanced stop line (ASL) or bike box: It appears that recessed/advanced stop lines increase cyclist safety at intersections, and the bike box may also be beneficial, although an ideal design and quantification of the safety effect are still being evaluated.
- The following variables have been found to increase the crash risk for bicyclists at intersections:
    - Higher traffic volumes
    - Higher speeds
    - Higher number of turning vehicles
    - Exclusive right-turn lanes

School Zone Roadway Variables

In 2005, the Pedestrian and Bicycle Information Center developed the Safe Routes to School National Course and a companion online guide. In 2006, the National Center for Safe Routes to School took over regular updates and promotion of both of these resources. For the past seven years the National Course has been taught all around the United States to increase local and state level capacity to determine safety issues that need to be addressed near schools to enable walking and bicycling to school. The course and online guide content include encouragement, education, law enforcement, evaluation and engineering strategies. Engineering countermeasures were identified and determined for inclusion based on input and engineering experience from an expert group of transportation professionals. The guiding principles for applying safe routes to school engineering solutions are:

- Identify and regulate the school zone.
- Provide and maintain bicycle and pedestrian facilities along the school route including sidewalks, on-street bicycle facilities, paths, curb ramps, and accessible pedestrian signals.
- Provide safe street crossings for bicyclists and pedestrians.
- Slow down traffic.

The countermeasures are:

- Color-coded curb striping to indicate where to unload and load students
- Pavement markings to guide traffic circulation through drop-off area
- Signage to instruct private vehicles on where to unload and load students
- Separation of modes arriving on-campus such as separated path or entrance for pedestrians versus bus riders
- Designated unloading/loading lane for private vehicles
- Temporary use of non-parking lot school grounds for unloading/loading students.
- Student safety patrol
- Queuing lane for private vehicles awaiting students on street
- Temporary street closures during student arrival/dismissal times
- Temporary one-way street designation during student arrival/dismissal times
- Adult crossing guards
- Active speed monitors (permanent sign that displays drivers' speeds)
- Photo enforcement
- School speed limit sign (identifies school zones speeds and when in effect)
- Overhead school flasher speed limit sign (flashes when school zone speed is in effect)
- Changeable message sign (allows school zone speed to be displayed when in effect)
- Portable speed feedback sign (displays speed of vehicles)
- School advance warning and crosswalk signs (notifies drivers of school and crosswalks)
- Pavement markings (enhances driver awareness near schools)
- Sidewalks
  - Presence of sidewalks
  - Buffers to separate sidewalk from traffic lanes
- Street lighting (improves pedestrian visibility and personal security)
- ADA / Universal Design
  - Presence of curb ramps provide access for wheelchairs, strollers and other wheel needs
  - Warning strips provide a tactile warning to pedestrians with a visual impairment
- Driveway design (The sidewalk continues across the driveway at the same elevation or 'level', and the driveway apron does not go through the sidewalk.)

- Separated multi-use paths are used to increase the connectivity of the pedestrian and bicycle network and separate the walker or cyclist from traffic.
- Increasing connectivity of streets, paths and sidewalks reduces travel distances and makes it easier for pedestrians and bicyclists to access destinations.

Crosswalks
- Marked Crosswalks at Uncontrolled Crossings
- High-Visibility Crosswalks
- In-Street Signs
- Overhead Signs and Flashing Beacons
- In-pavement Flashers
- Advance Stop/Yield Line
- Parking Restrictions

Traffic calming
- Narrow lanes
- Chokers and chicanes
- Speed humps
- Raised pedestrian crosswalks
- Neighborhood traffic circles
- Reduced corner radii
- Speed sensitive signals

Bike facilities
- Bike lanes that provide marked travel paths for bicycles
- Shared lane markings
- Shoulders that provide additional space for bicycles

Summary of Traffic and Roadway Features Having a Safety Relationship with Pedestrians and Bicyclists

The following series of tables summarize the findings from the review of pedestrian and bicycle roadway safety research. These tables identify whether the variable is currently collected in the iRAP model and whether the reported safety benefits of the variable come from crash-based or behavioral-based studies, or if there no current supporting research but there is an expected safety relationship.

General Pedestrian-Related Variables

Pedestrian and Vehicle Exposure and Operation

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Pedestrian volume	•		
Main road traffic volume (ADT)	•		
Side street traffic volume	•		

Vehicle speed	•		
Vehicle speed limit	•		

Pedestrian Facility Design

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Sidewalks and walkways	•		
ADA enhancements (e.g., curb ramps)			•
Marked crosswalks	•		
Crosswalk type (standard vs. high visibility)	•		
Zig-zag marking		•	
Transit stops present	•		
Roadway lighting	•		
Pedestrian overpass	•		
Pedestrian underpass	•		

Roadway Design

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Bicycle lane present			•
Roadway width		•	
Number of lanes	•		
Number of driveways by type			•
Raised medians	•		
One-way vs. 2-way street	•		
Right-turn slip lane			•
Driveway numbers and designs			•

Intersection Design

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Roundabouts	•		
Intersection median barrier			•
Intersection lighting	•		
Intersection turning radii			•

Traffic Calming

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Curb extensions (bulbouts)		•	
Chokers		•	
Crossing islands	•		
Chicanes			•
Mini-circles			•
Speed humps		•	
Speed tables		•	
Raised intersection		•	
Raised pedestrian crossing		•	

Traffic Management

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Diverter		•	
Full street closure		•	
Partial street closure		•	
Pedestrian mall			•

Signals and Signs

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Traffic signal	•		
Pedestrian signal (e.g., countdown timers)	•		
Pedestrian signal timing (Scramble, LPI)	•		
Right-turn-on-red prohibition	•		
Traffic signal phasing (left-turn signal)	•		
Pedestrian hybrid beacon	•		
Rectangular rapid flashing beacon		•	
Advance yield/stop lines		•	
Stop sign	•		
In-street warning signs		•	
Speed-sensitive traffic signals			•

Other Measures

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Speed-monitoring trailer			•
On-street parking		•	
In-pavement flashing lights	•		
Flashing beacons		•	
Police enforcement	•		
Area type (commercial vs. other)	•		
Photo enforcement	•		

General Bicycle-Related Variables

Bicycle and Vehicle Exposure and Operations

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Bicycle volume	•		
Traffic volume on the main street	•		
Traffic volume on the side street	•		
Number of turning vehicles	•		
Speed limit			•
Vehicle speeds			•

Shared Roadway

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Roadway surface improvements	•		
Bridge and overpasses		•	
Tunnels and underpasses		•	
Overhead lighting	•		
On-street parking	•		
Parking restriction		•	
Median/crossing island	•		
Number and type of driveways	•		
Number of through lanes	•		
Lane width	•		
Number of right-turn lanes	•		
Shared lane markings		•	

On-Road Bike Facilities

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship

Bike lane present	•		
Curb lane width		•	
Presence of paved shoulders	•		
Shared lanes		•	
Contra-flow bike lanes		•	
ADA enhancements (e.g., curb ramps)			•

Intersection Treatments

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Bike lanes at intersection	•		
Curb radius			•
Roundabouts	•		
Intersection Markings			•
Turning restrictions			•
Merge and weave area design	•		
Colored bicycle crossings		•	
Advance stop lines (bike boxes)		•	

Traffic Calming

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Mini traffic circles	•		
Chicanes		•	
Speed tables/humps/cushions		•	
Street width	•		
Traffic diversion	•		
Raised intersection	•		

Trails/Shared Use Paths

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Separate shared-use path	•		
Path intersection treatments			•
Intersection warning treatments			•
Shared path treatments		•	

Markings, Signs, and Signals

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Traffic signals		•	
Bike-activated signal			•
Pavement markings			•
School-zone markings			•

Support Facilities and Programs

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Bike parking			•

Specific School- Related Variables

Roadway and geometric improvements

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Sidewalks and walkways	•		
Buffer between sidewalk and travel lanes			•
Signs and Markings			•
School zone pavement markings			•
School zone signing			•
School zone high-visibility crosswalks	•		
Regulatory school zone signs with flashers		•	
Number and type of driveways			•
Separated multi-lane paths			•
Connected street network			•

Loading/Unloading traffic control

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Color-coded striping to indicate child loading/unloading			•
Signing or pavement marking for drop off circulation			•
Queuing lane for private vehicles			•

Enforcement measures

Variable	Crash related	Related to behavioral or speed measures	Expected safety relationship
Police enforcement	•		
Speed feedback signs			•
Photo enforcement		•	
Adult crossing guard		•	
Student safety patrol			•