A Review of Evidence-Based Traffic Engineering Measures Designed to Reduce Pedestrian–Motor Vehicle Crashes

We provide a brief critical review and assessment of engineering modifications to the built environment that can reduce the risk of pedestrian injuries.

In our review, we used the Transportation Research Information Services database to conduct a search for studies on engineering countermeasures documented in the scientific literature. We classified countermeasures into 3 categories—speed control, separation of pedestrians from vehicles, and measures that increase the visibility and conspicuity of pedestrians. We determined the measures and settings with the greatest potential for crash prevention.

Our review, which emphasized inclusion of studies with adequate methodological designs, showed that modification of the built environment can substantially reduce the risk of pedestrian–vehicle crashes. (*Am J Public Health.* 2003;93:1456–1463)

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DESPITE DECLINING RATES OF pedestrian fatalities (most notably declines among children and older adults), pedestrian crash injuries remain a serious public health problem. It is estimated that, each year, 80 000 to 120 000 pedestrians are injured and 4600 to 4900 die in motor vehicle crashes in the United States.[1,2] Pedestrians account for 11% of all motor vehicle deaths, and in cities with populations exceeding 1 million, they account for about 35%.[3] Children aged 5 to 9 years have the highest population-based injury rate, and people older than 80 years have the highest population-based fatality rate.[1] Pedestrians older than 65 years are more likely than younger pedestrians to be struck at intersections.[3,4] The prevalence of alcohol use among injured pedestrians is well documented.[5–7]

In terms of constructing a framework for prevention of pedestrian injuries, primary approaches include modification of the built environment, enforcement of traffic safety laws, motor vehicle design changes, and pedestrian education. Modification of car fronts and other vehicle features to reduce the severity of injuries to pedestrians is a focus in Europe, where approximately 20% of all fatalities among road users involve pedestrians and cyclists[8]; however, this approach has not been a priority in the United States despite research showing potential benefits.[9]

Pedestrian education is a popular approach, but with the exception of children, there is a lack of evidence regarding the effectiveness of safety education.[10–12] Modification of the built environment is a widely used approach that can be highly effective. In this article, we provide a brief review of engineering modifications to the built environment that can reduce the risk and severity of pedestrian injuries.

TRAFFIC ENGINEERING COUNTERMEASURES

Pedestrians have been largely ignored or given minimal consideration in the design of much of the nation's roadway system. When the built environment assigns low priority to pedestrians, it can be difficult for vehicles and pedestrians to share the road safely. Modifications to the built environment can reduce the risk and severity of vehicle–pedestrian crashes. Engineering modifications generally can be classified into 3 broad categories: separation of pedestrians from vehicles by time or space, measures that increase the visibility and conspicuity of pedestrians, and reductions in vehicle speeds.

Separation countermeasures reduce the exposure of pedestrians to potential harm both on the roadside and when they are crossing streets. Because in many pedestrian crashes the driver reportedly does not see the pedestrian before the accident, measures are needed to increase the visibility and conspicuity of pedestrians. Higher vehicle speeds are strongly associated with a greater likelihood of crashes involving pedestrians as well as more serious pedestrian injuries.[13–15]

We undertook a thorough review of traffic engineering countermeasures documented in the scientific literature as effective in reducing the risk of crashes involving pedestrians. The primary search engine used was the National Academy of Sciences' Transportation Research Information Services (TRIS) database. TRIS is the world's largest and most comprehensive bibliographic resource on transportation information. Keywords were *pedestrians* along with *injuries*, *safety*, *reduction*, *countermeasures*, and *crosswalks*. In terms of study types, we included before–after, case–control, and cross-sectional studies of the effects of speed reduction, separation, or visibility enhancement measures on the occurrence of pedestrian–vehicle collisions or conflicts.

Many studies of traffic engineering measures are limited by methodological flaws such as failure to account for regression to the mean associated with treatment of high-crash locations and reliance on simple before–after measurements without suitable controls. To the extent possible, we included in our review studies based on adequate scientific criteria, such as use of comparison sites to control for confounding factors. In the case of several promising countermeasures, only limited evaluations with somewhat less reliable methodologies were available.

A common weakness in many crash-based before-and-after evaluations of traffic engineering countermeasures is failure to account for regression to the mean, which can result in overestimation of the effects of an intervention when treatment sites are selected because they have involved high numbers of crashes. Selection of comparison sites with similar characteristics can partially, but not fully, address regression to the mean. We included in our review several studies with methodological weaknesses; in these cases, we make note of their limitations.

Some researchers conducting observational road safety studies evaluate pedestrian–motor vehicle conflicts in lieu of crash data to evaluate roadway countermeasures, in part because crashes are rare events and because conflict studies provide information about potential crash causes. Conflicts generally are defined as "near-miss" situations in which a vehicle had to abruptly brake or swerve to avoid striking a pedestrian or a pedestrian had to take sudden evasive action to avoid being struck. The validity of using conflicts to estimate crashes was examined by Hauer and Garder[16] and Garder.[17] Hauer and Garder formulated and tested statistical methods to measure the validity of traffic conflicts on the basis of empirical evidence. According to Garder, it can be shown that a 1-day conflict count provides a more accurate estimate of the expected number of crashes than a 1-year crash history if the expected number of crashes is less than 5 per year. In conflict studies and other short-term before–after evaluations of road user behavior, regression to the mean associated with treatment of high-crash locations is not a factor.

Managing Vehicle Speeds

Principal engineering measures designed to reduce vehicle speeds are summarized in Table 1. In residential settings with large numbers of children, speed management appears to offer the greatest potential for injury prevention. Pedestrian crashes involving a child most often result from the child's error. Slower speeds give motorists more time to react and can lessen injuries when crashes do occur. Slower speeds are desirable in areas with pedestrians because many young children fail to stop before proceeding from the curb onto the road[24]; Kraus et al.[25] reported that 69% of child pedestrian injuries occur midblock, when children dart into the street. Young children have difficulty judging vehicle distance and velocity[26] and lack the relevant cognitive skills required to make valid and consistent crossing judgments.[27]

In terms of crash reduction, installation of modern roundabouts in place of conventional intersections was the most effective speed control intervention identified. Roundabouts are circular intersections defined by 2 operational and design principles: yield at entry, which requires entering traffic to yield the right of way to vehicles in the circle, and deflection of entering traffic, which causes vehicles to enter at low speed. European studies indicate that, on average, converting conventional intersections to roundabouts can reduce the rate of pedestrian crashes by about 75%.[18,19] Single-lane roundabouts, in particular, have been reported to involve substantially lower pedestrian crash rates than comparable intersections with traffic signals.[20]

Other speed management measures include traffic calming and multiway stop sign control. Traffic calming techniques include lane narrowing, adjustments in roadway curvature, pedestrian refuge islands, and speed humps. Although traffic calming measures clearly are effective in reducing traffic speeds (e.g., see Smith and Appleyard[28]), effects on pedestrian–vehicle crashes are less certain. One study of "extensive" area-wide traffic calming measures, involving a before–after design without controls, reported that pedestrian–vehicle crashes decreased 25% after implementation of these measures.[21] However, a recent review of 13 controlled before–after studies of area-wide traffic calming reported no overall effect on pedestrian–vehicle crashes.[22] An investigation focusing on multiway stop sign control, which produces low vehicle speeds near intersections relative to traffic signal control or conventional 2-way stop signs, showed that pedestrian collisions decreased by 25% when multiway stop signs were installed in place of traffic signals at low-traffic-volume urban intersections.[23]

Separating Pedestrians and Vehicles

Engineering measures intended to separate pedestrians and vehicles by *time* are summarized in Table 2. These interventions have generally been evaluated in terms of their effects on road user behavior and pedestrian–vehicle conflicts rather than crashes, and their use is somewhat site dependent. One study reported that installation of traffic signals substantially reduced conflicts occurring at high-speed intersections where previously no signals were present and pedestrians had difficulty crossing.[30] At intersections with traffic signals, exclusive traffic signal phasings—which stop all vehicle traffic for part or all of the pedestrian crossing signal—have been shown to significantly reduce conflicts.[30,31] A comparative analysis of intersections with and without exclusive pedestrian

TABLE 1—Studies Evaluating Engineering Measures Designed to Manage Vehicle Speeds

Intervention	Study and Country	Outcome Measures	Study Design	Results
Modern roundabouts	Brilon et al., Germany[18]	Pedestrian–vehicle crashes	Before-and-after with data on traffic volume before and after; 25 intersections converted from traffic signals or stop signs to modern roundabouts; no attempt to correct findings for possible regression-to-mean effects	On average, pedestrian crashes decreased 75%
	Schoon and van Minnen, the Netherlands[19]	Pedestrian–vehicle crashes	Before-and-after without control; 181 intersections converted from traffic signals or stop signs to modern roundabouts; no attempt to correct findings for possible regression-to-mean effects	On average, pedestrian–vehicle crashes decreased 73%
	Brude and Larsson, Sweden[20]	Pedestrian–vehicle crashes	Observed minus expected: empirical data for 72 roundabouts as compared with expected values for comparable intersections with signals, controlling for pedestrian volumes and traffic flow; multiple linear regression used to predict crashes for comparison data	For single-lane roundabouts, the observed number of pedestrian crashes was 3–4 times lower than predicted for comparable intersections with signals; for 2-lane roundabouts, pedestrian crash risk was comparable to signalized intersections
Traffic calming	Brilon and Blanke, Germany[21]	Pedestrian–vehicle crashes	Before-and-after without control; "extensive" area-wide traffic calming measures implemented in 6 towns	On average, pedestrian–vehicle crashes decreased 25% after treatment
	Bunn et al., Australia, Germany, United Kingdom[22]	Pedestrian–vehicle crashes	Systematic review of 13 controlled before–after studies of area-wide traffic calming with pedestrian–vehicle crash data	Pooled rate ratio was 1.00, indicating no effect on pedestrian–vehicle crashes
Multiway stop-sign control	Persaud et al. United States[23]	Pedestrian–vehicle crashes	Before-and-after using empirical Bayesian procedure; 199 low-traffic-volume urban intersections converted from traffic signals to multiway stop-sign control	Pedestrian–vehicle crashes decreased by approximately 25%

signal phasings reported that the risk of pedestrian–vehicle crashes at intersections with exclusive timing was approximately half that at intersections with standard pedestrian signals.[29]

Adequately timed yellow and all-red clearance signals are necessary at traffic signals to ensure that drivers have sufficient time to clear the intersection before the display of pedestrian walk signals. One study showed that combined changes in the duration of yellow and all-red signal timing reduced the risk of pedestrian and bicycle crashes at intersections by 37% relative to control sites.[32] Automatic pedestrian detection, which can be used at traffic signals in lieu of pedestrian push buttons to automatically detect pedestrians and display a walk signal, has been reported to significantly reduce conflicts.[34] This technology also can extend crossing time to allow slower pedestrians to finish crossing. At intersections with traffic signals and high concentrations of elderly pedestrians, a walking speed of 1.0 m/second is recommended.[37]

Also, traffic signs and pavement markings that encourage pedestrians to look for potential conflicts have been shown to be effective at intersections with traffic signals.[33] In addition, 2 studies showed that vehicle speeds and conflicts at uncontrolled crossings were reduced by in-pavement flashing lights that were automatically activated by the presence of pedestrians and were intended to prompt drivers to yield to pedestrians.[35,36]

Engineering measures designed to separate pedestrians and vehicles by *space* are summarized in Table 3. Several highly effective interventions were identified. Overpasses and underpasses can substantially reduce conflicts and associated pedestrian crashes.[38] However, the high cost of such facilities requires that they be installed on a very limited basis—for example, at very wide crossings and at those with high traffic speeds. Safety effects may be limited in instances in which pedestrians are reluctant to use such facilities because of security concerns or inconvenient access points. Sidewalks can reduce the risk of pedestrian crashes in residential areas.[42]

Refuge islands located in the medians of 2-way streets allow pedestrians to cross in 2 stages, simplifying the crossing task. This is especially helpful for pedestrians who walk at slower speeds. Refuge islands decrease conflicts,[30] and there are significantly lower pedestrian crash rates on multilane roads with raised medians than on those without such medians.[43] Curb extensions (extension of the sidewalk toward the roadway in the vicinity of the crosswalk, about the width of a parked vehicle) also can be used to reduce crossing distance.

Barriers and fences, which are designed to channel pedestrians

TABLE 2—Studies Evaluating Engineering Measures Designed to Separate Pedestrians and Vehicles by Time

Intervention	Study and Country	Outcome Measures	Study Design	Results
Exclusive pedestrian signal phase	Zeegeer et al., United States[29]	Pedestrian–vehicle crashes	Comparative analysis approach including analysis of variance and covariance using data from 1297 intersections with signals in 15 cities; control for number of lanes, type of traffic signal, signal timing, speed limits, traffic volume, pedestrian exposure, and other variables	Risk of pedestrian–vehicle crashes for intersections with exclusive timing was approximately half that of intersections with standard pedestrian signals
	Garder, Sweden[30]	Pedestrian–vehicle conflicts	Before-and-after without controls; 3 urban intersections	At one intersection in a small town, conflicts decreased 24%; in Stockholm, at one intersection conflicts decreased 10% but did not significantly decline at a second intersection
Early release signal timing, also known as leading pedestrian interval (LPI)	Van Houten et al., United States[31]	Pedestrian–vehicle conflicts; pedestrians yielding to turning vehicles; distance traversed by lead pedestrian	Multiple-baseline design; 3 urban intersections	For pedestrians leaving the curb during the begin walk period, odds of conflict with turning vehicles were reduced by 95%; odds of pedestrians yielding to turning vehicles were reduced by 60%; mean distance traversed by the lead pedestrian during the LPI was 8.5 ft
Installation of traffic signal	Garder, Sweden[30]	Pedestrian–vehicle conflicts	Multiple linear regression model using data from 115 urban intersections; variables included type of traffic control, street width, existence of refuge island, traffic speeds, and exposure	Installation of traffic signal at a high-speed (mean speed > 30 km/h) intersection reduced the risk of pedestrian–vehicle conflicts by roughly half
Traffic signal change interval timing	Retting et al., United States[32]	Pedestrian/bicycle–vehicle crashes	Randomized before-and-after with controls; 40 experimental urban intersections and 51 controls	During 3 years after study period, there was a 37% reduction in pedestrian and bicycle crashes relative to controls
Pedestrian prompting devices	Retting et al., United States and Canada[33]	Pedestrians looking for potential vehicle threats; pedestrian–vehicle conflicts	Multiple-baseline design; 3 urban intersections	One year after treatment, percentage of pedestrians looking for potential vehicle threats doubled at 2 sites and tripled at 1 site; pedestrian–vehicle conflicts per 100 pedestrians declined at all 3 sites, from approximately 2.8 to < 1
Automatic pedestrian detection for display of walk signal	Hughes et al., United States[34]	Pedestrians who began to cross during the "don't walk" signal; pedestrian–vehicle conflicts	Before-and-after without controls; 4 urban intersections (conflicts were not studied at 1 site owing to visual limitations)	At 4 sites, reductions in the percentage of pedestrians who began to cross during the "don't walk" signal ranged from 52% to 88%; at 3 sites, reductions in the percentage of pedestrian–vehicle conflicts ranged from 40% to 90%
In-pavement flashing lights to warn drivers when pedestrians are present	Hakkert et al., Israel[35]	Vehicle speeds; drivers yielding to pedestrians; vehicle–pedestrian conflicts	Before-and-after without controls; 4 urban uncontrolled pedestrian crossings	Although changes were not uniform, overall effects were positive; vehicle speeds near crosswalks decreased slightly at 2 sites (2–5 kph); at 3 sites, the rate of drivers yielding to pedestrians doubled; across all sites, rate of conflicts decreased to less than 1% from 1% to 17%
	Prevedouros, United States[36]	Vehicle speeds, percentage of drivers who slowed or stopped; percentage of drivers not yielding to pedestrians in crosswalk	Before-and-after without controls; 1 urban uncontrolled pedestrian crossing	Average vehicle speeds declined 25% when in-pavement lights were activated; percentage of drivers who slowed or stopped for pedestrians increased from 30% to 62%; percentage of drivers not yielding to pedestrians declined from 31% to 8%

TABLE 3—Studies Evaluating Engineering Measures Designed to Separate Pedestrians and Vehicles by Space

Intervention	Study and Country	Outcome Measures	Study Design	Results
Pedestrian overpasses	Japan Road Association, Japan[38]	Pedestrian–vehicle crashes	Before-and-after without control; 31 pedestrian overpasses in urban areas; data limited to 6 months before and 6 months after intervention; no attempt to correct findings for possible regression-to-mean effects	Number of pedestrian–vehicle crashes decreased 91% within 100 m of the structures and 85% within 200 m; crashes unrelated to pedestrians crossing the road increased 14% within 100 m of the structures and 23% within 200 m
Advance stop lines	Berger, United States[39]	Distance of stopped vehicles from crosswalk	Before-and-after with control; stop lines were relocated 12 ft back from the standard 3–4-ft distance at 2 urban intersections with signals	Distance of stopped vehicles from the crosswalks increased by approximately 6 ft at one site and 7 ft at the other site (percentage change could not be readily computed from available documentation)
	Retting and Van Houten, United States[40]	Driver compliance with stop lines; percentage of drivers stopping at least 4 ft back from crosswalks; drivers stopping in crosswalks	Before-and-after without control; stop lines were relocated 20 ft back from the standard 4-ft distance at 4 urban intersections with signals	Overall, approximately 57% of drivers complied with advance stop lines; percentage of drivers who stopped at least 4 ft back from the crosswalks increased from 74% to 92%; percentage of drivers who stopped within crosswalks during any portion of the “walk” and pedestrian clearance phases declined from 25% to 7%
Pedestrian barriers and fences	Berger, United States[39]	Pedestrians crossing midblock	Before-and-after with control; 2 urban arterial streets with high traffic volumes in close proximity to elementary schools	In both cities, significant decreases were observed in number of pedestrians crossing midblock and entering roadway in front of parked vehicles (percentage change could not be readily computed from available documentation)
	Stewart, England[41]	Pedestrian–vehicle crashes	Before-and-after without control; unknown number of locations; no attempt to correct findings for possible regression-to-mean effects	Ordinary fences, which obscure the driver’s view of pedestrians, were associated with 20% reduction in pedestrian crashes, whereas fences that obstructed the motorist’s view to a lesser extent led to a 48% crash reduction; children (because of their short stature) especially benefited from fences that obstructed motorist’s view to a lesser extent
Sidewalks	Knoblauch et al., United States[42]	Pedestrian–vehicle crashes	Cross-sectional study of urban streets with and without sidewalks; data from 495 locations in 5 cities (16 hours of exposure data collected at each site); variables included land use, pedestrian–vehicle crashes, and exposure measures	In residential and mixed residential areas, pedestrian crashes were more than 2 times as likely to occur at locations without sidewalks than would be expected on the basis of exposure; residential areas with no sidewalks had 23% of all pedestrian–vehicle crashes and only 3% of exposures; commercial areas with no sidewalks were only slightly more hazardous than commercial areas with sidewalks
Refuge islands	Garder, Sweden[30]	Pedestrian–vehicle conflicts	Multiple linear regression; data from 115 urban intersections; variables included type of traffic control, street width, existence of refuge island, and exposure	Risk of pedestrian–vehicle conflicts decreased by roughly two thirds
	Zegeer et al., United States[43]	Pedestrian–vehicle crashes	Cross-sectional study: Poisson and negative binomial regression models fitted to crash data at 1000 marked crosswalk sites and 1000 matched unmarked comparison sites; controlled for traffic volume, pedestrian exposure, number of lanes, type of median, and other variables	On roads with > 2 lanes and > 15 000 vehicles per day, pedestrian crash rate (per million crossings) at marked crossings with raised medians was approximately half that of locations without raised medians; crash rate at unmarked crossings with raised medians was approximately 60% that of unmarked crossings without raised medians

to safe crossing areas and prevent them from running into traffic, have been found to reduce midblock crossings[39] and substantially decrease crash rates.[41] An inexpensive intervention at signal-controlled intersections involves repositioning of stop lines further back from crosswalks. This results in drivers stopping further back from crosswalks, thus increasing the separation between pedestrians and vehicles.[39,40]

Increasing Pedestrian Visibility

Engineering measures designed to increase the visibility and conspicuity of pedestrians are summarized in Table 4. Increased intensity of roadway lighting can increase pedestrians' visibility at night, when more than half of all fatal pedestrian crashes occur.[1] Increased intensity of roadway lighting at pedestrian crossings has been associated with significant reductions in nighttime pedestrian crashes.[44,45]

Because parked vehicles obscure the vision of pedestrians and drivers, parking restrictions can be effective. In a case–control study of child pedestrian injuries, the number of parked vehicles was the strongest risk factor on residential streets.[47] Examples of parking restrictions include removal of on-street parking and implementation of diagonal parking, which requires that vehicles park at an

TABLE 4—Studies Evaluating Engineering Measures Designed to Increase Visibility and Conspicuity of Pedestrians

Intervention	Study and Country	Outcome Measures	Study Design	Results
Increased intensity of roadway lighting	Pegrum, Australia[44]	Nighttime pedestrian–vehicle crashes	Before-and-after at 57 urban crosswalks; daytime crashes were used as controls for nighttime crashes; 2 years before and after; no attempt to correct findings for possible regression-to-mean effects	Number of nighttime pedestrian crashes decreased 59%; daytime pedestrian crashes and vehicle-only crashes remained relatively unchanged
Increased intensity of roadway lighting and installation of internally illuminated warning signs	Polus and Katz, Israel[45]	Nighttime pedestrian–vehicle crashes	Before-and-after with control; 99 urban crosswalks; 39 control sites; daytime crashes also used as controls; 2.5 years before and after; no attempt to correct findings for possible regression-to-mean effects	Number of nighttime pedestrian crashes at the experimental sites decreased 57%, and there was a nonsignificant 21% decrease in daytime pedestrian crashes; at the comparison sites, there was a nonsignificant 60% increase in nighttime pedestrian crashes
Bus stop relocation	Berger, United States[39]	Pedestrians entering roadway in front of stopped bus	Before-and-after with control; 1 bus stop was relocated from the near side to the far side of a traffic-signal-controlled intersection on a 2-way 5-lane urban arterial (the intervention was tested in a second city but with very small samples)	Significant decrease was observed in percentage of pedestrians entering roadway in front of a stopped bus (percentage change could not be readily computed from available documentation)
Diagonal parking	Berger, United States[39]	Pedestrians entering roadway in front of parked vehicle; pedestrians who scanned for traffic before entering roadway	Before-and-after without control; diagonal parking replaced parallel parking on a 34-ft-wide 1-way, 2-lane urban street (the intervention was tested in a second city but with very small samples)	Number of pedestrians entering roadway in front of a parked vehicle significantly decreased, and percentage of pedestrians who scanned for traffic before entering the roadway significantly increased; vehicle speeds significantly decreased by 5 mph (percentage change could not be readily computed from available documentation)
Crosswalk markings	Zegeer et al., United States[43]	Pedestrian–vehicle crashes	Cross-sectional study: treatment and matched comparison; regression models fitted to crash data at 1000 marked crosswalk sites and 1000 matched unmarked comparison sites	On 2-lane roads, marked crosswalk was associated with no difference in pedestrian crash rate; on wider roads with traffic volumes > 12 000 vehicles per day, marked crosswalks were associated with higher pedestrian crash rates
	Koepsell et al., United States[46]	Pedestrian–vehicle crashes	Case–control study of crashes involving older pedestrians (> 65 years) in 6 cities; 282 case sites and 564 control sites; adjusted for pedestrian flow, traffic volume, crossing length, and signalization	Crash risk was 2.1 times greater at sites with a marked crosswalk; almost all of the excess risk was due to 3.6-fold higher risk associated with marked crosswalks at sites with no traffic signal or stop sign

angle to the curb (typically about 30 degrees) in the direction of traffic flow. Diagonal parking directs pedestrians into the roadway at such an angle that looking in the direction of traffic is universal. Diagonal parking as a replacement for parallel parking has been shown to reduce the number of pedestrians entering the roadway in front of a parked vehicle.[39]

In addition, relocating bus stops from the near side to the far side of intersections can increase the visibility and conspicuity of pedestrians by decreasing the number of pedestrians who enter the roadway in front of a stopped bus. It has been shown that bus stop relocation significantly decreases the percentage of pedestrians who enter the roadway in front of a stopped bus at signal-controlled intersections.[39] Crosswalk pavement markings are widely used with the intent of reducing pedestrian crashes, but research indicates that they are largely ineffective and, in some settings, may be harmful.[43,46]

DISCUSSION

Pedestrian crashes are complex events that vary widely in terms of the age of the pedestrians involved and associated crash circumstances. According to our review of available studies, emphasizing those with adequate methodological designs, modification of the built environment can substantially reduce the risk of pedestrian–vehicle crashes. Given the scarcity of resources generally available for road engineering and the very large number of roads, priority must be given to the specific countermeasures and settings with the greatest potential for crash prevention.

Highly effective countermeasures include single-lane roundabouts, sidewalks, exclusive pedestrian signal phasing, pedestrian refuge islands, and increased intensity of roadway lighting. Other countermeasures, including advance stop lines, in-pavement flashing lights, and automatic pedestrian detection at walk signals, are promising but have been evaluated on a more limited basis. In the case of many traffic engineering measures, more definitive research is needed to establish their effects on pedestrian–vehicle crash risks. ■

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