A Review of Pedestrian Safety Research in the United States and Abroad

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Research, Development, and Technology
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Pedestrian and Bicycle Safety

FOREWORD

The overall goal of the Federal Highway Administration's (FHWA) Pedestrian and Bicycle Safety Research Program is to increase pedestrian and bicycle safety and mobility. From better crosswalks, sidewalks, and pedestrian technologies to expanded public educational and safety programs, the FHWA's Pedestrian and Bicycle Safety Research Program aims to pave the way for a more walkable future.

The following document summarizes research on pedestrian safety in the United States with a focus on crash characteristics and the safety effects of various roadway features and traffic-control devices; it also considers pedestrian educational and enforcement programs. This pedestrian safety synthesis was part of a large FHWA study ("Evaluation of Pedestrian Facilities") that has generated several other documents on the safety of pedestrian crossings and the effects of innovative engineering treatments on pedestrian safety. These other reports on pedestrian safety likely will interest readers.

The results of this research will be useful to transportation researchers, engineers, planners, and safety professionals involved in improving pedestrian safety and mobility.

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NOTICE

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16. Abstract

The purpose of this report is to provide an overview of research studies on pedestrian safety in the United States; some foreign research also is included. Readers will find details of pedestrian crash characteristics, measures of pedestrian exposure and hazard, and specific roadway features and their effects on pedestrian safety. Such features include crosswalks and alternative crossing treatments, signalization, signing, pedestrian refuge islands, provisions for pedestrians with disabilities, bus stop location, school crossing measures, reflectorization and conspicuity, grade-separated crossings, traffic-calming measures, and sidewalks and paths. Pedestrian educational and enforcement programs also are discussed.

This report is an update resulting from two earlier reports. The most recent was *Synthesis of Safety Research: Pedestrians*, by C.V. Zegeer (FHWA-SA-91-034, Aug. 1991). The earlier work was Chapter 16, "Pedestrian Ways" by R.C. Pfefer, A. Sorton, J. Fegan, and M.J. Rosenbaum, which was published by the Federal Highway Administration (FHWA) in *Synthesis of Safety Research Related to Traffic Control and Roadway Elements* (from Volume 2, Dec. 1982). This updated report includes results from numerous studies, foreign and domestic. A review of pedestrian safety research from Australia, Canada, the Netherlands, Sweden, and the United Kingdom is given at: www.walkinginfo.org/rd/international.htm.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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PART 1. INTRODUCTION

Walking, the most traditional mode of transportation, can carry a high risk of injury or death on many of our Nation's streets and highways. Motor vehicles only have been around for about a century, but during that comparatively short time, they often have made walking hazardous.

Emphasis on highway transportation historically has focused on increasing the safety and mobility of motor vehicles; less attention has been given to pedestrians. The trend has begun to shift in recent years. Several detailed studies have been conducted on various aspects of pedestrian safety. These studies have attempted to quantify the magnitude and characteristics of pedestrian collisions and identify the traffic and roadway characteristics associated with such crashes. Some research has also involved attempts to evaluate the safety effects of various roadway and educational treatments. (Editor's note: The terms "accident", "collision", and "crash" are used throughout this report. Some authors use one term and some another. All of these terms should be assumed to mean a crash between a pedestrian and a motor vehicle.)

Figure 1. Pedestrians include a wide range of ages and physical abilities.

The purpose of this report is to provide an overview of research studies on pedestrian safety, including details of pedestrian crash characteristics, measures of pedestrian exposure and hazard, and specific roadway improvements and their effects on pedestrian safety. Pedestrian educational considerations and enforcement programs also are discussed. Because this report is confined to a review of safety research, it follows that other important topics are left out. Thus, we do not address matters of facility design, finance, pedestrian comfort, convenience, factors affecting the amount of walking by pedestrians, and other salient issues.

This report is an update resulting from two earlier reports. The most recent was *Synthesis of Safety Research: Pedestrians*, by C.V. Zegeer (FHWA-SA-91-034, August 1991). Before that was Chapter 16, "Pedestrian Ways," by R.C. Pfefer, A. Sorton, J. Fegan, and M.J. Rosenbaum, which was published by the Federal Highway Administration (FHWA) in *Synthesis of Safety Research Related to Traffic Control and Roadway Elements (*Volume 2, December 1982). This updated report includes results from numerous foreign and domestic studies. A review of pedestrian safety research from Australia, Canada, the Netherlands, Sweden, and the United Kingdom is given at: www.walkinginfo.org/rd/international.htm.

Organization of this Report

This report consists of five parts. Part 1 is an executive summary followed by introductory text. Part 2 deals with statistics regarding traffic collisions and injuries to pedestrians. Part 3 reviews published research on the effectiveness of facilities and other measures adopted for increased pedestrian safety. Most research cited was carried out in the United States; many studies are recent, but some date back to the 1960s. Some older studies now may be less valid. There is also a series of reviews of pedestrian safety research in several foreign countries, authored by research professionals in Australia, Canada, United Kingdom, the Netherlands, and Sweden. These may be found at www.walkinginfo.org/rd/international.htm.

Summary of Main Findings

- In terms of marked vs. unmarked crosswalks at uncontrolled intersections (i.e., no stop sign or traffic signal on the approach roadway) on a two-lane road, the presence of a marked crosswalk alone is associated with no difference in pedestrian crash rate compared to an unmarked crosswalk. On multilane roads with traffic volumes above 12,000 vehicles per day, having a marked crosswalk alone (without other substantial improvements) is associated with a higher pedestrian crash rate (after controlling for other site factors) compared to an unmarked crosswalk. More substantial improvements are recommended to provide for safer pedestrian crossings at such pedestrian crossings, such as adding traffic signals (with pedestrian signals) when warranted, providing raised medians, installing speed-reducing measures, and/or others.

- Providing raised medians on multilane roads can substantially reduce pedestrian crash risk (and can also make it easier to cross the street).

- There is evidence that substantially improved nighttime lighting can enhance pedestrian safety in certain situations.

- At intersections with traffic signals, adding a WALK/DON'T WALK signal with a standard timing scheme (i.e., motorists move parallel to pedestrians and may turn right or left on a green light across pedestrians' path) has no significant effect on pedestrian crashes. Providing an exclusive pedestrian interval (i.e., motorists are stopped in all directions during the same interval each cycle while pedestrians cross in any direction) reduces pedestrian collisions by 50 percent. However, exclusive timing schemes can increase pedestrian and motorist delay and are most appropriate at downtown intersections with a combination of heavy pedestrian volumes, good pedestrian compliance, and low vehicle volumes.

- Allowing vehicles to make a right-turn-on-red (RTOR) maneuver appears to result in a small but clear safety problem for pedestrians. In fact, 21 percent of motorists violate NO TURN ON RED (NTOR) signs if given the opportunity, and 23 percent of RTOR violations result in a conflict with a pedestrian. Countermeasures that have been effective in reducing pedestrian risks related to RTOR include illuminated NTOR signs, offset stop bars at intersections where RTOR is allowed (i.e., motorists are more likely to make a full stop often), variations in NTOR signs, and others.

- Various pedestrian and motorist warning signs have been found to reduce vehicle speeds or conflicts between pedestrians and motorists. These devices include the "strong yellow green" pedestrian warning sign, YIELD TO PEDESTRIANS WHEN TURNING sign, PEDESTRIANS WATCH FOR TURNING VEHICLES sign, three-section WALK WITH

CARE signal head, a DON'T START display to replace the flashing DON'T WALK display, and others.

- Curb medians provide a safer environment for pedestrians compared with two-way, left-turn lanes (TWLTLs), while undivided highways have the highest crash risk for pedestrians in TWLTLs setings.

- Numerous treatments exist to address the needs of pedestrians with disabilities, such as textured pavements, audible and vibrating pedestrian signals, larger signs and pedestrian signals, wheelchair ramps, and others. While formal safety studies are difficult to conduct on such treatments, benefits may result from such devices, depending on site conditions and pedestrian needs.

- Careful placement of bus stops can affect pedestrian safety. Use of bus stops on the far side of an intersection and at locations with good sight distance and alignment (e.g., not on steep grades or on horizontal curves) is important.

- Safety of trips to and from school can be enhanced by sidewalks and proper signalization, but also by well-trained adult crossing guards and selective police enforcement. Certain warning signs (e.g., flashing school speed limit signs) and markings (e.g., school crosswalks) are also appropriate and beneficial to pedestrians in many school zones.

Figure 2. School-trip safety can be enhanced by well-trained adult crossing guards.

- Pedestrian safety and mobility are enhanced by sidewalks and walkways. This is a critical component of a pedestrian transportation network in urban and suburban areas. Rural roads should also provide shoulders for pedestrian travel.

- Overpasses and underpasses can substantially improve safety for pedestrians needing to cross freeways or busy arterial streets at certain locations. However, such facilities must be carefully planned and designed to encourage pedestrians to use the facilities and not continue to cross at street level.

- Countermeasures to improve conspicuity of pedestrians include a flashlight, jogger's vest, dangle tags, and rings (retroreflective material on the head band, wrist bands, belt, and ankle band). Such measures can increase a motorist' visibility distance of a pedestrian up to 1,300 feet, compared with about 200 feet for a "base pedestrian" wearing blue jeans and a white t-shirt.

- Several studies have shown that converting from two-way to one-way streets can substantially reduce pedestrian collisions. In many cases, however, converting from two-way to one-way streets may not be solely justified by pedestrian safety considerations. More often, several concerns such as capacity, traffic circulation, and overall traffic safety are major considerations. However, one-way streets can greatly simplify the task of crossing a street, particularly if the one-way street conversion does not result in increased vehicle speeds.

- While traffic-calming measures are primarily intended for neighborhood streets to reduce vehicle speeds and/or reduce cut-through vehicle traffic, measures such as street closures, speed humps, chicanes (series of alternating curb extensions), traffic curbs, diverters, and others are in use in various U.S. cities. While controversial, many of these measures have been found to effectively improve safety for pedestrians and/or traffic as a whole based on reductions in crashes, vehicle speeds, and/or reductions in cut-through traffic on neighborhood streets.

- Educational measures have been found to reduce crashes involving child pedestrians to age groups receiving the educational program. However, most U.S. educational programs have received few if any formal evaluations and had limited measurable effects.

- Enforcement of traffic laws and regulations represents another important element in safe pedestrian activity in a roadway environment. This includes not only the enforcement of pedestrian regulations (e.g., jaywalking, crossing against the signal) but also motorist actions related to pedestrians (e.g., speeding, yielding to pedestrians when turning, drunk driving). While a number of U.S. cities (including Seattle, Milwaukee, and San Diego) have had active police enforcement programs in recent years, no quantitative studies have been done to deter- mine the specific effects of police enforcement on pedestrian crashes and injuries. Such a study would be difficult to conduct because of many other contributing crash factors in a city.

Evolution of Vehicle/Pedestrian Collision Problems

Even the ancients knew it was a good idea to separate pedestrians from vehicles roadways. Fruin (1973) presents a comprehensive historical perspective of the methods used in the past to limit vehicular intrusion into cities; regulations prohibiting heavy wagons within the central city after dusk; vehicle/ pedestrian separation using stone barriers and metal spikes; and special areas along main thoroughfares where pedestrians could rest. Medieval city planners provided central pedestrian plazas as an open space for the marketplace and the cathedral, as well as a location for festive occasions and recreation. In a number of cities, pedestrians were protected from the elements by galleries, canopies, colonnades, and porticos.

The introduction and increased use of motor vehicles in urban areas has made it much more difficult to ensure pedestrian mobility and safety. Most space provided for pedestrians has been sacrificed to provide space for motor vehicle traffic. Both motorist and pedestrian face visual clutter of traffic signals and signs.

The central business district (CBD) of a city hosts various land uses: office buildings, government, shopping, entertainment centers, restaurants, historical sites, and high-rise residential developments. The CBD is the focal point of the regional transportation network and the confluence of transit and highways. Because of its flexibility, walking is the only means of transportation satisfying the short, dispersed trip linkages required in the CBD. Downtown-origin-and-destination surveys in most cities show that approximately 90 percent of all internal trips within the CBD are made on foot.

The traditional urban core is often superimposed on an archaic street system surviving from past land use and a smaller population. The street system of the Manhattan financial district of New York City, for example, dates to colonial times when the tallest structure was two or three stories. Now these same streets serve buildings rising 50 to 100 stories, representing millions of square feet of office space. Thousands of workers and visitors enter and leave these buildings each day, exceeding the capacity of the sidewalk and spilling over into the roadway. In such situations, maximum use of sidewalk area and flow capacity is a necessity.

In many high-density CBDs, the sidewalk width has been reduced to facilitate vehicular traffic movement. This reduces pedestrian traffic capacity, but does not always produce a commensurate increase in vehicle capacity. The wider streets increase the likelihood of pedestrian-vehicle crosswalk conflicts, which limits vehicle capacity at intersections.

The potential pedestrian capacity of the CBD sidewalks is further reduced by the intrusion of refuse cans, fire hydrants, fire alarm boxes, parking meters, traffic signals, control boxes and poles, signposts, newsstands, telephone booths, mailboxes, bus benches, planters, sewer and ventilation gratings,

Figure 3. Pedestrian capacity of CBD sidewalks is reduced by light posts, mailboxes, parking meters, etc.

and other street furniture. In addition, building service operations, such as unloading or loading of trucks, often inconvenience and sometimes endanger the pedestrian. Many intersections were built with little control over the location of fixed sidewalk furniture and utilities that often appear in clusters at intersections, the most critical points in the pedestrian circulation network.

Pedestrians waiting at intersections need space, and intersections must accommodate weaving, opposing pedestrian flows. The intersection is also the most common location for bus stops and rapid transit entrances. The pedestrian is further harassed by vehicles stopped in the crosswalk or turning into the path of crossing pedestrians. When a rapid transit entrance is situated along a narrow sidewalk near an intersection, narrow subway stairs can cause pedestrian queues both in the transit station below and on the surface.

This all adds to inconvenience, potential danger, and delay for the pedestrian. Although the total amount of pedestrian delay time may far exceed driver delay time within the CBD, traffic signalization is usually designed to facilitate vehicular flow. Often, the only consideration given to pedestrians at signals is to meet the minimum pedestrian WALK and clearance times, which may not be sufficient for pedestrians with special crossing needs. Where automatic detection is provided for motor vehicles, pedestrians typically must push a button to be detected. In some cases, long cycle lengths encourage pedestrians to cross against a signal.

The rectangular grid pattern of the typical CBD is not conducive to characteristically short pedestrian trips. In some instances, the grid pattern of Manhattan's streets requires a time- and energy-consuming 1,000-foot walk for a straight-line trip distance of only 200 feet. Larger midblock buildings with frontages on adjacent streets are often used as through-routes so the pedestrian can reduce trip distances. This practice is more common in inclement weather. Depending on city location, one day in four may be too windy, cold, wet, or hot for the pedestrian's comfort. But, protection of the pedestrian from the elements is a low priority in most cities.

Guides and Model Programs

There is some variation among the States' laws and regulations for pedestrian movement, though the *Uniform Vehicle Code* (1992) and the *Manual on Uniform Traffic Control Devices* (1998 and 2001) have helped to reduce this variability. Since the early 1970s, numerous publications have discussed alternative measures to prevent pedestrian crashes. Several studies in the 1970s suggested possible countermeasures for predominant pedestrian crash types, such as dart-outs, midblock dash crashes, and others. Brief synopses of some of these are provided in the following paragraphs.

A recent FHWA guide provides a matrix of 47 possible pedestrian treatments for 13 groups of pedestrian crashes (Zegeer et al., Pedestrian Facilities Users Guide: *Providing Safety and Mobility*, FHWA, March, 2002). The matrix of candidate engineering countermeasures is given in table 1. This guide provides information for each of the 47 engineering treatments, including a description of the countermeasure, considerations for using it, implementation cost, and a photo and/or sketch. A countermeasure matrix is also provided in that report (see table 2) for use in addressing various performance objectives (e.g., reducing vehicle speeds, reducing vehicle volume). Finally, the guide provides examples of pedestrian case studies and success stories, as well as recommendations and priorities for installing sidewalks and walkways, marked crosswalks and other pedestrian crossing treatments. This guide may be found at http://www.walkinginfo.org/rd/for_ped.htm#guide.

FHWA's *Model Pedestrian Safety Program*, written in 1977 and updated in 1987, provides a six-step process for planning, implementation, and evaluation relative to an agency's pedestrian safety

Table 1. Matrix of potential engineering countermeasures for urban pedestrian crashes.

CRASH GROUP COUNTERMEASURES	Midblock Dart/Dash	Multiple Threat	Midblock Mailbox Etc.	Failure to Yield (Unsignalized)	Bus-Related	Turning Vehicle At Intersection	Through Vehicle At Intersection	Walking Along Roadway	Working/ Playing in Road	Not in Road	Backing Vehicle	Crossing Expressway
1. Sidewalk/Walkway					•			•	•	•	•	
2. Curb Ramp				•	•	•	•	•				
3. Crosswalk Enhancements	•	•		•	•	•	•					
4. Transit Stop Treatments	•	•		•	•	•	•					
5. Roadway Lighting	•	•	•	•	•	•	•	•	•	•	•	•
6. Overpass/Underpass	•	•		•		•	•					•
7. Street Furniture	•				•			•				
8. Bike Lane/Shoulder	•	•	•	•	•			•	•	•		
9. Road/Lane Narrowing	•	•	•	•				•	•			
10. Fewer Lanes		•		•	•			•				
11. Driveway Improvement										•	•	
12. Raised Median	•	•	•	•		•	•					
13. One-Way Street						•	•					
14. Smaller Curb Radius				•		•				•		
15. Right-Turn Slip Lane						•						
16. Modern Roundabout						•	•					
17. Modified T-Intersection						•						
18. Intersection Median Barrier		•		•		•	•					
19. Curb Extension	•	•		•	•	•	•			•	•	
20. Choker	•			•								
21. Pedestrian Crossing Island	•	•		•	•	•	•					
22. Chicane	•		•	•					•			
23. Mini-Circle						•	•		•			
24. Speed Humps	•		•	•					•			
25. Speed Table	•	•	•	•					•			
26. Raised Intersection				•		•	•					

Table 1. Matrix of potential engineering countermeasures for urban pedestrian crashes. (Con't)

CRASH GROUP COUNTERMEASURES	Midblock Dart/Dash	Multiple Threat	Midblock Mailbox Etc.	Failure to Yield (Unsignalized)	Bus-Related	Turning Vehicle At Intersection	Through Vehicle At Intersection	Walking Along Roadway	Working/ Playing in Road	Not in Road	Backing Vehicle	Crossing Expressway
27. Raised Ped. Crossing	•	•		•	•	•	•				•	
28. Gateway	•		•	•					•			
29. Landscape Options				•						•	•	
30. Paving Treatments				•		•	•					
31. Driveway Link/Serpentine	•			•					•			
32. Woonerf	•								•			
33. Diverter	•					•	•		•			
34. Full Street Closure	•					•	•		•			
35. Partial Street Closure	•					•	•		•			
36. Pedestrian Street	•			•					•			
37. Traffic Signal	•	•		•	•	•	•					
38. Pedestrian Signal	•	•		•	•	•	•					
39. Pedestrian Signal Timing						•	•					
40. Signal Enhancement	•					•	•					
41. RTOR Restriction						•						
42. Advanced Stop Lines		•			•	•	•					
43. Sign Improvement	•	•	•	•	•	•	•	•	•	•		•
44. School Zone Improvement	•	•		•	•	•	•	•		•		
45. Identify Neighborhood	•		•	•				•	•			
46. Speed-Monitoring Trailer	•		•	•			•	•	•			
47. Parking Enhancement	•		•	•	•	•	•			•	•	
48. Ped./Driver Education	•	•	•	•	•	•	•	•	•	•	•	•
49. Police Enforcement	•	•	•	•	•	•	•	•	•	•		•

Table 2. Matrix of potential performance objectives for urban pedestrian crashes.

Objective	A. Pedestrian Facility Design	B. Roadway Design	C. Intersection Design	D. Traffic Calming	E. Traffic Management	F. Signals and Signs	G. Other Measures
1. Reduce Speed of Motor Vehicles		• Add Bike Lane/Shoulder • Road Narrowing • Reduce Number of Lanes • Driveway Improvements • Curb Radius Reduction • Right-Turn Slip Lane	• Modern Roundabouts	• Curb Extension • Choker • Chicane • Mini-Circle • Speed Humps • Speed Table • Raised Pedestrian Crossing • Raised Intersection • Driveway Link/Serpentine • Woonerf		• Signal Enhancement (e.g., Adjust Signal Timing for Motor Vehicles)	• Speed-Monitoring Trailer • School Zone Improvement
Use in Conjunction With Other Treatments	• Street Furniture			• Landscaping Options • Paving Treatments		• Sign Improvement	
2. Improve Sight Distance and Visibility for Motor Vehicles and Pedestrians	• Crosswalk Enhancements • Roadway Lighting • Move Poles/Newspaper Boxes at Street Corners	• Add Bike Lane/Shoulder		• Curb Extension • Speed Table • Raised Pedestrian Crossing • Raised Intersection • Paving Treatments		• Sign Improvement (e.g., Warning Sign) • Advanced Stop Lines	
3. Reduce Volume of Motor Vehicles		• Reduce Number of Lanes		• Woonerf	• Diverters • Full Street Closure • Partial Street Closure • Pedestrian Street		
4. Reduce Exposure for Pedestrians	• Overpasses/Underpasses	• Road Narrowing • Reduce Number of Lanes • Raised Median • Pedestrian Crossing Island		• Curb Extension • Choker • Pedestrian Crossing Island		• Pedestrian Signal Timing • Accessible Pedestrian Signal	
5. Improve Pedestrian Access and Mobility	• Sidewalk/Walkway • Curb Ramps • Crosswalk Enhancements • Transit Stop Treatments • Overpasses/Underpasses	• Raised Median		• Choker • Pedestrian Crossing Island		• Traffic Signal • Signal Enhancement • Accessible Pedestrian Signal • Pedestrian Signal Timing	
6. Encourage Walking by Improving Aesthetics	• Street Furniture • Roadway Lighting • Landscaping Options	• Raised Median		• Gateway • Landscaping • Paving Treatments			• Identify Neighborhood
7. Improve Compliance With Traffic Laws			• Red-Light Cameras	• Traffic Calming: Choker, Chicane, Mini-Circle, Speed Hump, Speed Table			• Speed-Monitoring Trailer • Pedestrian/Driver Education • Police Enforcement
8. Eliminate Behaviors That Lead to Crashes			• Red-Light Cameras	• Traffic Calming: Choker, Chicane, Mini-Circle, Speed Hump, Speed Table		• Pedestrian Signal Timing	• Pedestrian/Driver Education • Police Enforcement

program. The User's Guide Supplement presents detailed information on the various countermeasures for pedestrian crashes, including their advantages and disadvantages and implementation considerations. Details on work-zone management for improved pedestrian protection is given in *Work Zone Traffic Management*, a report published by FHWA in 1989.

In 1981, a report by Vallette and McDivitt reviewed available pedestrian literature and operational experiences of 19 U.S. cities concerning pedestrian safety programs. The study included the development of a matrix of 450 pedestrian-related articles and publications by 71 subject categories. Operational experiences of 19 city agencies were provided based on visits and interviews with those agencies relevant to their safety program coordination, traffic engineering, school and child safety programs, provisions for the handicapped, public information and education, enforcement of pedestrian-related laws, safety analysis, and safety program recommendations and philosophy.

The WALK ALERT program is a national pedestrian safety program, a cooperative effort of the National Safety Council, FHWA, National Highway Traffic Safety Administration (NHTSA), and more than 100 service and community organizations. The primary objective is to reduce pedestrian crashes. The 1989 *WALK ALERT Program Guide* (National Safety Council, 1988) provides the steps needed to organize and implement a local pedestrian safety effort. The guide includes information on engineering improvements, educational materials for all age levels, and possible enforcement/laws and ordinances to improve pedestrian safety. Information is also provided for working with the news media, along with a resource guide that lists pedestrian safety programs, audiovisuals, and print materials recommended for the WALK ALERT program.

In 1988, a Transportation Research Board (TRB) synthesis, *Pedestrians and Traffic-Control Measures*, was published by C. Zegeer and S. Zegeer. This report provides details on publications and information related to 21 specific types of engineering traffic-control measures. This information is based on question- naire responses from 48 city and state transportation agencies on pedestrian facilities, including traffic and roadway conditions under which each measure is most and least effective. The report includes discussions of special pedestrian situations (e.g., work-zone travel) and traffic-control needs for special pedestrian groups (e.g., college students, children in school zones, older and handicapped adults). Recommendations are provided for selecting effective traffic-control measures to improve pedestrian safety and movement.

A 1987 National Cooperative Highway Research Program (NCHRP) report, *Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas* contains information on

Figure 4. Pedestrians in rural and developing areas need to be able to get from one place to another safely and conveniently.

Table 3. Partial summary of pedestrian facility problems and possible solutions.*

Description of Problem	Magnitude of Problem	Possible Solutions	Current Level of Use or Acceptance	Limitations in Applicability	Potential Effectiveness	Barriers to Implemen-tation	Cost	Impact on Other Groups	Comment
CrossSection Design									
Difficulty of crossing wide, arterial streets, especially undivided arterials	Major	1. Install medians on all new suburban highways of 4 or more lanes.	Moderate	Virtually no limitations for new hwys. However, some limitations are currently perceived.	High	Moderate	Moderate	Positive	Potentially the most effective solution to street crossing problems.
		2. Install European-style refuge islands in strategic locations on existing undivided highways.	Low	Must narrow lanes on existing hwys. to accommodate refuge islands. Must be well lighted.	High	Moderate	Low to moderate	Minimal	This solution is greatly underutilized in U.S.
		3. Design for reduced street width between signalized intersec-tions (since capacity constraints are at signal[s].	Low	Could only be done where spacing between intersections is high.	Moderate	High	Low	Negative	Probably not feasible as a general practice.
		4. Introduce additional traffic signals to facilitate ped. crossings.	Low	Could only be done in a few selected locations.	Moderate	High	Moderate	Highly negative	More feasible where ped. crossings are concentrated at a point
		5. Provide midblock actuated flashing ped. signal.	Low	Should only be installed in key locations.	Moderate	Moderate	Low	Slightly negative	Designed to inform driver of presence of ped; may not make crossing easier.
		6. Provide ped. overpass.	Low	Only effective where at-grade crossing is blocked or is inconvenient.	Moderate- depends on no. of peds	Moderate	High	Positive	Lack of use of facility continues to be a problem.
Difficulty of crossing highways with two-way left turn lanes	Moderate to Major	1. Reduce use of this technique and provide medians to control access.	Low	Would need to design infrequent U-turn capability.	High	High	Moderate to high	Negative	Merchants and drivers will object heavily.
		2. Instal refuge islands in spots where no turning is necessary.	Low	Must have at least some "dead spots" where turning would not generally occur.	High	Moderate	Low	Minimal	Islands must be well-lighted and marked.
No facilities provided for ped. to walk along side of road	Major	1. Require sidewalk/pathway with all new hwy. construction. Paved or stabilized shoulder adequate in outlying areas.	Moderate	Only allowed exclusion should be low-volume residential streets.	High	Moderate	Moderate	Minimal	Could be required by FHWA for Federal projects.
		2. Provide easier methods for obtaining easements to address existing highways constrained by right of way.	Low	Probably would be viewed as giving excess authority to public agencies.	High	High	Low	Negative	Would put property owners at a disadvantage.
Narrow bridges with no pedestrian accommodations	Moderate	1. Design all new bridges with shoulder or raised walkway.	Moderate	None	Moderate to high	Moderate	Moderate to high	Positive	
		2. Design low-cost walkway system for attaching to outside of bridge.	Low	Feasibility and design dependent on structural nature of existing bridge	Moderate to high	Moderate	Moderate	Positive	

*Source: Smith, S.A., et al., 1987.

providing for pedestrian needs outside of urban areas. The report discusses the nature of suburban and rural pedestrian problems and how they occur, the planning process, pedestrian facilities within highway right-of-way, and practical considerations for providing such facilities. A summary addresses pedestrian facility problems and possible solutions, and a sample of such information is given in table 1. Many of the deficiencies that were found in suburban and developing rural areas were attributed to planners' failure to think about how to get pedestrians safely and conveniently from one place to another.

A report entitled, *Handbook on Planning, Design, and Maintenance of Pedestrian Facilities* (Bowman, Fruin, and Zegeer, 1989) assembled current information to help design, construct, and maintain pedestrian facilities. The planning and design details are emphasized for such facilities as sidewalks and walkways, crosswalks, curb ramps and refuge islands, overpasses and underpasses, pedestrian priority zones (e.g., malls, auto-restricted zones, and temporary street closings), traffic-control devices, and pedestrian facilities in work zones. The report also provides information on pedestrian characteristics and how to conduct pedestrian traffic and safety studies.

Planning Community Pedestrian Safety Programs— An Agenda for Action (NHTSA, 1980) is a guide to assist local communities in either integrating pedestrian safety into an existing community traffic safety program or developing and implementing a new and independent pedestrian safety program. The components of community programs are discussed in addition to methods for developing the plan of action and program evaluation.

As discussed above, a number of user guides and procedural manuals have been written on developing local or statewide pedestrian safety programs (e.g., *WALK ALERT Program Guide*, *Planning Community Pedestrian Safety Programs*, *Model Pedestrian Safety Program User's Guide*) (National Safety Council, 1988; Planning Community Safety Programs, 1980; Work Zone Traffic Management, 1989). Other publications document city pedestrian safety programs and/or provide information from previous pedestrian literature in selected areas (e.g., Vallete and McDivitt, 1981; Zegeer and Zegeer, 1988). Still others assist the planning, design, implementation, and maintenance of pedestrian facilities (e.g., Smith et. al., 1987 and Bowman et. al. 1989).

PART 2. CRASHES INVOLVING PEDESTRIANS

Introduction

The sheer number of pedestrians killed or seriously injured in U.S. traffic collisions each year is an important consideration in the Nation's highway transportation system. The NHTSA estimated that 5,300 pedestrians were killed in the United States during 1997 (*Traffic Safety Facts*, 1997). NHTSA also reported 77,000 nonfatal injuries. Casualties of this magnitude take on even greater meaning in view of the national policy to encourage increased walking as a matter of both transportation and health.

Limitations of National Pedestrian Crash Data

Pedestrian crash statistics must be considered with two caveats: First, the numbers presented in this report are estimates, aggregated from information compiled in 50 States plus the District of Columbia, or taken from studies that sample pedestrian collisions. Predictably, there is some uncertainty in the reporting processes and expectable variations due to sampling differences. Second, definitions vary among agencies. Thus, fatality estimates from the National Safety Council (NSC) differ somewhat from those of the NHTSA due to their definitions of death. NSC counts a traffic fatality as any crash death that ensues within 1 year after the crash, whereas NHTSA only counts those deaths that occur within 30 days. Other totals would result if, for example, traffic death counts were confined to victims who died at the crash scene.

Another caution pertains to interpreting the following data tables, which may themselves be overly simplistic. A collision may be associated with several factors, therefore a table that displays only two or three factors leaves much unsaid. For example, a table depicting pedestrian crashes by time of occurrence will show that a certain proportion occurs at night. However, not all of the observed trends shown in such a table would be caused by reduced nighttime visibility. Although reduced visibility at night plays an important role in the likelihood of a crash, the nighttime figures are also influenced by the number of people who are exposed to risk at night as opposed to in the daytime, the ages of the pedestrians, and the role of alcohol.   Thus, any table of crash data reflects the influence of variables not shown, as well as the influence of the variables that are depicted.

Moreover, many studies do not consider the number of people actually exposed to risk.

Reports reviewed here span the period during which standardized terminology was evolving. Thus, various authors use the term “accident”, “collision”, or “crash” to describe the phenomena under examination here. While the terms are sometimes used interchangeably, “crash” has become the term preferred by safety organizations.

The Number of Pedestrian Fatalities

The NSC annually publishes an estimate of U.S. pedestrian deaths for the most recent year available, as well as for years as far back as 1927 (*Accident Facts*, 1995, 1996, 1997 editions). The estimated number of pedestrian fatalities for 1927 was 10,820, as shown in table 4. The pedestrian death count irregularly grew until 1937, when 15,500 pedestrian deaths were reported, the largest number in U.S. history. Thereafter, the number declined. The number of pedestrian fatalities exceeded 10,000 during 1969, 1972, and 1973, and since then decreased to 6,100 in 1996. It should be noted that the NSC estimating procedure was changed in 1987 and the annual number of deaths it reported became substantially lower beginning that year.

Table 4. Estimated national traffic fatalities by year.

Year	National Safety Council			National Highway Traffic Safety Administration (U.S. DOT)**		
	Total Fatalities	Pedestrian Fatalities	% Pedestrian	Total Fatalities	Pedestrian Fatalities	% Pedestrian
1927	25,800	10,820	41.9			
1928	28,000	11,420	40.8			
1929	31,200	12,250	39.3			
1930	32,900	12,900	39.2			
1931	33,700	13,370	39.7			
1932	29,500	11,490	38.9			
1933	31,363	12,840	40.9			
1934	36,101	14,480	40.1			
1935	36,369	14,350	39.5			
1936	38,089	15,250	40.0			
1937	39,643	15,500	39.1			
1938	32,582	12,850	39.4			
1939	32,386	12,400	38.3			
1940	34,501	12,700	36.8			
1941	39,969	13,550	33.9			
1942	28,309	10,650	37.6			
1943	23,823	9,900	41.6			
1944	24,282	9,900	40.8			
1945	28,076	11,000	39.2			
1946	33,411	11,600	34.7			
1947	32,697	10,450	32.0			
1948	32,259	9,950	30.8			
1949	31,701	8,800	27.8			
1950	34,763	9,000	25.9			
1951	36,996	9,150	24.7			
1952	37,794	8,900	23.5			
1953	37,956	8,750	23.1			
1954	35,586	8,000	22.5			
1955	38,426	8,200	21.3			
1956	39,628	7,900	19.9			
1957	38,702	7,850	20.3			
1958	36,981	7,650	20.7			
1959	37,910	7,850	20.7			
1960	38,137	7,850	20.6			
1961	38,091	7,650	20.1			
1962	40,804	7,900	19.4			
1963	43,564	8,200	18.8			
1964	47,700	9,000	18.9			
1965	49,163	8,900	18.1			
1966	53,041	9,400	17.7			
1967	52,924	9,400	17.8			
1968	54,862	9,900	18.0			
1969	55,791	10,100	18.1			
1970	54,633	9,900	18.1			
1971	54,381	9,900	18.2			
1972	56,278	10,300	18.3			
1973	55,511	10,200	18.4	44,525	7,516	16.9
1974	46,402	8,500	18.3	45,523	7,427	16.3
1975	45,853	8,400	18.3	47,878	7,732	16.1
1976	47,038	8,600	18.3	50,331	7,795	15.5
1977	49,510	9,100	18.4	51,093	8,096	15.8
1978	52,411	9,600	18.3	51,091	8,070	15.8
1979	53,524	9,800	18.3	49,301	7,837	15.9
1980	53,172	9,700	18.2	43,945	7,331	16.7
1981	51,385	9,400	18.3	42,589	6,826	16.0
1982	45,779	8,400	18.3	44,257	7,025	15.9
1983	44,452	8,200	18.4	43,825	6,808	15.5
1984	46,263	8,500	18.4	46,087	6,779	14.7
1985	45,901	8,500	18.5	46,390	6,745	14.5
1986	47,865	8,900	18.6	47,087	6,870	14.6
1987	48,290	7,500*	15.5*	45,582	6,556	14.4
1988	49,078	7,700	15.7	44,599	6,482	14.5
1989	47,575	7,800	16.4	41,508	5,801	14.0
1990	46,814	7,300	15.6	39,250	5,549	14.1
1991	43,536	6,600	15.2	40,150	5,649	14.1
1992	40,982	6,300	15.4	40,676	5,472	13.5
1993	42,200	6,400	15.2			
1994	43,000	6,300	14.6			
1995	43,,363	6,700	15.4			
1996	43,,300	6,100	14.1			

*Estimation procedure changed effective 1987 figures.

**Published information not available from NHTSA prior to 1973.

Sources:

1. *Accident Facts*, 1995 and 1997 editions, National Safety Council, Chicago, IL, 1995.

2. *Traffic Safety Facts'1994*, National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, DC, August 1995.

It is also of interest to consider pedestrian fatalities as a percentage of total traffic fatalities. During 1927, pedestrian deaths accounted for 41.9 percent of total traffic deaths. That percentage has declined and was 14.1 percent of the total in 1996, a substantial decline from 1927 (figure 5). Increased travel by car is one factor in that change. Evans (1991), among others, has reported that the higher the degree of motorization in a country, the number of motor vehicles per 100,000 population, the lower the proportion of pedestrian deaths to total traffic deaths. The proportion of pedestrian deaths declined as the United States progressively became more motorized. This trend also is seen in less motorized countries (Choueiri et al., 1993).

This influence of car travel was highlighted by the U.S. experience during World War II when there was an interruption in the steady decline in pedestrian fatalities as a percentage of total traffic fatalities. The pedestrian fatalities were 33.9 percent in 1941. During the war years (1942-1945) the total abruptly jumped to values between 38 and 41 percent. In 1947, the figure reversed again to a new low of 32 percent, and after 1949 did not again reach 30 percent (See table 4). The increase during World War II probably reflected the fact that motor vehicle mileage fell during those years because civilian vehicle production gave way to military needs, and the existing civilian motor vehicle fleet amassed drastically fewer miles because of gasoline and tire (that is, rubber) rationing. It is also likely that the characteristics of highway users changed during that period, what with millions of young men away in the military, plus unprecedented numbers of women in the work force. It should be noted that Choueiri et al. (1993) show a greater pedestrian death decline in Europe during recent years than in the United States.

Table 5 shows a comparison of States (and Puerto Rico), using NHTSA data (*Traffic Safety Facts*, 1995) from highest rank to lowest according to pedestrian deaths per 100,000 population. The table is reproduced here to suggest some of the complexities that underlie pedestrian crash and death figures. The 10 States with the highest pedestrian death rate per 100,000 population vary significantly: two are urban and densely populated (DC and Puerto Rico), 3 are sparsely populated desert states, and 3 are among the 11 most populous states (California, Florida, and North Carolina). This suggests that the complex of factors producing high pedestrian death rates may differ from one State to another. Also, none of these rates consider pedestrian exposure or vehicle exposure, the proportion of pedestrians by age, or many other possible contributing factors.

At the other end of the spectrum, the 10 States with the lowest pedestrian death rate per 100,000 population also differ. The lowest 10 include rural States, cold weather States, industrial heartland states, and the agricultural midwest. This may be indicative of lower amounts of walking by pedestrians and/or less pedestrian interaction with high volumes of motor vehicles.

When Do Pedestrian Collisions Occur?

A. TIME OF DAY

Collisions can and do occur at any time, but there are trends involving the time of occurrence. Table 6 shows how pedestrian crashes, injuries, and fatalities vary by time of day.

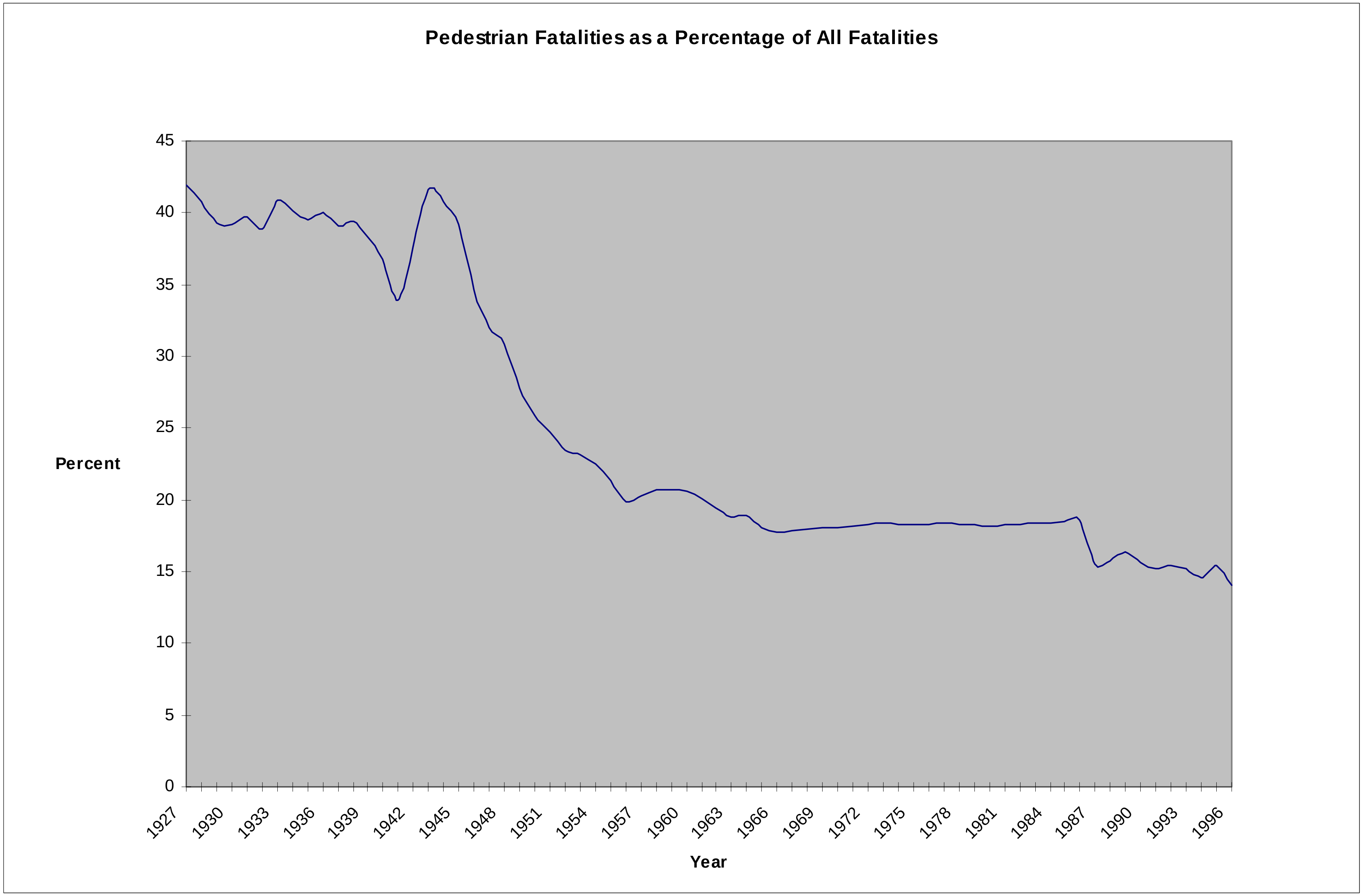

Figure 5. Pedestrian fatalities as a percentage of total traffic fatalities, 1927-1996.

Table 5. Ranking of State pedestrian fatality rates per 100,000 residents , 1994.

Rank	State	Pedestrians Killed	Population (Thousands)	Pedestrian Fatality Rate per 100,000 Population
1	New Mexico	72	1,654	4.35
2	District of Columbia	23	570	4.04
3	Florida	531	13,953	3.81
4	Nevada	54	1,457	3.71
5	Arizona	148	4,075	3.63
6	South Dakota	23	721	3.19
7	South Carolina	108	3,664	2.95
8	California	843	31,431	2.68
9	North Carolina	184	7,070	2.60
10	Maryland	129	5,006	2.58
11	Delaware	18	706	2.55
12	Louisiana	103	4,315	2.39
13	Texas	436	18,378	2.37
14	Georgia	163	7,055	2.31
15	Arkansas	55	2,453	2.24
16	Oregon	69	3,086	2.24
17	Hawaii	26	1,179	2.21
18	New York	397	18,169	2.19
19	Utah	40	1,908	2.10
20	New Jersey	165	7,904	2.09
21	Mississippi	54	2,669	2.02
22	Alaska	12	606	1.98
23	Illinois	232	11,752	1.97
24	Alabama	81	4,219	1.92
25	Connecticut	63	3,275	1.92
26	Michigan	182	9,496	1.92
27	Tennessee	97	5,175	1.87
28	Maine	20	1,240	1.61
29	Missouri	85	5,278	1.61
30	Oklahoma	52	3,258	1.60
31	Rhode Island	16	997	1.60
32	West Virginia	29	1,822	1.59
33	Virginia	102	6,552	1.56
34	Washington	83	5,343	1.55
35	Pennsylvania	171	12,052	1.42
36	Kentucky	54	3,827	1.41
37	Massachusetts	85	6,041	1.41
38	Colorado	51	3,656	1.39
39	Indiana	80	5,752	1.39
40	Montana	11	856	1.29
41	North Dakota	8	638	1.25
42	Minnesota	53	4,567	1.16
43	Ohio	127	11,102	1.14
44	Nebraska	17	1,623	1.05
45	New Hampshire	11	1,137	0.97
46	Wisconsin	49	5,082	0.96
47	Kansas	22	2,554	0.86
48	Iowa	24	2,829	0.85
49	Wyoming	4	476	0.84
50	Idaho	8	1,133	0.71
51	Vermont	2	580	0.34
	USA	**5,472**	**260,341**	**2.10**
	Puerto Rico	205	3,700	5.54

Source: *Traffic Safety Facts*, 1994: 1994 Motor Vehicle Crash Data from FARS and GES National Highway Traffic Safety Administration, US DOT, Washington, D.C., 1995.

Table 6. Pedestrian collisions by time of day.

	National Fatalities[1]		National Injuries[1]		Sample of Crashes[2]	
	%	N	%	N	%	N
6-9 AM	7.5	409	9.5	9,000	8.9	420
9 AM-Noon	6.9	377	9.3	8,000	9.3	440
Noon-3 PM	8.8	480	18.4	16,000	32.20	735
3-6 PM	13.9	760	25.5	23,000	20.2	1271
6-9 PM	24.8	1359	21.2	19,000	11.3	954
9 PM-Midnight	19.4	1062	10.7	10,000	6.0	536
Midnight-3 AM	11.7	638	4.3	4,000	1.9	283
3-6 AM	6.5	353	1.1	1,000	9.2	92
	100%	5472	100%	90,000	100%	4,731

[1]Estimates of national figures. Source: *Traffic Safety Facts*, 1994: 1994 Motor Vehicle Crash Data from FARS and GES, National Highway Traffic Safety Administration, USDOT, Washington, D.C., August 1995.

[2]Sample data from six states. Source:Derived from database used in *Pedestrian and Bicycle Crash Types of the Early 1990s,* Hunter, W., Stutts, J., Pein, W., Cox, C., UNC HSRC, FHWA-RD-95-163, 1996. The sample noted crashes of all severities ranging from fatal to no injury, and was drawn from California, Florida, Maryland, Minnesota, North Carolina, and Utah, covering collisions that occurred in 1991 or 1992.

Table 6 can be used to contrast the time of occurrence for "all" pedestrian crashes, fatally injured pedestrians, and pedestrians injured but not killed.

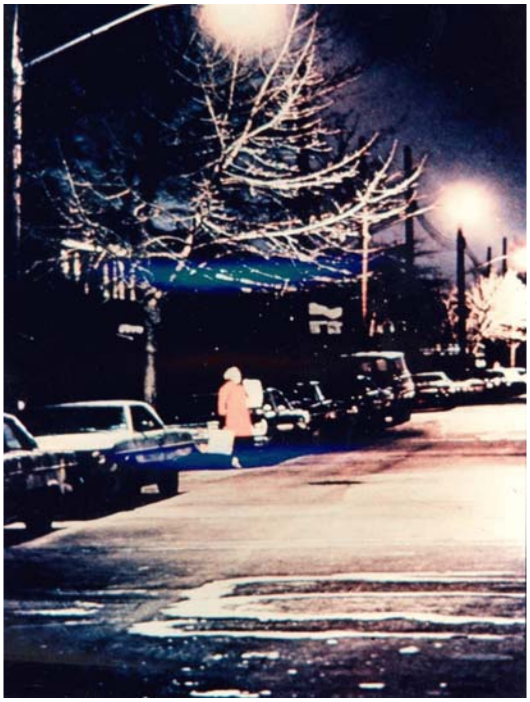

Figure 6. A disproportionately high percentage of pedestrian deaths occur at night.

Among the sample of pedestrian collisions (Hunter et al., 1996), 62 percent happened during the day between 6:00 a.m. and 6:00 p.m. Consistent with those daytime numbers are other findings, based on data from urban areas. These show general agreement that the peak time for pedestrian crashes is between 3 p.m. and 6 p.m. This peak represents about 30 to 40 percent of the collisions (*Fatal Accident Reporting System*, 1990; Knoblauch, 1977; Davis and Huelke, 1969; Cove, 1990) and the proportion decreases on either side of this period. Smaller secondary peaks from 7 a.m. to 9 a.m. and Noon to 1 p.m. were reported by Smeed (1968).

NHTSA figures (*Traffic Safety Facts*, 1995) show that the distribution by time of occurrence for pedestrian injuries is somewhat similar to that of all collisions (about 63 percent of injuries concentrated from 6:00 a.m. to 6:00 p.m., compared with 61 percent for all collisions). This was also reported by Cove (1990), showing pedestrian injury crashes to have a major peak between 3 p.m. and 7 p.m. and a minor peak between 7 a.m. and 9 a.m., based on data from the National Accident Sampling System (see figure 7).

The time distribution of pedestrian fatalities stands in sharp contrast to the above. Among pedestrian fatalities, 62 percent happened at night (table 6). Fatal pedestrian crashes peak in the evening hours (Cove, 1990), between 5 and 11 p.m., including one minor peak from midnight to 2 a.m. (See figure 8).

This trend in fatalities could be partly associated with rural pedestrian crashes involving high-speed vehicles and pedestrians walking along a dark road or in some cases lying unconscious (sleeping) in the road. In fact, in North Carolina, 10 percent of all pedestrian fatalities involve a pedestrian lying in the road (*North Carolina Traffic Accident Facts*, 1990). Thus, the role of alcohol among adults is thought to be involved in nighttime pedestrian fatalities. Fatality figures suggest that the victim profile would vary by time of day. Alcohol is a greater factor at night, but children are less likely to be involved at night.

Both the severity of pedestrian injury and the type of pedestrian crash vary by time of day. Data from six states, reported by Hunter et al. (1996), illustrate this point. Based on a sample of all pedestrian crashes, table 7 shows a breakdown of pedestrian crash types according to four different light conditions (i.e., related to time of day), distributed as follows:

Crashes occurred during	Percent of sample
Daylight hours	60.6
Dawn or dusk	4.6
Dark, street lighted	23.3
Dark, street not lighted	11.6

These four categories create a rough scale from the greatest amount of light (daylight) to the least (dark, street not lighted), thus partly related to time of day, and table 7 shows the crash types that are most frequent under each light condition. Though daylight hours account for about 61 percent of all crashes in Hunter's study, more than 70 percent of some types of crashes occur in the daytime (e.g., 73 percent of pedestrian crashes related to buses occur in daylight).

Although unlit rural streets and roads might be considered a considerable hazard for pedestrians, the data in table 7 show that these conditions account for a much smaller percent of all crashes than, for example, walking along a roadway in daylight.

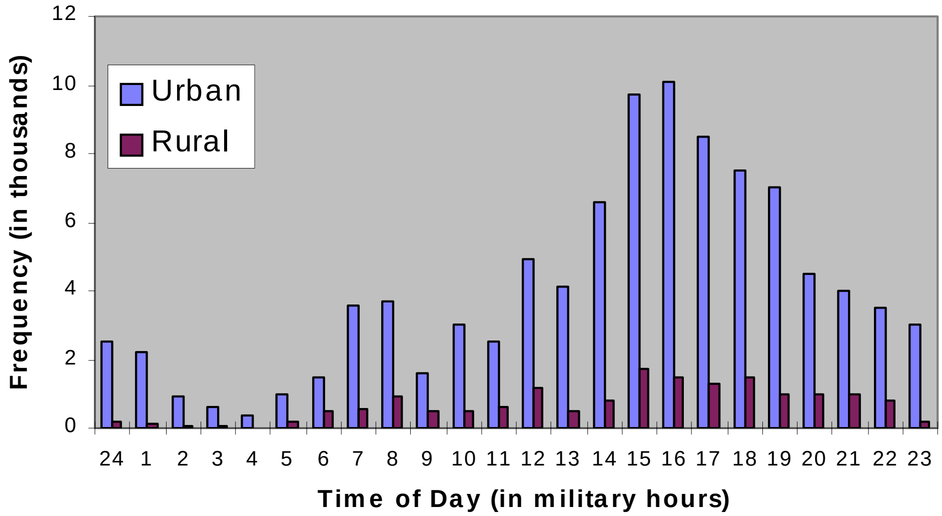

Figure 7. Pedestrian injuries by time of day for urban and rural land use. Source: Cove, 1990.

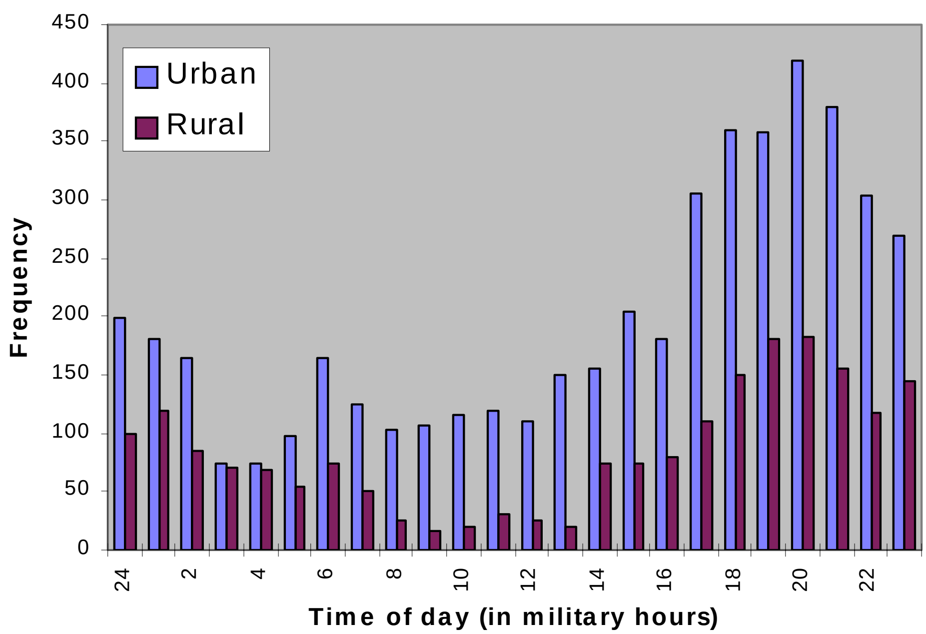

Figure 8. Pedestrian fatalities by time of day for urban and rural land use. Source: Cove, 1990.

Table 7. Fatal and non-fatal pedestrian crash types by light condition.

Pedestrian Crash Type	Light Condition*/Percent of All Crashes			
	Daylight	Dawn/Dusk	Dark, Street Light	Dark, No Street Light
Bus related	72.7	4.5	20.5	2.3
Other vehicle specific	74.2	2.2	13.5	10.1
Driverless vehicle	82.4	4.1	4.1	9.5
Backing vehicle	72.0	3.2	19.1	5.7
Disabled vehicle	40.0	6.7	16.7	36.7
Working/playing in road	74.7	8.2	11.6	5.5
Walking along roadway	33.5	5.5	19.4	41.6
Not in road	67.8	4.2	22.6	5.4
Vehicle turning at intersection	72.0	5.3	20.5	2.2
Intersection dash	70.9	4.5	20.4	4.2
Driver violation at intersection	63.1	2.7	32.9	1.2
Other intersection	53.8	4.4	34.8	7.0
Midblock dart/dash	73.4	5.7	14.7	6.2
Other midblock	46.8	3.4	32.1	17.7
Miscellaneous	49.5	3.8	28.6	18.1
ALL CRASHES	60.6	4.6	23.3	11.6

*Cases with unknown light condition excluded.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s* Hunter, W., Stutts, J.,Pein, W., Cox, C., UNC HSRC, FHWA-RD-95-163, 1996.

The nighttime association with fatal crashes is emphasized in a study of the effects of daylight savings time (DST) (Ferguson et al., 1995). This study asserts that if DST were retained year-round, approximately 900 additional traffic deaths would be avoided (727 pedestrians and 174 motor vehicle occupants, say the authors) because the DST clock setting results in more daylight at the end of the day, when fatal crashes are more likely, an advantage that is apparently not fully offset by the comparably less daylight during the morning hours.

B. DAY OF WEEK

Pedestrian crashes also vary by day of week. Available data indicate that pedestrian crashes are overrepresented on Friday and Saturday and are underrepresented on Sunday. These trends may be related to such factors as: the amount of walking by day of week; less pedestrian interaction with rush-hour traffic; and/or less late-night drinking and walking. A Wayne County, MI, study (Davis and Huelke, 1969) reported that 35 percent of the crashes there occurred on Friday and Saturday. This was especially true for children, with Friday being the highest crash day. Similar patterns were found for urban, suburban, and rural data samples from a number of U.S. cities and counties (Knoblauch, 1977). The highest overrepresentation of pedestrian crashes was on Friday.

Data dealing with pedestrian fatalities also reveal that Friday and Saturday have the greatest percentages of such crashes for both rural and urban areas, with pedestrian fatalities nearly constant for Sunday through Wednesday (see figure 9). Pedestrian crashes resulting in non-fatal injuries were most prevalent on Fridays and lowest on Sundays (Cove, 1990).

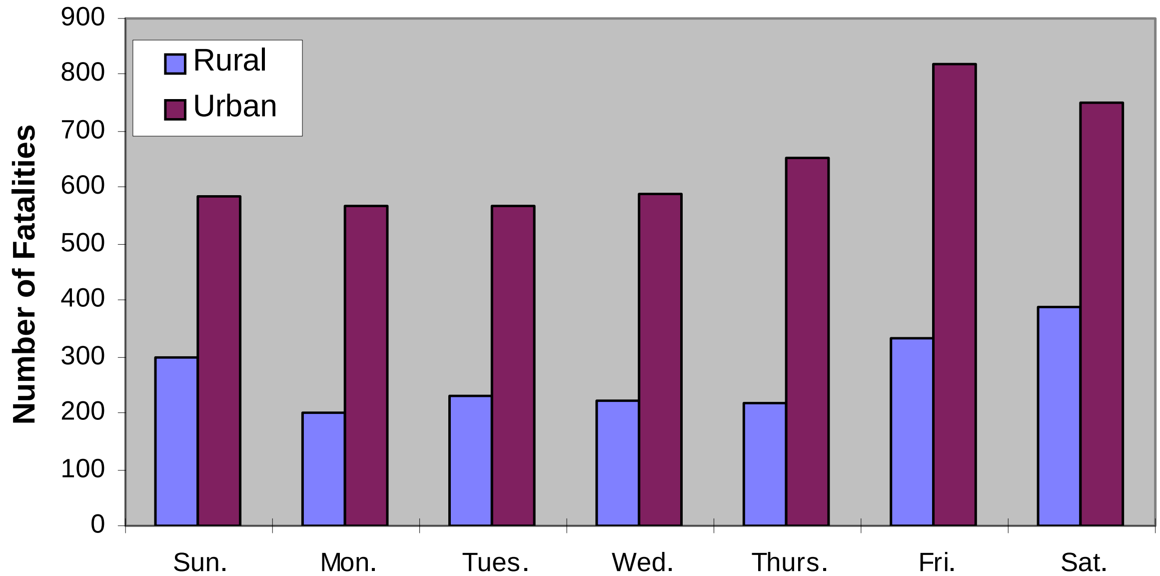

Figure 9. Pedestrian fatalities by day of week for urban and rural land use. Source: Cove, 1990.

C. MONTH OF YEAR

Beyond the trends by hour of day and day of week, there are also differences in U.S. pedestrian crashes by season of year, mediated in part by factors related to pedestrian age. Figure 10 shows that among older pedestrians, more crashes occur during the fall and winter months, whereas among younger pedestrians more occur during the spring and summer (Zegeer et al., 1993).

Consistent with the above, a study conducted in Wayne County, MI (Davis and Huelke, 1969) showed that more pedestrians (13 percent) were killed during December than in any other month. A study of rural and urban data samples of U.S. areas (Knoblauch, 1977) showed December to be the month having the greatest overrepresentation. Nationwide pedestrian fatalities in 1989 were found to be highest in September through January (Figure 11), months with fewer daylight hours and more inclement weather.

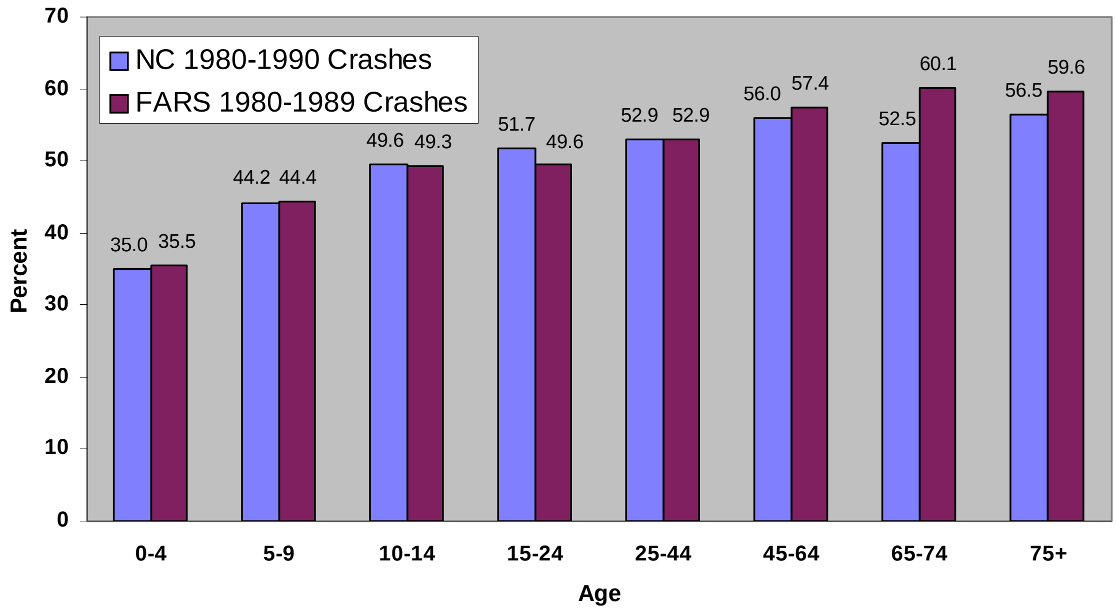

Figure 10. Pedestrian crashes by age and occurring in fall or winter months. (September—February).
Source: Zegeer et al., 1993.

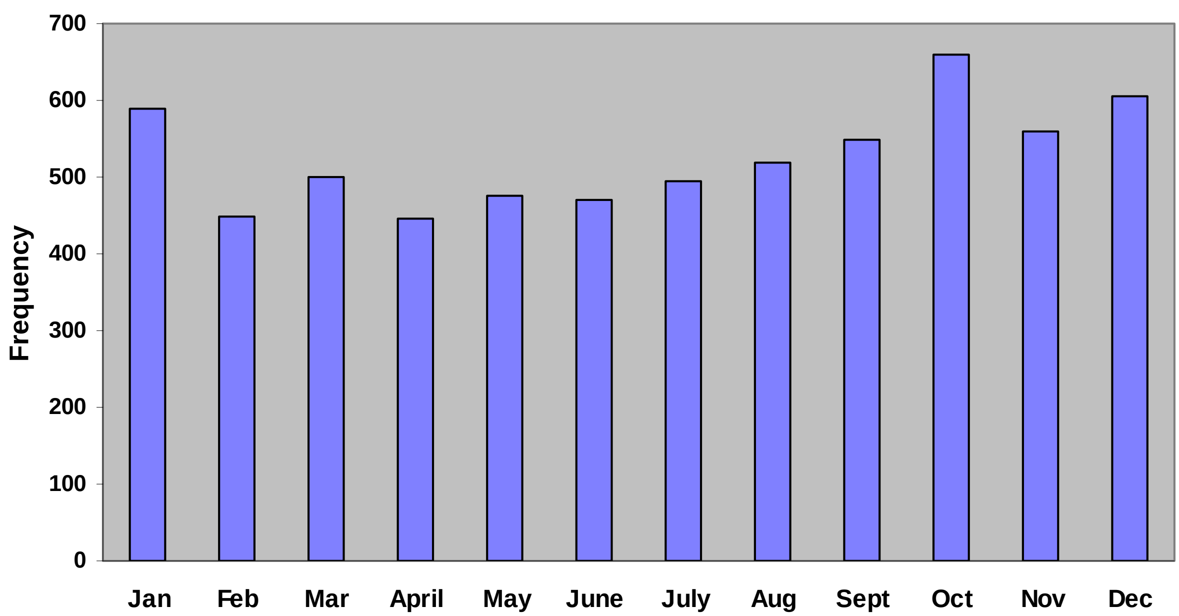

Figure 11. Pedestrian fatalities by month.
Source: Cove, 1990.

D. SUMMARY: WHEN DO PEDESTRIAN COLLISIONS OCCUR?

1. Fatal pedestrian crashes tend to occur during nighttime hours.

2. Non-fatal pedestrian crashes tend to occur during daytime hours.

3. Pedestrian crashes are more frequent on Friday and Saturday and less frequent on Sunday.

4. Child-pedestrian crashes occur more often during summer.

5. Adult pedestrian crashes occur more often in the winter.

6. Type of pedestrian crashes also varies with time of day, day of week, and season.

Who Is Involved in Pedestrian Crashes?

A. AGE

Table 8 shows that the largest percentage of pedestrian deaths is seen for the two age groups that span the 25-44 year age range. A total of 31.8 percent (15.4 percent + 16.4 percent) of pedestrian fatalities occur in this age range, a greater percentage than for the 5 preceding age groups combined. (Note the varying age intervals used in this table prepared by NHTSA [*Traffic Accident Facts*, 1995.] The 25-34 age category spans 10 years while the next lower category (21-24) only covers 4 years. Thus, the 15.4 percent of fatalities that falls in the 25-34 year category is not as much greater as might appear when compared with the next younger category, since the latter includes data from less than half as many years. Note also that 13.9 percent of fatalities fall in the oldest category [greater than 75 years old]; however, the open-ended age span of this category includes data from more years than the immediately preceding category. Overall, more than twice as many male pedestrians (3742) are killed as female (1727) pedestrians.

The final column shows fatalities expressed as deaths per 100,000 persons in a given age category. The oldest age category stands in greatest contrast to the rest.

The oldest age category does not contrast as sharply to the next younger age groups in terms of injury statistics (non-fatal). This may stem in part from the fact that older pedestrians are more likely to succumb to their injuries than younger adults. Children may be more likely to survive collisions on lower speed neighborhood streets. The difference in injuries between male and female pedestrians is less than that for fatalities. The ratio of male/female pedestrian injuries is 1.4 while the ratio of male/female pedestrian deaths is 2.2.

For “all” pedestrian crashes (Hunter et al., 1996), the distribution by age is more similar to injury crashes than to fatal crashes. Also, the ratio of male to female differs. In fatal crashes, there are more males in every age category, but in “all” crashes, males make up fewer than half of the cases in several age categories, including the 10-20 year age range and the categories that include persons 55 years old and older. In this database, 61 percent of the pedestrians involved in a collision were males. In short, samples of fatal pedestrian crashes are more likely to involve males and ages 25-54 compared to nonfatal pedestrian crashes.

Table 8. Pedestrian deaths, injuries, and total collisions by gender of victim.

	Killed[1]							
	Male		Female		Total			Deaths/
	N	%	N	%	N	%	M/F	100,000 pop.
Age <5	148	3.9	86	5.0	234	4.3	1.7	1.2
5-9	196	5.2	96	5.6	292	5.3	2.0	1.6
10-15	179	4.8	101	5.8	280	5.1	1.8	1.2
16-20	188	5.0	82	4.7	270	4.9	2.3	1.5
21-24	221	5.9	61	3.5	282	5.2	3.6	1.9
25-34	637	17.0	207	12.0	844	15.4	3.1	2.0
35-44	670	17.9	227	13.1	897	16.4	3.0	2.2
45-54	439	11.7	172	10.0	611	11.2	2.6	2.0
55-64	305	8.2	152	8.8	457	8.4	2.0	2.2
65-74	288	7.7	200	11.6	488	8.9	1.4	2.6
75+	427	11.4	334	19.3	761	13.9	1.3	5.3
Unknown	44		9		56			
Total	3742		1727		5472		2.2	
	Injured[1]							
Age <5	2229	4.3	1810	4.8	4039	4.5	1.2	
5-9	7523	14.6	4629	12.2	12152	13.6	1.6	
10-15	8007	15.5	6637	17.4	14642	16.3	1.2	
16-20	5030	9.8	5038	13.2	10068	11.2	1.0	
21-24	2357	4.6	3778	9.9	6135	6.8	0.6	
25-34	7456	14.5	3733	9.8	11188	12.5	2.0	
35-44	7307	14.2	4818	12.6	12124	13.5	1.5	
45-54	4355	8.5	3024	7.9	7379	8.2	1.4	
55-64	3764	7.3	1266	3.3	5030	5.6	3.0	
65-74	1374	2.7	1719	4.5	3093	3.5	0.8	
75+	2121	4.1	1636	4.3	3757	4.2	1.3	
Total	51520		38088		89608		1.4	
	Total Collisions[2]							
Age <5	173	6.1	96	5.3	269	5.8	1.2	
5-9	390	13.7	207	11.5	597	12.9	1.2	
10-15	341	12.0	292	16.2	633	13.6	0.74	
16-20	265	9.3	202	11.2	467	10.1	0.83	
21-24	213	7.5	124	6.9	337	7.3	1.1	
25-34	556	19.6	286	15.9	842	18.2	1.2	
35-44	346	12.2	193	10.7	539	11.6	1.1	
45-54	189	6.6	104	5.8	293	6.3	1.1	
55-64	140	4.9	95	5.3	235	5.1	0.92	
65-74	109	3.8	83	4.6	192	4.1	0.83	
75+	120	4.2	115	6.4	235	5.1	0.66	
Total	2842		1797		4639		1.6	

[1]Source: *Traffic Safety Facts* 1994: Motor Vehicle Crash Data from FARS and GES
National Highway Traffic Safety Administration, US DOT, Washington, D.C., 1995.
[2]Source: *Pedestrian and Bicycle Crash Types of the Early 1990s*, Hunter, W., J. Stutts, W. Pein,
C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

Figure 12. Pedestrian groups overrepresented in pedestrian crashes include males and children. Older adults are more at risk for serious injury or death than younger pedestrians if struck by a motor vehicle.

Table 9 shows a relationship of crash type to age of the collision-involved pedestrian. Certain crash types are overrepresented in certain age groups. Among the youngest age group shown here, 0-9 years old, the intersection dash and the midblock dash account for 41 and 55 percent, respectively, even though only 19 percent of all crashes affect children in this age group. For the 10-14-year-old category, the crash types most overrepresented are bus related (24 percent) and the intersection dash (23 percent), compared with 11 percent overall. For the oldest age group, backing vehicles seem to constitute the greatest risk (19 percent).

Special mention should be made of children in pedestrian crashes because of their particular vulnerability. One study (Dunne et al., 1992) asserts that parents overestimate their children’s ability to handle street crossings. They overestimate what the children know and how well they will perform. The discrepancy between expectations and performance is greatest for the younger children (5 years old).

A German study reported that a significant portion of pedestrians younger than 6 years old and involved in a collision on the way to a playground were not accompanied by an adult (Kloeckner, et al., 1989). Injury severity was also greater in crashes involving unaccompanied children. Another study showed that children struck in a pedestrian collision that caused injury showed slightly poorer performance on a laboratory vigilance test than did a closely matched control group who were not in a collision (Pless et al., 1995).

Other factors of a more global, societal nature also are associated with a higher likelihood of a child’s involvement in a pedestrian collision. One study reports that children are four-to-five times more likely to be in a pedestrian collision in poor neighborhoods compared with well-to-do neighborhoods (Cagley, 1992). Another study reported the statistical association of lower family cohesion with a higher risk of a child pedestrian crash (Christoffel, 1996).

Children’s risk for a pedestrian collision reflect a number of factors, some of which can be addressed by a traffic engineer, while others are more properly addressed by various disciplines.

Table 9. Pedestrian crash types by age of pedestrian.

	PEDESTRIAN AGE*						
Pedestrian Crash Type Subgroup	**0-9**	**10-14**	**15-19**	**20-24**	**25-44**	**45-64**	**65+**
Bus related	23.8	23.8	35.7	2.4	9.5	2.4	2.4
Other vehicle-specific	37.5	13.6	3.4	4.6	21.6	8.0	11.4
Driverless vehicle	13.7	1.4	6.8	9.6	37.0	16.4	15.1
Backing vehicle	15.4	3.2	7.5	12.5	30.1	12.5	18.6
Disabled vehicle related	2.5	1.7	7.6	14.4	53.4	15.3	5.1
Working/playing in road	31.7	14.8	6.3	7.0	25.4	12.0	2.8
Walking along roadway	1.3	6.9	17.4	14.3	43.7	11.5	4.9
Not in road	14.3	10.0	13.4	9.4	30.6	12.0	10.3
Vehicle turning at intersection	4.4	8.3	9.8	9.1	33.3	21.2	13.9
Intersection dash	40.6	23.1	13.2	2.9	13.5	4.1	2.6
Driver violation at	7.9	13.0	11.1	9.1	33.6	11.1	14.2
Other intersection	8.5	14.9	9.5	8.9	31.0	12.6	14.7
Midblock dart/dash	55.2	16.2	6.0	4.1	12.5	2.9	3.2
Other midblock	14.1	7.8	9.7	8.9	33.3	15.3	10.9
Miscellaneous	4.1	7.5	18.5	14.6	40.3	9.4	5.5
ALL CRASHES	18.7	11.1	10.9	9.0	29.7	11.4	9.2

*Row percents. Cases with unknown age excluded.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s* Hunter, W., J. Stutts, W. Pein, C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

B. GENDER

More males than females are seen in every single age category for fatal crashes (table 8). The ratio of male to female deaths varies from 3.6 to 1 in the 21 to 24 age group, down to 1.3 to 1 in the oldest age group. Despite the greater numbers of females compared to males in the 65+ age group, males slightly outnumber females in pedestrian fatalities; indicating that if the male and female populations in this age group were equal, the ratio of male to female fatalities would be even higher. Even in the youngest age group, pedestrians less than 5 years of age, the ratio of deaths among boys compared with girls is 1.7 to 1. In one study, boys were found to be involved in about twice as many pedestrian crashes as girls from 5 to 7 (*AAA Pedestrian Safety Report* 1984, 1977). Such differences between males and females have been observed for pedestrians as young as 2 years old. In an analysis of all pedestrian collisions in North Carolina for 1993, 1994, and 1995, crash records of 1,336 pedestrians were reviewed for those 12 years old or younger (Campbell, 1996). In this group, 61 percent were male. Even among 3-year-olds in pedestrian crashes, 62 percent were male; among 2-year-olds, 66 percent were males. Only for the 2-year-old and younger category (54 percent male) did the proportion approach the baseline proportion of males seen in birth statistics. This indicates the possibility of fundamental differences between the behavior of young boys and girls, and/or in the way they are supervised, even as toddlers.

The trends for pedestrian crashes by gender are somewhat different when looking at non-fatal injuries (table 8). The heavy preponderance of males is not seen in each and every category. Also, the 5-to-9 and 10-to-15 age categories account for a larger proportion of total injuries than any other age categories, contrary to the trends seen when only fatalities are considered. For the sample of all crashes, female involvement is relatively greater. Males are overrepresented, and the degree of overrepresentation is greater in fatal crashes than in non-fatal crashes.

C. ALCOHOL

Studies have reported that alcohol impairment is a major problem for pedestrians and drivers. Most states have a statutory definition of driver impairment of 0.08 or 0.10 blood-alcohol concentration (BAC). While it is illegal to drive a motor vehicle with BACs of 0.10, there is no such prohibition for walking.

One study reported that from 1980 and 1989, between 37 and 44 percent of fatally injured pedestrians had BACs of 0.10 percent or greater (*Alcohol Fatality Facts*, 1990). These percentages were slightly lower than for fatalities involving passengers, vehicle operators, and motorcycle operators. Among adults pedestrians killed in 1989 nighttime collisions with motor vehicles, 59 percent had BACs of 0.10 percent or greater, while only 31 percent had no alcohol in their blood.

One Phoenix study showed that 29 percent of all pedestrians involved in collisions had been drinking, while only 4.4 percent of the drivers had been drinking before the collision (another 13 percent of these drivers had an “unknown” physical condition, likely due to “Hit and Run” [Cynecki, 1998]. Considering that many pedestrians are younger than legal drinking age, but most of the drivers are of legal drinking age, this difference is substantial.

The percentage of fatally injured pedestrians with high BACs (0.10 percent or more) did not decline during the 1980s. This contrasts a 20-percent decrease in high BACs for drivers during that period (*Alcohol Fatality Facts*, 1990; Williams and Lund, 1990).

A study of motor vehicle fatalities in North Carolina between 1972 and 1989 (figure 13) showed that between 42 and 61 percent of pedestrian fatalities involved pedestrians under the influence of alcohol (i.e., BAC of 0.10 percent or greater). This compared with the range of 53 to 64 percent of drivers of single-vehicle collisions who were under the influence. Among 176 fatally injured pedestrians tested in 1989 (*Rehabilitation Alcohol Test, 1990*), the following distribution was reported:

Pedestrian fatalities	Number of cases	Percentage of total cases
BACs of 0.10% or above	81	46
BAC less than 0.10% but had been drinking	5	3
No alcohol	90	51
Total	176	100

Figure 13. Studies have found that approximately half of pedestrian fatalities in motor vehicle crashes involve pedestrians under the influence of alcohol.

Alcohol and age are associated in pedestrian crashes (Zegeer et al., 1993). The North Carolina data shown in figure 14 are the distribution by age of pedestrians in all reported crashes involving use of alcohol.
The FARS data address alcohol use among fatally injured pedestrians, broken down by pedestrian age.

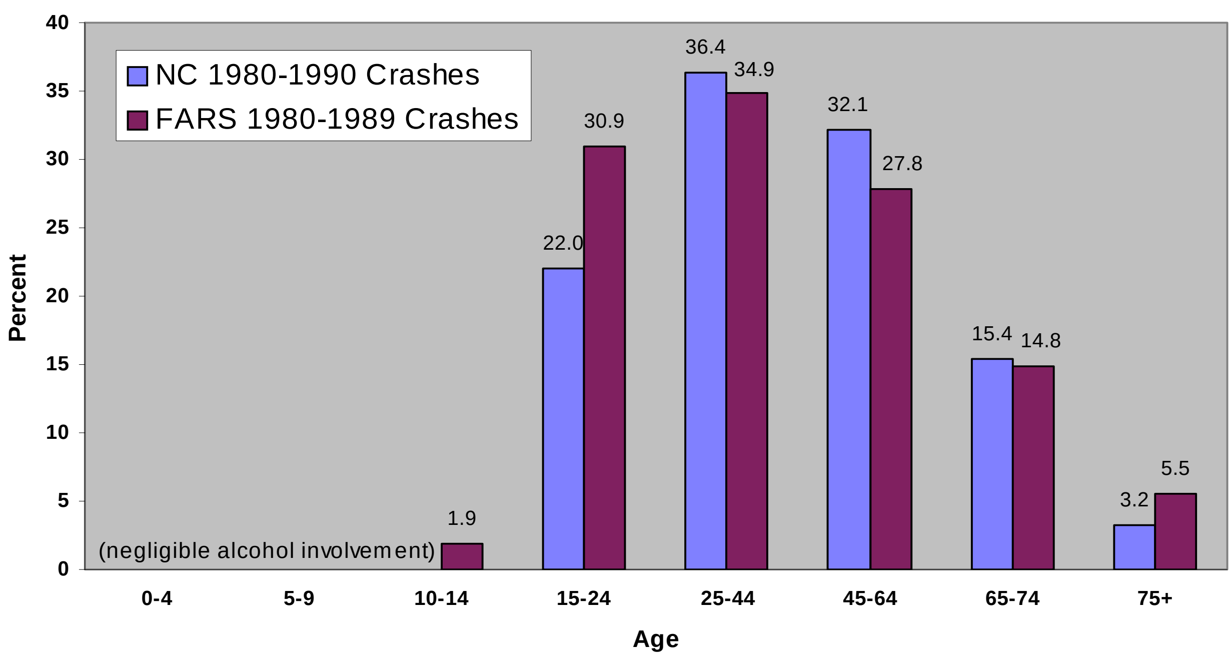

Figure 14. Percent of crashes involving pedestrians drinking alcohol. Source: Zegeer et al., 1993.

Alcohol is most often present for pedestrians 25-44 years old, with the proportion declining for older pedestrian age categories. These findings indicate that part of the overall age distribution in pedestrian crashes is related to alcohol use, although the involvement of the elderly in fatal pedestrian crashes seems likely to be attributable to factors other than alcohol.

As might be expected, pedestrian sobriety is also related to crash type (Hunter, et al., 1996). As seen in Table 10, 15.4 percent of all pedestrians in a collision were reported to be using alcohol or drugs before the collision. For certain crash types, however, the proportion is higher. For the crash type of walking along the roadway, the alcohol percentage for pedestrians is nearly double (29.6 percent). Adding to the significance of that figure is the fact that for drivers, the "walking along the road" crash type is likewise more frequent for drivers using alcohol or drugs (Hunter, et al., 1996).

Table 10. Pedestrian crash types by pedestrian sobriety.

	SOBRIETY*		
Pedestrian Crash Type Subgroup	No Alcohol or Drugs	Alcohol or Drugs	Other
Bus-related	97.1	2.9	0.0
Other vehicle-specific	87.2	5.1	7.7
Driverless vehicle	96.7	1.7	1.7
Backing vehicle	85.6	10.8	3.6
Disabled vehicle related	84.8	7.1	8.1
Working/playing in road	97.5	0.8	1.7
Walking along roadway	62.4	29.6	8.0
Not in road	85.0	10.6	4.4
Vehicle turning at intersection	91.1	5.3	3.6
Intersection dash	86.0	9.0	5.0
Driver violation at intersection	88.0	8.3	3.7
Other intersection	70.5	23.0	6.5
Midblock dart/dash	89.4	7.8	2.8
Other midblock	61.9	30.6	7.5
Miscellaneous	71.3	22.0	6.7
ALL CRASHES	79.4	15.4	5.2

*Cases with unknown sobriety excluded.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s*, Hunter, W., J. Stutts, W. Pein, C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

A 1992 study by Dickman and Cope (1992) reported on 4,329 injured pedestrians, of whom 2,109 (49 percent) had been drinking. The blood alcohol levels were:

BAC level	Number	Percent of total
0	2,220	51.2
0.01 - 0.099%	586	13.6
0.10 - 0.199%	486	11.2
0.20 - 0.299	686	15.9
0.30 or higher	351	8.1

A substantial proportion of those who had been drinking had seriously elevated BACs. Not only is alcohol use by pedestrians a significant factor associated with involvement in a crash, but it is also reported that excessive amounts of alcohol significantly increased the likelihood that death will result from the collision (Miles-Doan, 1996).

D. VEHICLE TYPE

Another factor related to the "who" of pedestrian crashes is vehicle type. In a NHTSA report (*Traffic Safety Facts*, 1995, table 93), pedestrian collision percentages with regard to vehicle type are:

Vehicle Type	Pedestrians Killed	Pedestrians Injured
Passenger car	55.8%	76.5%
Light truck	29.2%	20.0%
Other (including motor-cycles & heavy trucks)	15.0%	3.5%
	100%	100%

Light trucks as well as the "other" vehicle classes are more often represented in fatal pedestrian crashes than in injury crashes.

E. SUMMARY: WHO IS INVOLVED IN PEDESTRIAN COLLISIONS?

1. The largest percentage of pedestrian fatalities falls into the 25-44 age category.

2. However, when fatalities per 100,000 population is calculated, the oldest age category stands out higher than the rest.

3. Nevertheless, compared with their proportion in the U.S. population, children and young adults ages 2-22 are overrepresented in terms of pedestrian deaths and injuries.

4. More male than female fatalities are seen in every age category.

5. Even in the youngest age group, pedestrians less than 5 years of age, the population pedestrian death rate for males is 1.7 times greater than females, and males outnumber females in pedestrian collisions at the age of 2.

6. Alcohol is an important factor in pedestrian crashes. A North Carolina study showed that between 42 and 61 percent of fatally-injured pedestrians had BAC levels of 0.10 or greater.

There is some indication that pedestrians who have been drinking pose a greater threat to pedestrian safety than do drinking drivers.

7. Light trucks and "other" vehicles (e.g., heavy trucks) are overrepresented in pedestrian fatalities.

Where Do Pedestrian Collisions Occur?

A. RURAL VERSUS URBAN

The rural/urban distribution of pedestrian crashes is given in table 11, based on estimates by the NSC (*Accident Facts*, 1994). Of the estimated 71,200 pedestrian collisions in the United States in 1993, 75 percent occurred in urban areas, where pedestrian traffic is much higher than in rural areas. The table

Table 11. Pedestrian injuries and fatalities by area type.

Area Type	Non-fatal Injury		Fatal		Totals	
	Number	Percent (Raw %)	Number	Percent (Raw %)	Number	Percent (Raw %)
Rural	15,000	23.1	2,800	45.2	17,800	25.0
Urban	50,000	76.9	3,400	54.8	53,400	75.0
Totals	65,000	100.0	6,200	100.0	71,200	100.0

Source: *Crash Facts*, 1994

also shows that rural areas account for only 23.1 percent of nonfatal injury pedestrian crashes, but 45.2 percent of fatal pedestrian crashes. The overrepresentation of fatalities in rural areas is most likely because of the higher speeds and more severe crash types in rural areas.

Figure 15. Rural areas account for 23.1 percent of non-fatal injury pedestrian crashes, but 45.2 percent of pedestrian deaths.

B. LAND USE

Several studies that categorized pedestrian crashes by land use are summarized below:

Thirteen major cities (Snyder and Knoblauch, 1971)
Sample - 2,100 pedestrian crashes

Place	Percent of Crashes
Central business district	1
Residential area	50
Mixed commercial	7
Commercial area	40
School area	2

Wayne County, MI (Davis and Huelke, 1969)
Sample - 268 Fatal pedestrian crashes

Shopping business area	58
Residential area	29
School area	2
Expressway area	2
Other	9

Rural and suburban area sample (Knoblauch, 1977)

Residential area	50
Commercial area	24
Open area	16
School area	7
Other	3

Tucson, AZ (Nizlek, 1984)

Business area	60
Residential area	37
School crossing	1
Other	2

The four studies vary in definition of categories and outcome, but they are similar in the prominence of pedestrian crashes in residential and commercial areas where most pedestrian exposure occurs.

C. TRAFFIC CONTROL BY CRASH TYPE

Another way of describing pedestrian crashes is by the nature of any traffic control present at the pedestrian crash site. Table 12 is based on the aforementioned 1992 sample of 4,329 pedestrian crashes of all kinds (Diekman and Cope, 1992), and the following overall distribution is seen with respect to traffic controls:

Traffic Control Type	Percent of Pedestrian Collisions
No traffic control	74.4
Stop sign	7.0
Traffic signal	17.3
Other	1.4

	100

Specific types of crashes markedly depart from the above distribution. Thus, whereas 74 percent of pedestrian crashes happen where there is no traffic control, the value is 96 percent for crashes involving walking along the roadway. On the other hand, only 15.5 percent of pedestrian crashes that involve turning at an intersection occur where there is no traffic control (as compared with 74 percent overall). Overall, 7 percent of pedestrian crashes occur where a stop sign is the traffic control, but for vehicles turning at an intersection, the value is higher at 20 percent. As a final example, 17.3 percent of all pedestrian crashes occur at signalized locations, but the value is 63 percent for crashes involving vehicles turning at an intersection. Thus, a strong association with crash type accompanies the overall distribution of pedestrian crashes with respect to traffic control types.

Table 12. Pedestrian crash types by traffic control.

	TRAFFIC CONTROL*			
Pedestrian crash type	No control	Stop sign	Traffic signal	Other traffic control**
Bus-related	79.1	11.6	9.3	0.0
Other vehicle specific	90.6	4.7	4.7	0.0
Driverless vehicle	97.6	1.2	1.2	0.0
Backing vehicle	96.1	1.1	2.2	0.7
Disabled vehicle related	87.3	2.5	7.6	2.5
Working/playing in road	77.9	8.6	5.0	8.6
Walking along roadway	96.1	2.1	1.3	0.5
Not in road	94.3	3.1	0.9	1.7
Vehicle turning at intersection	15.5	20.0	63.3	1.2
Intersection dash	66.0	9.8	24.0	0.3
Driver violation at intersection	38.8	24.7	34.1	2.4
Other intersection	47.5	9.6	42.2	0.6
Midblock dart/dash	94.4	1.9	2.9	0.8
Other midblock	91.1	1.0	6.6	1.4
Miscellaneous	85.0	5.3	7.2	2.5
ALL CRASHES	74.4	7.0	17.3	1.4

*Cases with unknown traffic control excluded.
**Flashing signal, yield sign, railroad crossing, official flagger.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s*, Hunter, W., J. Stutts, W. Pein, C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

SPEED LIMIT BY CRASH TYPE

Table 13 shows pedestrian crashes according to the speed limit posted where the collision took place. The posted speed limit is certainly not a perfect indication of the actual speed at which a collision may occur. The overall distribution is:

Speed Limit	Percent Pedestrian Crashes
Speed limit to 40 km/h	27.0
48-56 km/h	46.9
64-73 km/h	14.3
81 km/h or greater	118.0
	100

Table 13. Pedestrian crash types by speed limit.

	SPEED LIMIT*			
Pedestrian Crash Type	< 40 km/h	48 to 56 km/h	64 to 73 km/h	81+ km/h
Bus related	23.7	68.4	5.3	2.6
Other vehicle specific	44.9	38.5	6.4	10.3
Driverless vehicle*	45.7	30.4	0.0	23.9
Backing vehicle**	50.0	38.7	2.8	8.5
Disabled vehicle related	4.7	24.3	16.8	54.2
Working/playing in road	39.2	36.8	8.0	16.0
Walking along roadway	14.3	32.7	16.2	36.8
Vehicle turning at intersection	20.8	65.8	11.9	1.6
Intersection dash	24.0	54.8	17.4	3.7
Driver violation at intersection	32.1	56.7	10.3	0.9
Other intersection	18.0	56.4	20.4	5.2
Midblock dart/dash	34.7	41.8	14.7	8.8
Other midblock	21.7	47.4	19.2	11.8
Miscellaneous	30.1	40.6	12.0	17.4
ALL CRASHES	27.0	46.9	14.3	11.8

*Cases with unknown speed limit excluded.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s* Hunter, W., J. Stutts. W. Pein, C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

Some specific crash types markedly differ from this breakdown. Pedestrian crashes involving a backing vehicle are higher on roads with low speed limits than overall (50 percent versus 27 percent). In contrast, for pedestrian crashes involving walking in the roadway, sites with higher speed limits account for more than expected (37 percent versus 12 percent), with a correspondingly smaller proportion at the lower speed limit sites (14 percent versus 27 percent).

E. INTERSECTION VERSUS NON-INTERSECTION

Almost 60 percent of U.S. urban pedestrian crashes occur at places other than intersections. In rural areas, the figure is closer to 67 percent. When considering fatalities, the proportion remains essentially the same in urban areas. In rural areas, approximately 85 percent of the deaths occur at places other than intersections (*Accident Facts*, 1988).

A 1977 survey of child pedestrian crashes in more than 1,900 cities indicated that approximately 75 percent occurred at non-intersection locations. This increases to between 80 and 90 percent for the 5-year-old-and-under age group (*AAA Pedestrian Safety Report*, 1984). This high percentage is likely associated in part with the high incidence of young children running into the street at midblock locations.

A 1989 summary of pedestrian injuries and deaths by age was estimated by NHTSA for intersections and nonintersections. As illustrated in figure 16, a majority of crashes involving pedestrians up to age 44 occurs at nonintersections. For ages 45-64, there almost is an equal number of pedestrian

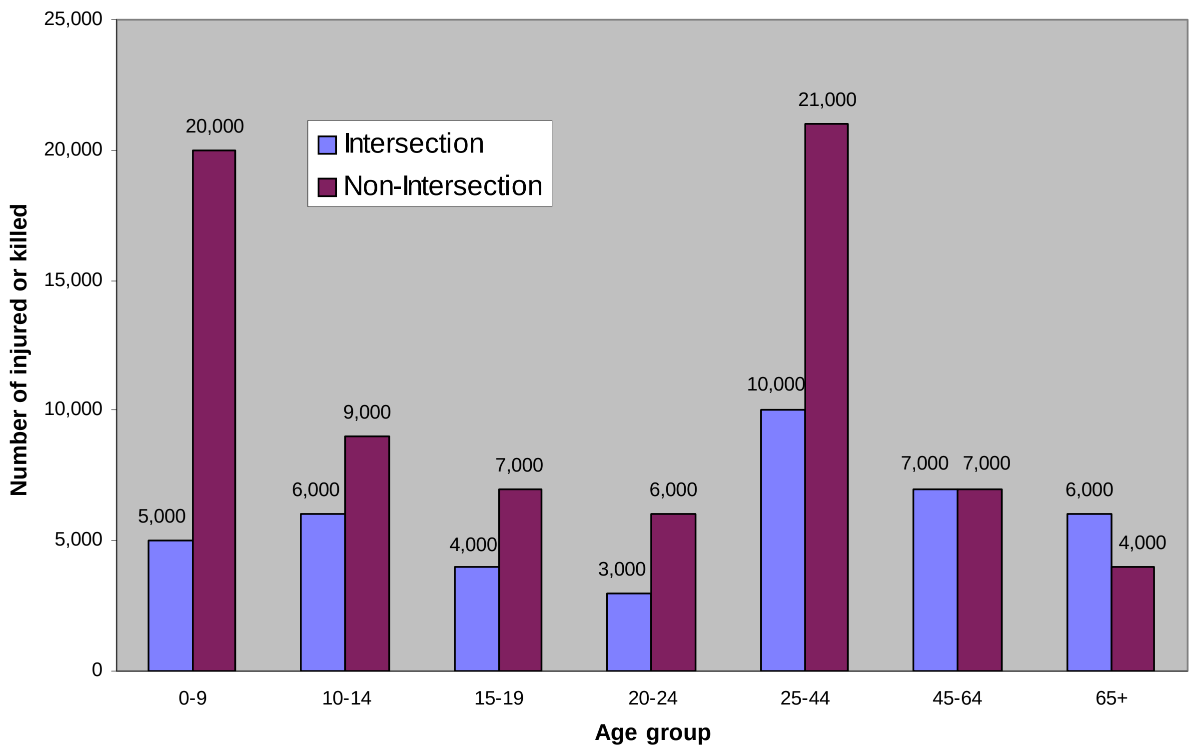

Figure 16. Pedestrian crashes (fatal and nonfatal) by age and intersection vs. nonintersection.
Source: General Estimates System, NHTSA, 1990.

crashes at intersections and nonintersections. For pedestrians age 65 and older, the trend reverses, and more are struck at intersections than at nonintersections. Although only limited pedestrian behavioral and survey data are available concerning choice of crossing locations, older pedestrians generally are more likely to cross at intersections than are younger ones (General Estimates System, 1990).

Figure 17. In U.S. cities, most pedestrian crashes occur at places other than intersections.

F. SUMMARY: WHERE DO PEDESTRIAN COLLISIONS OCCUR?

1. One study showed that about 85 percent of pedestrian collisions occur in urban areas and about 15 percent in rural areas. However, 25 percent of fatal pedestrian crashes occur in rural areas, reflecting the generally more severe character of pedestrian collisions outside urban areas.

2. Another study of pedestrian crashes showed a breakdown of 68 percent urban and 32 percent rural. In this study, certain crash types were overrepresented in some categories. In rural areas, pedestrians walking along the road were overrepresented. In urban areas, pedestrian crashes associated with driver violations at an intersection were overrepresented.

3. Overall, 74 percent of pedestrian crashes occur where there is no traffic control, 7 percent where there is a stop sign, and 17 percent in the presence of a traffic signal. However, this breakdown greatly varies by crash type. When pedestrian crashes involve a vehicle turning at an intersection, 63 percent occur where there is a traffic light, versus 17 percent overall.

4. With respect to speed limits, most pedestrian crashes occur where speed limits are low or moderate.

5. Though most pedestrian crashes occur in urban areas, 60 percent of all pedestrian crashes in urban areas do not occur at intersections. This compares to 75 percent of child pedestrian crashes which occur not at an intersection. The percentage that do occur at intersections varies by crash type. Age is also a variable of importance, with 75 percent of child pedestrian crashes not at intersections, contrasting with the majority of the elderly that do occur at intersections.

How Do Pedestrian Collisions Occur?

A. CONTRIBUTING FACTORS

A considerable number of factors, singly or in combination, increase the likelihood of a pedestrian collision. Table 14 shows the breakdown of a series of contributing factors related to 5,073 pedestrians involved in crashes (Hunter, et al., 1996). These are shown in four groups:

Pedestrian contributing factors
Roadway/environment factors
Driver contributing factors
Vehicle factors.

It is noteworthy that for each of the four major data groupings, the largest single category is "None indicated." Thus, despite numerous categories for assigning crashes, an appreciable portion of crashes defy such categorization. (This is all the more noteworthy because a main purpose of Hunter's study was to categorize pedestrian crashes.)

With respect to "Pedestrian Factors", the largest single category is "ran into road." Yet this category accounts for only 15 percent of collisions. Many other contributing factors are cited, but each is identified in only a small percent of cases. The largest specific "Roadway Factor" is "vision obstruction" (11 percent). For drivers, the largest category is "failure to yield right-of-way."

"Hit and run" is a somewhat larger category in the driver group, but such a classification tells nothing about the driver's actions that contributed to the crash, only that unlawful flight took place afterwards. Some characteristics of the hit-and-run situation are presented for fatal crashes in a 1995 study (Solnick and Hemenway, 1995). The authors examined the FARS database for 1989-1991 and listed factors that were over- or underrepresented in fatal hit-and-run situations. Overall, 20 percent of drivers left the scene:

Hit and run was less likely when:	victim was a child or was elderly
Hit and run was more likely when:	crash was in an urban area crash was outside of southern U.S. crash was at night or on a weekend driver was male driver was drunk driver had a bad past driving record

Vehicle factors are cited in only 12 percent of the cases. Because numerous factors can contribute to pedestrian collisions, and because each individual factor accounts for only a small portion of the crash total, a successful pedestrian collision prevention program must pursue many different countermeasures. Only a small portion of total collisions will be reduced by any given countermeasure.

Table 14. Factors contributing to pedestrian collisions.

Pedestrian Contributing Factors	N	%[1]	Driver Contributing Factors	N	%
None indicated	1719	33.9	None indicated	2263	44.6
Jaywalking (near intersection)	157	3.1	Hit and run	824	16.2
Ran into road	763	15.0	Exceeding safe speed	225	4.4
Stepped into road	207	4.1	Exceeding speed limit	87	1.7
Stepped from between parked vehicles	360	7.1	Reckless driving	171	3.4
			Failure to yield to ped.	762	15.0
Failed to yield	599	11.8	Failure to signal	4	0.1
Failed to obey signal	151	3.0	Ignored traffic sign	26	0.5
Unsafe movement	127	2.5	Ignored traffic signal	50	0.1
Alcohol impaired	524	10.3	Avoiding veh./ped./obj.	25	0.5
Drug impaired	20	0.4	Safe movement	243	4.8
Vision/hearing impaired	32	0.4	Improper backing	285	5.6
Other physical disability	13	0.3	Improper passing	36	0.7
Other mental disability	19	0.4	Improper turning	40	0.8
Walk/run wrong direction	267	5.3	Right turn on red	84	1.7
Talking/standing in road	158	3.1	Wrong direction	24	0.5
Lying in road	32	0.6	Improper lane use	35	0.7
Playing in road	78	1.5	Changing lanes	6	0.1
Jogging in road	15	0.3	Pass stopped school bus	9	0.2
Unsafe skateboard maneuver	13	0.3	Improper parking	6	0.1
Unsafe rollerblade maneuver	6	0.1	Fail to secure gear in park	93	1.8
Lack of conspicuity	147	2.9	Left engine running	12	0.2
Unsafe enter/exit of vehicle	37	0.7	Alcohol impairment	157	3.1
Fell from truck bed	1	0.0	Drug impairment	3	0.1
Working on parked car	50	1.0	Illness	5	0.1
Leaning/clinging to vehicle	82	1.6	Drowsy/fell asleep	4	0.1
Pushing disabled vehicle	6	0.1	Other physical impairment	14	0.3
Other	72	1.4	Inattention/distraction	213	4.2
Unknown	113	2.2	No driver's license	70	1.4
			Inexperience	21	0.4
Roadway/Environment Factors			Restriction non-compliance	3	0.1
None indicated	3801	74.9	Improper vehicle equipment	9	0.2
Sun glare	53	1.0	Assault by vehicle	63	1.2
Other glare	25	0.5	No lights	5	0.1
Dusk/darkness	162	3.2	Police pursuit	5	0.1
Vision blockage	539	10.6	Failed to secure cargo	2	0.0
Construction zone	56	1.1	Other	72	1.4
Glass/debris/etc.	7	0.1	Unknown	96	1.9
Pothole/grate/etc.	8	0.2			
Narrow roadway	2	0.0	**Vehicle Factors**		
Other	330	8.5	None indicated	4507	88.8
Unknown	36	0.7	No inspection sticker	2	0.0
			Oversized vehicle/load	4	0.1
			Extended mirror	19	0.4
			Defective brakes	15	0.3
			Defective lights	4	0.1
			Defective tires	12	0.2
			Foggy/dirty windshield	16	0.3
			Other	42	0.8
			Unknown	457	9.0

[1]N = 5073 (total number pedestrian cases with contributing factors). Since up to 3 factors could be coded in each category, the percentages add to more than 100.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s*, Hunter, W., J. Stutts, W. Pein, C. Cox, C. UNC HSRC, FHWA-RD-95-163, 1996.

Table 15 shows a breakdown of who was primarily responsible for causing a pedestrian collision according to a study that reported that police ascribe fault to the pedestrian in 43 percent of cases and to drivers in 35 percent (Hunter et al., 1996). These are only the overall values, however. In specific circumstances the results vary, as shown in table 16. For example, though drivers are at fault in about 35 percent of the situations overall, the figure is 88 percent for driver violations at intersections, and 79 percent in situations involving vehicles turning at an intersection. Drivers alone are at fault in as few as 18 percent of crashes involving pedestrians walking along the roadway, but are at least partially at fault in another 35 percent of these collisions.

Table 15. Pedestrian crash fault.

	N	Percent
Pedestrian only	2189	43.2
Ped. (Driver fault unknown)	170	3.4
Driver only	1764	34.8
Driver (Ped fault unknown)	104	2.1
Both ped. and driver	633	12.5
Neither ped. nor driver	50	1.0
Both unknown, unable to determine	163	3.2
Total	5,073	100.2

Source: Pedestrian and Bicycle Crash Types of the Early 1990s,
Hunter, W. J. Stutts, W. Pein, C. Cox,UNC HSRC, FHWA-RD-95-163,1996.

Figure 18. Pedestrians running into the road without looking are a factor in approximately 15 percent of pedestrian collisions.

When the pedestrian alone is at fault (43 percent of cases overall), the situation varies by crash type. When a vehicle is backing, the pedestrian is adjudged at fault only 10 percent of the time, but in an intersection or midblock dash, the pedestrian is adjudged at fault 91 percent of the time.

Table 16. Pedestrian crash types by party at fault (N=5,073).

	FAULT*						
Pedestrian Crash Type Subgroup	Driver Only	Driver; Pedestrian Unknown	Pedestrian Only	Pedestrian; Driver Unknown	Both	Neither	Unknown
Bus-related	34.1	0.0	50.0	2.3	9.1	2.3	2.3
Other vehicle specific	21.3	4.3	45.7	6.4	20.2	0.0	2.1
Backing vehicle	67.8	3.7	10.3	0.3	13.4	0.6	4.0
Disabled vehicle related	62.9	0.8	8.9	3.2	21.0	1.6	1.6
Working/playing in road	36.8	0.7	50.7	2.6	6.6	0.0	2.6
Walking along roadway	18.0	2.8	28.8	12.8	34.5	0.2	3.0
Ped. not in road	61.0	3.2	22.0	0.7	8.3	0.9	3.9
Vehicle turning at intersection	79.1	1.8	9.3	0.6	6.8	0.2	2.2
Intersection dash	0.6	0.0	90.6	2.2	6.6	0.0	0.0
Driver violation at intersection	87.6	3.9	0.4	0.4	6.6	0.0	1.2
Other intersection	12.6	3.3	59.5	5.5	11.4	0.4	7.3
Midblock dart/dash	1.0	0.2	91.8	1.8	5.0	0.2	0.0
Other midblock	11.5	2.2	60.4	5.3	16.0	0.5	4.1
Miscellaneous	39.3	2.0	21.7	3.3	18.9	7.1	7.8
ALL CRASHES	34.8	2.1	43.2	3.4	12.5	1.0	3.2

*Cases with unknown fault excluded.

Source: *Pedestrian and Bicycle Crash Types of the Early 1990s*, Hunter, W. J. Stutts, W. Pein, C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

B. CRASH TYPES AND CAUSAL BEHAVIOR

Several major U.S. studies of pedestrian behavior were based on field observations, on interviews with pedestrian safety professionals, and on data from collision reports (*AAA Pedestrian Safety Report*, 1984; *Rehabilitation Alcohol*, 1990; *Accident Facts*, 1988). These studies categorized crash types for urban, rural, and freeway locations as shown in Tables 17, 18, and 19 (*Model Pedestrian User's Manual*, 1987 edition, Knoblauch, 1975; Knoblauch, 1977; and Knoblauch, 1978). The objective of these studies was to identify crash causes and to develop countermeasures.

Another source of information is a study of freeway pedestrian crashes (Knoblauch et al., 1978), which examined driver and pedestrian activities leading to freeway pedestrian crashes. Table 20 gives the percentages of various driver activities preceding the crash, such as going straight, driving off the road, etc. The percentage distribution of pedestrian activities, such as running across the freeway, standing next to a disabled vehicle, etc., is in table 21.

Table 17. Urban pedestrian collision types and critical behavior descriptors (N=2,044).

Collision Type	Percent of Collisions Studied	Location and/or Critical Behavioral Descriptors
Dart out (first half)	23	Midblock (not at intersection). Pedestrian sudden appearance and short time exposure. Driver has no time to react to avoid collision. Pedestrian crossed less than halfway.
Dart out (second half)	9	Same as above except pedestrian gets more than halfway across before being struck.
Midblock dash	7	Midblock (not at intersection). Pedestrian running but *not* sudden appearance or short-term exposure as above.
Intersection dash	12	Intersection. Short time exposure *or* running. Same as "dart out" except occurs at intersection.
Vehicle turn merge with attention conflict	4	Intersection or vehicle merge location. Vehicle turning or merging into traffic. Driver attending to auto traffic in one direction collides with pedestrian located in direction different from driver's attention.
Turning vehicle	5	Intersection or vehicle merge location. Vehicle turning or merging into traffic. Driver attention not documented. Pedestrian not running.
Multiple threat	3	One or more vehicles stop in traffic lane (e.g., lane 1) for pedestrian. Pedestrian hit stepping into parallel same direction traffic lane (e.g., Lane 2) by vehicle moving in same direction as stopped vehicle. Collision vehicle driver's vision of pedestrian obstructed by stopped vehicle.
Bus stop related	2	At bus stop. Pedestrian steps out from in front of bus at bus stop and is struck by vehicle moving in same direction as bus while passing bus. Same as "multiple threat" except stopped vehicle is bus at bus stop.
Vendor, ice cream truck	2	Pedestrian struck while going to or from vendor in vehicle on street.
Disabled vehicle related	2	Pedestrian struck while working on or next to disabled vehicle.
Result of vehicle-vehicle crash	3	Pedestrian hit by vehicle(s) as result of vehicle-vehicle collision
Trapped	1	Signalized intersection. Pedestrian hit when traffic light turned red (for pedestrian) and cross-traffic vehicles started moving.

Source: *Knoblauch, 1975 and Model Pedestrian User's Manual,* 1987 edition.

Table 18. Rural pedestrian collision types and critical behavior descriptors (N=1,750).

Collision Type	Percent of Collisions Studied	Location and/or Critical Behavioral Descriptors
Dart out (first half)	11	Pedestrian sudden appearance, short time exposure. Driver does not have time to react to avoid collision. Pedestrian crossed less than halfway.
Dart out (second half)	10	Same as above except pedestrian more than halfway across before being struck.
Midblock dash	10	Midblock (not at intersection). Pedestrian running but *not* sudden appearance or short-term exposure as above.
Intersection dash	10	Intersection. Short time exposure *or* running. Same as "dart out" except occurs at intersection.
Vehicle turn merge with attention conflict	1	Intersection or vehicle merge location. Vehicle is turning or merging into traffic. Driver attending to auto traffic in one direction collides with pedestrian located in different direction than that of driver's attention.
Turning vehicle	2	Intersection or vehicle merge location. Vehicle turning or merging into traffic. Driver attention not documented. Pedestrian not running.
Multiple threat	2	One or more vehicles stop in traffic lane (e.g., Lane 1) for pedestrian. Pedestrian hit stepping into next parallel same direction traffic lane (e.g., Lane 2) by vehicle going in same direction as stopped vehicle. Collision vehicle driver's vision of pedestrian obstructed by stopped vehicle.
School bus related	3	Pedestrian hit while going to or from school bus or school bus stop.
Vendor, ice cream truck	1	Pedestrian struck while going to or from vendor in vehicle on street.
Disabled vehicle related	6	Pedestrian struck while working on or next to disabled vehicle.
Result of vehicle-vehicle crash	1	Pedestrian hit by vehicle(s) as result of vehicle-vehicle collision
Backing up	2	Pedestrian hit by vehicle backing up.
Walking along roadway	12	Pedestrian struck while walking along edge of highway or on shoulder. Can be walking facing or in same direction as traffic.
Hitchhiking	2	Pedestrian hit while attempting to thumb ride.
Weird	8	Unusual circumstances. Not countermeasure corrective.

Source: *Knoblauch, 1977 and Model Pedestrian User's Manual*, 1987 edition.

Table 19. Freeway pedestrian collision types and critical behavior descriptors (N=236).

Collision Type	Percent of Collisions Studied	Location and/or Critical Behavioral Descriptors
Disabled vehicle related	20	Pedestrian struck while working on or next to disabled vehicle.
Result of vehicle-vehicle crash	10	Pedestrian hit by vehicle(s) as result of vehicle-vehicle collision.
Weird	10	Unusual circumstances. Not countermeasure corrective.
Hitchhiking	9	Pedestrian hit while attempting to thumb ride.
Walking to/from disabled vehicle	8	Pedestrian struck while walking along edge or shoulder of highway. Reason for walking because of disabled vehicle. Can be walking facing or in same direction as traffic.
Dart out	5	Not at interchange. Pedestrian sudden appearance and short time exposure. Driver does not have time to react to avoid collision.
Walking along roadway	5	Pedestrian struck while walking along edge of highway or on shoulder. Can be walking facing or in same direction as traffic.
Working on roadway	3	Pedestrian (flagperson or other construction worker) struck while working on roadway or shoulder.
Midblock dash	*	Not at interchange. Pedestrian running but not sudden appearance or short time exposure.
Vehicle turn-merge with attention conflict	*	Vehicle merge location. Vehicle merging into traffic. Driver attending to auto traffic in one direction collides with pedestrian located in different direction than that of driver's attention.
Turning vehicle	*	Vehicle merge location. Vehicle merging into traffic. Driver attention not documented. Pedestrian not running.

*Less than 1 percent.
Source: *Knoblauch, 1978 and Model Pedestrian User's Manual,* 1987 Edition.

A 1980 study by Habib identified causal factors related to pedestrian crashes at intersection crosswalks and recommended possible solutions. While 51.4 percent of such pedestrian crashes in Habib's study involved a through vehicle, left-turn vehicle maneuvers were involved twice as often as right-turn crash maneuvers (24.8 percent vs. 13.1 percent). The left-turn maneuver was nearly four times as hazardous as the through-movement in terms of collisions and exposure. Also, driver error was found to increase when the left-turn movement was made as compared with right-turn maneuvers. Factors identified as contributing to the left-turn crashes with pedestrians include driver visibility problems, poor driver habits, and signal location.

Table 20. Driver activity leading to pedestrian collisions on freeways (N=236).

Percent of Pedestrian Collisions	Driver Activity
51	Going straight and/or sustaining speed
15	Driving off traveled way or out of control
9	Decelerating
8	Unknown
4	Other
3	Changing lanes
3	Speeding
1	Negotiating curve
1	Starting from stopped position
1	Backing up
1	Passing
1	Merging

Source: Knoblauch et al., 1978.

Table 21. Pedestrian activity leading to pedestrian collisions on freeways (N=236).

Percent of Pedestrian Collisions	Pedestrian Activity
21	Crossing, running
11	Standing next to a disabled vehicle
10	Crossing, walking
10	Working on a vehicle
10	Other
8	Walking with traffic
6	Standing
5	Flagging vehicle
4	Crossing, not further specified
3	Entering or exiting vehicle
3	Pushing vehicle
3	Unknown
2	Sitting or lying down
2	Walking against traffic
1	Working on roadway

Source: Knoblauch et al., 1978.

Obviously, a left-turning driver has a complex task. Oncoming traffic must be monitored to identify a safe gap to permit the turn. Traffic coming up from behind is also factor in the safety of the left-turning driver (risk of turning vehicle's being struck from rear). Add to this the necessity to monitor pedestrian traffic at the left of the driver's field of view and it is easy to realize that the left turn is a high-demand situation for the driver. Solutions proposed by Habib include changes in vehicle design to improve driver visibility, location of an additional signal mounted on the left far-side of the sidewalk, improved crosswalk illumination, and driver education concerning the problem.

Figure 19. Turning vehicles pose a particular threat to pedestrians at intersections.

A study of the causes of pedestrian collisions in Arizona by Matthias and Stonex (1985) found that urban pedestrian collisions and fatalities tended to occur on wide, high-speed arterial streets. Causes of approximately half of the pedestrian collisions were failure to yield by the driver or pedestrian and failure to use the crosswalk. The authors concluded that there was little in the way of engineering countermeasures that would be useful. They indicated that public education, particularly for children under 14 years of age, appeared to be the most useful countermeasure.

Many factors characterize pedestrian crashes. Some lend themselves to traffic engineering intervention to improve safety, but others are associated with general societal characteristics and generally beyond the traffic engineer's influence. For example, the 1990 Nationwide Personal Transportation Survey (Antonakos, 1995) characterized pedestrians as: slightly lower in socioeconomic status; less likely to be employed; less likely to own a motor vehicle; and less likely to be licensed to drive a motor vehicle.

Still, almost no one can avoid occasional pedestrian status.

C. SUMMARY: HOW DO PEDESTRIAN CRASHES OCCUR?

1. Many factors contribute to a pedestrian crash, but each contributes only a small portion to the crash totals. Any given crash-prevention measure, targeted to any one crash factor, is likely to produce only a small improvement overall.

2. It is reported that pedestrians are solely responsible for causing 43 percent of collisions and drivers solely responsible for 35 percent of collisions. The remainder have multiple causes or are caused by unknown factors.

3. Culpability varies by crash type, as would be expected. For crashes involving a midblock dash, pedestrians are judged at fault most of the time. Driver culpability is rated high for pedestrian crashes involving vehicles turning at an intersection.

How Severe Are Pedestrian Collisions?

A. FINDINGS

Although many pedestrians are killed in motor vehicle collisions, most pedestrian collisions do not result in fatal injuries, in spite of pedestrians' vulnerability in a collision with a 908-kg or 2000-lb rigid motor vehicle. Data from NHTSA (*Traffic Safety Facts*, 1995) show that in 1994 there were:

Pedestrian deaths	5,472
Incapacitating injuries	22,000
Not incapacitating injuries	30,000
Other injuries	38,000

Other data sources indicate that, in some pedestrian crashes, the police report indicates that the pedestrian is not injured. The injury scale shown here is one used by many police departments. The five-category scale is shown below along with the injury distribution reported by Hunter et al., 1996, who reported on 5,073 pedestrian crashes.

	Percent
No injury	3
"C" Injury (minor)	29
"B" Injury (moderate)	35
"A" Injury (severe)	27
Fatal	6

Table 22 shows how this injury distribution differs according to type of crash. Note the crash type categories that indicate most and least severe injuries. As to the fatal category, the greatest risk is "Walking along the roadway" (13.3 percent versus 6.1 percent fatal overall). At the other end of the scale, the crash types in which the largest number of pedestrians who escape with minor injuries or no injuries (that is, "C" injuries plus "No injuries") are those involving a backing vehicle, 42 percent compared with 31 percent overall. Speed is a likely factor in these differences. Pedestrian crashes resulting in little or no injury are more likely to go unreported than those in which the pedestrian was seriously injured or killed.

Table 22. Pedestrian crash types by pedestrian injury severity (N=5,073).

	INJURY SEVERITY*				
Pedestrian Crash Type Subgroup	**No Injury**	**Minor (C)**	**Moderate (B)**	**Severe (A)**	**Fatal**
Bus related	2.3	25.0	45.5	22.7	4.5
Other vehicle specific	0.0	24.7	43.8	25.8	5.6
Driverless vehicle	1.4	24.3	36.5	35.1	2.7
Backing vehicle	2.4	39.2	35.8	20.8	1.7
Disabled vehicle related	2.5	24.2	31.7	32.5	9.2
Working/playing in road	3.5	32.2	37.1	25.9	1.4
Walking along roadway	1.5	23.9	34.3	27.2	13.2
Not in road	3.3	31.9	36.4	24.7	3.6
Vehicle turning at intersection	2.4	44.6	34.5	16.6	1.8
Intersection dash	3.4	25.4	37.6	29.4	4.2
Driver violation at intersection	2.4	32.2	37.6	22.7	5.1
Other intersection	3.0	27.2	33.6	30.8	5.4
Midblock dart/dash	2.4	23.2	38.8	30.0	5.6
Other midblock	1.5	23.0	28.7	35.7	11.1
Miscellaneous	3.8	26.5	36.8	25.7	7.3
ALL CRASHES	2.5	28.7	35.3	27.4	6.1

*Cases with unknown injury severity excluded.
Source: *Pedestrian and Bicycle Crash Types of the Early 1990s*, Hunter, W., J. Stutts, W. Pein, C. Cox, UNC HSRC, FHWA-RD-95-163, 1996.

Figure 20 shows that injury severity is also related to age (Zegeer et al., 1993). Older persons succumb to injuries that a younger person might survive. Fatal injuries among the youngest age group also are elevated relative to the lowest point of the curve. Fatalities among those 0-4 years are greater than for the next two older age groups.

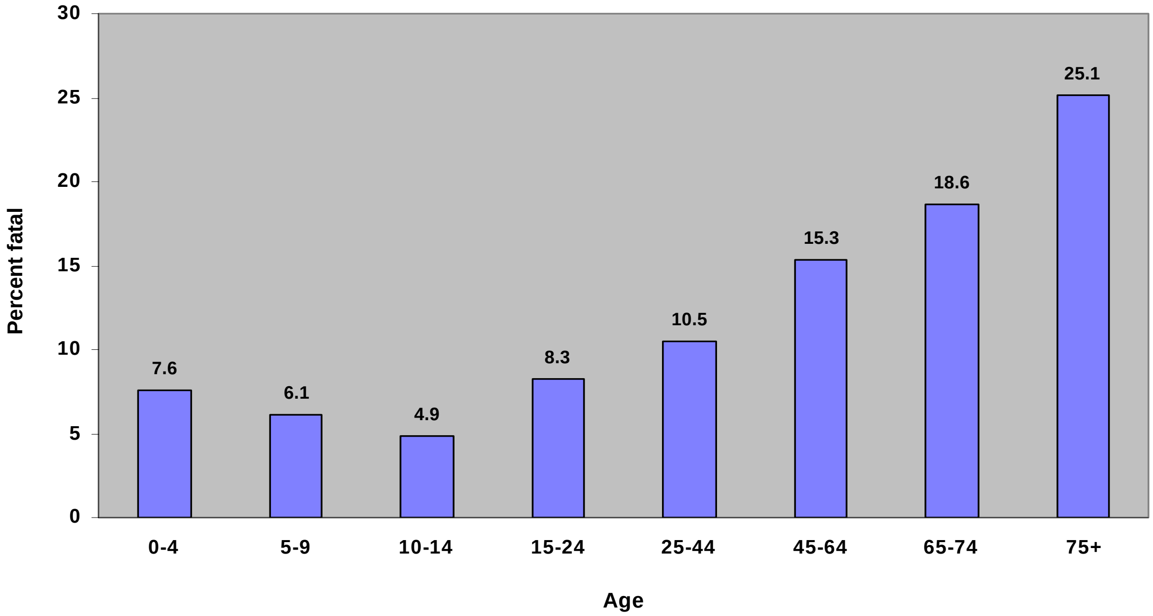

Figure 20 Percentage of pedestrian/motor vehicle crashes resulting in death, by pedestrian age, 1980-1990, North Carolina data. Source: Zegeer et al., 1993.

B. SUMMARY: HOW SEVERE ARE PEDESTRIAN COLLISIONS?

1. Although too many pedestrian crashes result in fatal injuries, the great majority of pedestrian collisions do not produce fatal injuries.

2. Some crash types are overrepresented in fatal outcomes. The walking-along-the-roadway crash type is an example.

3. Some crash types are overrepresented in less severe outcomes. This includes pedestrian crashes involving backing vehicles and those involving driver violations at an intersection.

4. Older pedestrians are more likely to die from injuries in a collision than are younger pedestrians.

Summary of Pedestrian Collision Statistics

1. Fatal pedestrian crashes tend to occur at night.

2. Nonfatal pedestrian crashes tend to occur during the day.

3. Pedestrian crashes are more frequent on Friday and Saturday and less frequent on Sunday.

4. Child pedestrian crashes occur more often in the summer.

5. Adult pedestrian crashes occur more often in the winter.

6. The largest percentage of fatal pedestrian crashes is in 25-44 age category.

7. The oldest age category (75 years or older) shows higher percentages of collisions per unit population.

8. Compared with their proportion in the U.S. population, children ages 21–22 are overrepresented in pedestrian deaths and injuries.

9. More male than female pedestrian fatalities are seen in every age category.

10. Some data show that even for children 2 and 3 years old, more males than females are struck.

11. Alcohol use by pedestrians is an important factor in pedestrian crashes. A North Carolina study showed that between 42 and 61 percent of fatally injured pedestrians were under the influence of alcohol (i.e., BAC of 0.10 or greater).

12. As might be expected, pedestrian sobriety is also associated with crash type. For the crash type of walking along the roadway, alcohol involvement is overrepresented for both drivers and pedestrians. While alcohol-related collisions are dropping in the driving population, there has been little change in alcohol-related collisions involving drinking pedestrians.

13. Vehicle types overrepresented in fatal pedestrian crashes include the light truck category as well as heavy trucks and motorcycles.

14. One study shows that approximately 85 percent of pedestrian crashes occur in urban areas and approximately 15 percent in rural areas. However, 25 percent of fatal pedestrian crashes occur in rural areas, showing the disproportionately severe character of such pedestrian crashes.

15. Another study of pedestrian collisions showed a breakdown of 68 percent urban and 32 percent rural. Certain crash types were overrepresented in each category. In rural areas, pedestrian crashes involving walking along the road were overrepresented. In urban areas, pedestrian crashes involving driver violations at an intersection were overrepresented.

16. Three-quarters of pedestrian crashes occur where there are no traffic controls, 7 percent where there is a stop sign, and 17 percent where there is a traffic signal. However, this varies by crash type. For the crash type of walking along the roadway, 96 percent occur where there is no traffic control versus 74 percent overall. For the category of vehicle turning at an intersection, 63 percent occur where there is a traffic light, versus 17 percent overall.

17. With respect to speed limits, most pedestrian crashes occur where speed limits are low or moderate (consistent with the fact that most pedestrian crashes occur in urban areas).

18. Approximately 40 percent of pedestrian crashes occur at intersections, although 75 percent of child pedestrian crashes are not at intersections. The majority of pedestrian crashes involving the elderly do occur at intersections.

19. Many factors contribute to a pedestrian crash, but no single factor accounts for a sizable percentage of crashes. Thus, any given crash prevention measure, targeted to address any one factor, can produce only a small overall improvement.

20. Pedestrians are solely culpable in 43 percent of crashes and drivers in 35 percent of crashes.

21. Culpability varies by crash type. For crashes involving a midblock dash, pedestrians are found at fault most of the time. Drivers are more often categorized as culpable in crashes involving vehicles turning at an intersection.

22. Some crash types are overrepresented in fatal outcomes. Walking along the road is an example.

23. Some crash types are overrepresented in less severe outcomes. This includes pedestrian crashes involving backing vehicles.

Figure 21. Some pedestrian crash types are overrepresented in fatal outcomes, including walking along road.

Exposure-Based Hazard Index

Several studies have addressed the need for a measure of the relative exposure to hazards based on pedestrian crash statistics (Knoblauch, 1977; Lea et al., 1978; Goodwin and Hutchinson, 1977).

In 1977, Knoblauch developed a hazard index, defined as the ratio of the frequency with which any particular attribute was present in the crash sample to the frequency with which it was present in the general population at the site (base rate), at approximately the same time of day. Tables 23 and 24 show the relative hazards of pedestrian and vehicle actions derived in this manner. Table 23 shows that while crossing at a location other than an intersection was the most frequent action identified in the pedestrian crash sample, when compared with non-involved pedestrian actions at the site, it is a substantially less hazardous action than, for example, standing in the roadway. Similarly, out-of-control and backing vehicles are shown to be extremely hazardous to the pedestrian compared with turning vehicles. This procedure did not take collision severity into account when defining a hazard index (fortunately, these collisions are of low severity). The hazard index was computed based on the percent of pedestrian crashes divided by the relative exposure. Thus, for example, in table 24, the hazard index for "vehicle straight ahead" was relatively safe (hazard index of 0.9), even though 77.2 percent of pedestrian crashes involved a vehicle traveling straight ahead. This is because 85.1 percent of the vehicle exposure involved the straight ahead vehicle movements. Thus, the ratio of crash percentage divided by exposure percentage = (77.2) ÷ (85.1) = 0.9

Table 23. Pedestrian action and crash data with resulting hazard index.

Pedestrian Action	Crash Data Percent	Base Rate Data Percent	Hazard Index	
			Safer	More Hazardous
Standing in roadway	8.1	1.5		5.4
Coming from behind parked vehicle	5.3	1.1		4.8
Working in roadway	2.2	0.8		2.8
Working on vehicle	3.5	1.8		1.9
Crossing, not at intersection	39.4	27.0		1.5
Walking in road with traffic	10.8	12.3	0.9	
Playing in road	3.6	4.9	0.7	
Walking in road against traffic	4.8	8.0	0.6	
Crossing at intersection	18.3	29.0	0.6	
Getting on/off school bus	1.6	3.6	0.4	
Getting on/off other vehicle	2.4	9.9	0.2	

Source: Knoblauch, 1977.

Table 24. Vehicle action and pedestrian collision data with resulting hazard index.

Vehicle Action	Crash Data Percent	Base Rate Data Percent	Hazard Index	
			Safer	More Hazardous
Out of control	2.7	0.0		
Backing up	3.0	0.1		3.0
Passing	2.5	0.1		2.5
Other	3.6	0.2		1.8
Standing in roadway	1.9	0.5		3.8
Changing lanes	1.2	0.4		3.0
Going straight ahead	77.2	85.1	0.9	
Turning right	2.3	5.1	0.5	
Turning left	2.2	5.2	0.4	

Source: Knoblauch, 1977.

In a later study, additional hazard relationships were updated, as shown in figure 22 (Knoblauch et al., 1987). Samples of pedestrian crashes and exposure were used to develop hazard scores for various pedestrian and vehicle characteristics. Scores of +1 or higher represent higher–than–average and -l- or less, a safer–than–average level of hazard. Pedestrians aged 1 to 4 years old had the highest hazard scores (+8.3); pedestrians aged 5-9 (+4.0), 10-14 (+1.2), and 60 and older (+1.7) had higher–than–average hazard scores. Running is more hazardous for pedestrians than walking (+4.7 vs. -1.9). Walking against a traffic signal has a hazard score of 5.1 compared with a score of -1.8 for crossing with the signal, while a right-turn-on-red maneuver by a motor vehicle was the most hazardous (score of +3.2) vehicle maneuver. Motorcycles and buses are associated with higher hazards to pedestrians (+3.3 and +2.9, respectively) than other vehicle types.

Conflict Analysis Hazard Formula

Conflict analysis has been used in a number of pedestrian crash studies to determine the hazard level as a basis for developing countermeasures (Knoblauch, 1977; Petzold, 1977; Zegeer et al., 1980; Husband and Sobey, 1978; Cynecki, 1980).

In a Rochester, MI, study, pedestrian conflicts were defined for school zones, based on observations at 10 school sites (Zegeer et al., 1980). These conflicts and events are:

- Vehicle slows or stops for pedestrian
- Secondary vehicle conflict resulting from the first vehicle slowing for pedestrian
- Vehicle weaves for crossing pedestrian
- Vehicle brakes or weaves for standing pedestrian
- Vehicle brakes or weaves for pedestrian walking on shoulder
- Turn conflict
- Pedestrian runs across street
- Pedestrian stops in street
- Pedestrian violation of traffic signal
- False start across street
- Jaywalking

The number of pedestrians crossing the street within the school zone, where pedestrians could be exposed to approaching vehicles, was also counted. The authors selected five conflict variables:

S - Severe conflicts
M - Moderate conflicts
R - Routine conflicts
J - Jaywalkers
C - Legal street crossings

Their relative contributions to hazard was determined by establishing weightings for an index using a delphi procedure. The result was the following formula for a subjective danger index (DI):

$$DI = 7.4\ S + 2.8\ M + 1.0\ R + 0.7\ J + 0.2\ C$$

This model was then proposed for use as a ranking tool for identifying high hazard school-zone sites and for guiding the selection of countermeasures.

A conflict analysis technique was developed by Cynecki (1980) for use in identifying hazardous pedestrian crossing locations. A total of 13 types of pedestrian conflicts were defined with assigned

Pedestrian and Vehicle Characteristics	Percentage of Pedestrian Accidents	Percentage of Pedestrians or Vehicles Observed	Hazard Score (Less Hazard -5 -3 -1 / More Hazard +1 +3 +5)
Pedestrian Age			
1-4	8.3	1.0	8.3
5-9	21.6	5.4	4.0
10-14	12.2	10.1	1.2
15-19	10.9	11.5	-1.1
20-29	18.4	22.6	-1.2
30-59	15.8	41.7	-2.6
60+	12.8	7.7	1.7
Pedestrian Mode			
Walking	47.1	88.8	-1.9
Running	52.9	11.2	4.7
Pedestrian Crossing Location			
Crosswalk	24.0	54.3	-2.3
Within 50' of Intersection	24.1	9.4	2.6
Diagonally Across Intersection	0.9	1.7	-1.9
Midblock	51.0	34.6	1.5
Pedestrian Signal Response			
With Signal: Green	51.3	90.4	-1.8
Against Signal: Red	48.7	9.6	5.1
Vehicle Action			
Going Straight	90.0	84.6	1.1
Turning Right	3.8	7.7	-2.0
Turning Left	4.6	7.2	-1.6
Right Turn on Red	1.6	0.5	3.2
Vehicle Type			
Cars	79.3	83.5	-1.1
Vans, Pickups	12.4	11.6	1.1
Trucks, Other	2.3	2.4	-1.0
Buses	2.0	0.7	2.9
Taxis	0.7	0.8	-1.1
Motorcycles	3.3	1.0	3.3

Figure 22. Relative hazard of selected pedestrian characteristics. Source: Knoblauch et al., 1987

severity levels. The technique was tested at five locations and used to select pedestrian crash countermeasures. The author recommended further investigation of relationships among pedestrian conflicts and vehicle-pedestrian crashes.

Another study that attempted to determine the relationship between pedestrian-vehicle conflicts and pedestrian crashes based on a predictive model used discriminate analysis to develop crash-group models for the cities of Washington, DC and Seattle, WA (Davis et al., 1989). These models were used to predict intersection groups expected to have, for example, 0, 1, 2, or 3 or more pedestrian crashes. The crash groups were defined based on conflicts, as well as such exposure measures as pedestrian volume, vehicle volume, number of lanes, and type of traffic control. The models were considered particularly useful in setting priorities for hazardous locations and for evaluating various traffic control strategies. The model was developed using a subset of the crash data, and then was at least partly validated by being applied to the remaining crash data.

PART 3. OVERVIEW OF PEDESTRIAN CRASH COUNTERMEASURES AND SAFETY PROGRAMS

Cautions Regarding Design Problems in Studies of Countermeasure Effectiveness

This report is based on a review of many evaluation studies of pedestrian safety initiatives, so it is useful to comment on the difficulties inherent in this kind of research and the study design problems that plague such research efforts.

First, research on the effectiveness of pedestrian safety initiatives is inherently difficult because pedestrian crashes are generally quite rare at any given location; therefore, a study may not have enough data for numerical stability. It is common that years will pass between instances of a pedestrian-vehicle collision at a given site. While the rarity of pedestrian collisions at a site is fortunate, it makes the study of countermeasures difficult.

To compensate for small numbers, investigators often aggregate data from many sites. Many intersections will be studied, and the study period will be extended for as long as possible because this is the only way that usable numbers of crashes can be accumulated. However, such aggregation of sites and long time periods creates other sources of crash variability, perhaps partly offsetting the benefit of the larger sample size.

The other significant problem is the almost inevitable study design flaws in many research efforts. These critical study design flaws include selection bias and regression to the mean. These particular study design problems generally are encountered because of the procedures used to decide where to install treatments.

Given limited funds and great needs, authorities earmark countermeasure sites based on some kind of priority procedure. It may be a formal warranting procedure, or an informal approach of placing the remedies where the problem is judged to be greatest. This latter procedure is prudent, and is completely justified from an operational standpoint. However, from a research standpoint it can be troublesome, especially in assessing pre- and post-treatment data.

The problem is that the sites where the treatments are introduced were usually different from the comparison sites before the interventions were introduced. That is why the treatments were put there rather than somewhere else.

This pre-existing difference is very likely to overwhelm the effect of the treatment. If the “after” experience is different from the “before” experience, one cannot know how much of the change was produced by the treatment and how much is a continuation of the pre-existing difference.

A special case of selection bias is regression to the mean. If the pretreatment collision record is the basis for introducing an intervention at a particular site, and if the “worst” sites are selected for introduction of countermeasures, then the after-crash experience will be better than before the experience because of the operation of the probability phenomenon called “regression to the mean.” When that particular flaw is embedded in a study design, one cannot know whether the favorable results are from the countermeasure, from the regression effects, or from a combination of the two.

Many studies reviewed herein likely suffer from one or the other of these study design flaws. This is not said as a particular criticism of the study authors: Sometimes it is virtually impossible to carry out a study without such flaws, given the manner in which operational decisions are made to install treatments.

If studies are to be done in a way that avoids these study design problems, it will be necessary to change the manner of deciding how treatments are to be introduced. These study design problems are not mentioned in many following reviews, but the reader should keep these cautions in mind in assessing the studies reported in the following discussion.

Marked Crosswalks

Crash Studies

Zegeer, Stewart, Huang and Lagerwey (2002) have completed what is the largest and most comprehensive study of marked crosswalks reported so far. The authors analyzed data from 1,000 marked crosswalk sites and 1,000 matching unmarked sites in 30 U.S. cities. Information was collected at each of the 2,000 sites, including pedestrian crash history (average of five years per site), daily pedestrian volume, traffic volume, number of lanes, speed limit, area type, type of median, type and condition of crosswalk marking, location type (midblock vs. intersection), and other site characteristics. All study sites were at intersection or midblock locations with no traffic signals or stop signs on the approaches. The comparatively large sample size permitted analysis of relevant data subsets.

A number of site factors were found to be related to crashes and therefore had to be used as control variables in the analysis. Such factors included: higher pedestrian average daily traffic (ADT), higher traffic ADT, and number of lanes (three or more lanes vs. two lanes). In addition, multilane roads with raised medians had significantly lower crash rates than similar roads with no median or painted medians only. There was also a significant regional effect: Sites in western U.S. cities had a significantly higher crash risk than in eastern U.S. cities (after controlling for other site conditions).

Some site factors were not found to be associated with crashes in and of themselves. These included area type, speed limit, and type of crosswalk marking pattern (see figure 12 for various crosswalk marking patterns from that study).

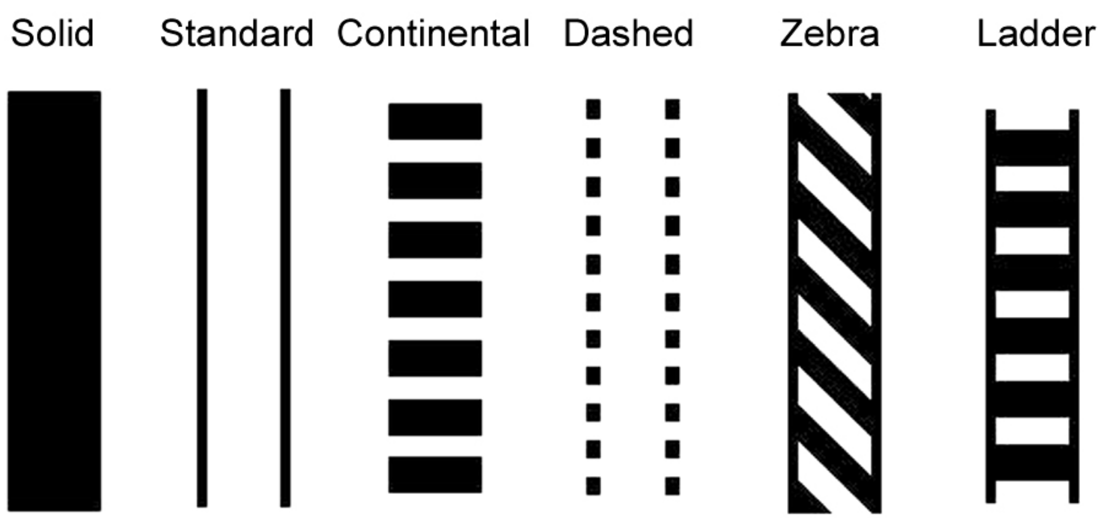

Figure 23. Crosswalk marking patterns.

All site factors that were related to crashes (i.e., pedestrian ADT, traffic ADT, number of lanes, median type, and region of the country) were then included in the statistical models used to determine effects of marked vs. unmarked crosswalks. (Poisson and negative binomial regression models were used.)

The study found that on two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate, compared to an unmarked crosswalk. Further, on multilane roads with traffic volumes above about 12,000 vehicles per day, having a marked crosswalk alone, without other substantial improvements, was associated with a higher pedestrian crash rate after controlling for other site factors, compared to an unmarked crosswalk (see figure 13). Raised medians provided significantly lower pedestrian crash rates on multilane roads, compared to roads with no raised median. Older pedestrians' crash rates were high relative to their crossing exposure.

The authors state (page 1): "Pedestrians are legitimate users of the transportation system, and they should, therefore, be able to use this system safely. Pedestrian needs in crossing streets should be identified, and appropriate solutions should be selected to improve pedestrian safety and access."

Some improvements suggested by the authors at unsignalized crossing locations:

- Providing raised medians on multilane roads, which can substantially reduce pedestrian crash risk and also facilitate street crossing
- Installing traffic signals (with pedestrian signals) where warranted and/or where serious pedestrian crossing problems exist
- Reducing the effective street-crossing distance for pedestrians by providing curb extensions and/or raised pedestrian islands, "road diets" (i.e., reducing four-lane undivided roads to two through-lanes with left-turn lane)
- Installing raised crossings (raised crosswalk, raised intersection, speed humps)
- Providing street-narrowing measures (chicanes, slow points, "skinny street," etc.)
- Using intersection designs (traffic mini-walks, diagonal diverters)
- Providing adequate nighttime lighting for pedestrians
- Designing safer intersections and driveways for pedestrians (e.g., tighter turn radii)
- Constructing grade-separated crossings or pedestrian-only streets
- Using innovative signs, signals and markings shown to be effective

Two studies by Knoblauch were conducted on pedestrian and motorist behavior as part of the overall FHWA study on crosswalks in conjunction with the study summarized above.

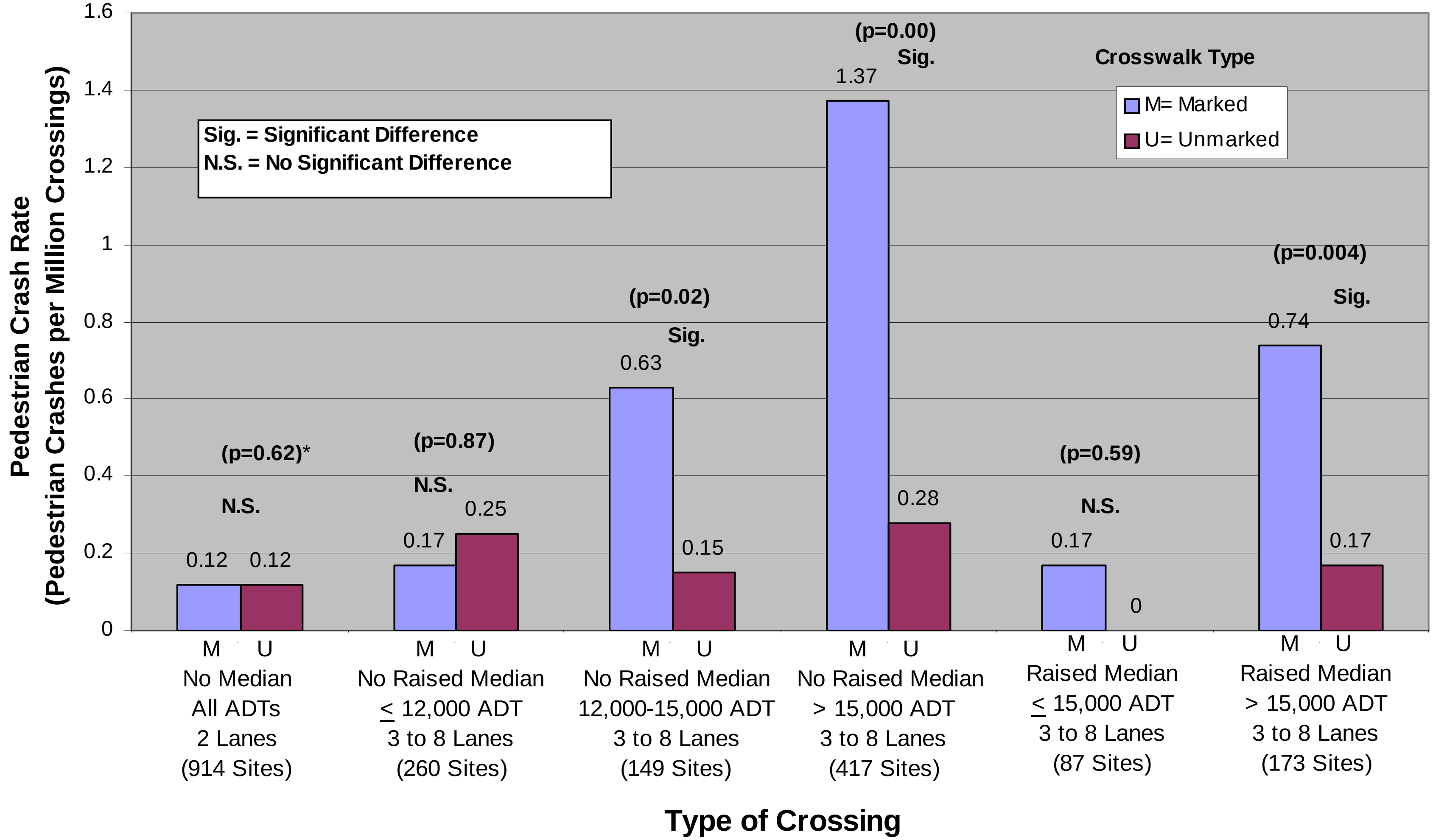

Figure 24. Pedestrian crash rates at types of crossing.

One study was conducted to determine the effect of crosswalk markings on driver and pedestrian behavior at unsignalized intersections (Knoblauch, Nitzburg, and Seifert, 2000). A before-and-after evaluation of crosswalk markings was conducted at 11 locations in 4 U.S. cities. Behavior observed included: pedestrian crossing location, vehicle speeds, driver yielding, and pedestrian crossing behavior. The authors found that drivers approach a pedestrian in a crosswalk somewhat slowly, and that crosswalk usage increases after markings are installed. No evidence was found indicating that pedestrians are less vigilant in a marked crosswalk. No changes were found in driver yielding or pedestrian assertiveness as a result of adding the marked crosswalk. Marking pedestrian crosswalks at relatively low-speed, low-volume, unsignalized intersections was not found to have any measurable negative effect on pedestrian or motorist behavior at the selected sites, which were all 2- or 3-lane roads with speed limits of 35 or 40 mph.

In a comparison study, a before-and-after evaluation of pedestrian crosswalk markings was performed in Maryland, Virginia, and Arizona (Knoblauch and Raymond, 2000). Six sites were selected that had been recently resurfaced. All sites were at uncontrolled intersections with a speed limit of 56 km/h (35 mi/h). "Before data" were collected after the centerline and edgeline delineation was installed but before the crosswalk was installed. "After" data were collected after the crosswalk markings were installed. Speed data were collected under three conditions: no pedestrian present, pedestrian looking, and pedestrian not looking. All pedestrian conditions involved a staged pedestrian. The results indicate a slight reduction at most, but not all, of the sites. Overall, there was a significant reduction in speed under both the no-pedestrian and the pedestrian-not-looking conditions.

These more recent studies must be considered in the context of contradictory results among several earlier studies. The above study shows that marked crosswalks do not differ in safety from unmarked crosswalks under most circumstances, while in the high-volume, multilane case, the use of marked crosswalks alone is associated with increased pedestrian risk. This does not fully agree with several other studies that reported that marked crosswalk crashes in general were much more frequent than at unmarked crosswalks. However, most of the older studies typically did not analyze the effects of marked crosswalks as a function of number of lanes, traffic volume, or other roadway factors.

For example, Herms (1972) authored an early and oft-quoted (and sometimes mis-quoted) study from San Diego, CA, reporting that crashes on marked crosswalks were twice as frequent per unit pedestrian volume. In this study, 400 intersections were selected, each having one marked and one unmarked crosswalk leg on the same street.

Herms made no mention in 1972 of warrants used to determine where to paint crosswalks, but an earlier version of the study did (Herms, 1970). The warrant directive for San Diego (January 15, 1962) established a point system calling for painting crosswalks when: 1) traffic gaps were fewer rather than more numerous; (2) pedestrian volume was high; (3) speed was moderate; and (4) "other" factors prevailed, such as previous crashes. Thus, it is possible that crosswalks may have been more likely to be painted in San Diego where the conditions were most ripe for pedestrian collisions, compared to unmarked sites.

In a 1994 study, Gibby et al. revisited the issue in an analysis of crashes at 380 California highway intersections. These were picked in a multi-step selection process from among more than 10,000 intersections. Results showed that crash rates at the selected 380 unsignalized intersections were 2 or 3 times higher in marked than in unmarked crosswalks when expressed as crash rates per pedestrian-vehicle volume.

Other studies on crosswalk effects have also been conducted. Gurnett (1974) described a project to remove painted stripes from some crosswalks that had shown a bad crash experience in the recent past. This is a before-after study of three locations picked because they had a recent bad crash record. Crosswalk paint was removed. Subsequent crashes were tallied and fewer were found. The findings of this study are likely an artifact of the well-known statistical phenomenon of regression to the mean.

Another study of marked crosswalks at non-signalized intersections was reported by the Los Angeles County Road Department in July, 1967. In a before-after study of 89 intersections, painted crosswalks were added at each site. Collisions increased from 4 during the before period to 15 in the after period. All sites that showed crash increases after crosswalks were installed had ADT of less than 10,900 vehicles. At sites with smaller ADT volume, no change in crashes was seen.

The above finding regarding ADT above approximately 11,000 is consistent with the findings of Zegeer, Stewart, and Huang and Lagerwey (2002) reported at the beginning of this section. Moreover, Zegeer et al. attempted to compare their results with those of Herms. They lumped all their study sites together and computed a simple ratio of crashes divided by pedestrian crossing volume, as did Herms. By replicating the Herms analysis method on the 2000-site (30-city) data set, they too found the marked crosswalks were worse by slightly more than 2-to-1 than the unmarked. It is only when the data were disaggregated (and more appropriate Poisson and negative binomial modelling analyses were done) that it was seen that higher pedestrian crash risk of marked crosswalks is confined to the high volume, multi-lane case.

In contrast to the foregoing, however, Tobey and colleagues (1983) reported reduced crashes associated with marked crosswalks. They examined crashes at marked and unmarked crosswalks as a function of pedestrian volume (P) multiplied by vehicle volume (V). When the P x V product was used as a denominator, crashes at unmarked crosswalks were overrepresented, and considerably underrepresented at marked crosswalks. Communication with the authors indicates that this study included controlled (signalized) as well as uncontrolled crossings. It seems likely that more marked crosswalks were at controlled crossings than were unmarked crosswalks, which could partially explain the different results compared to other studies.

It should be noted that the study methodology was useful for determining pedestrian crash risk for a variety of human and location features. It was never intended, however, to be used for quantifying the specific safety effects of marked vs. unmarked crosswalks for various traffic and roadway situations.

Results of a study of pedestrian crossings in London, England calculated crash risk as the ratio of crashes per unit time to pedestrian volume counts (Mackie and Older, 1965). The authors found that the risk was lower in zebra crosswalks than in areas up to 45.7 m (50 yards) away from the crosswalks. There was a gradient effect, with crash risk highest nearer to the zebra crossing, but the risk was lower in the crossing. They found similar results for zebra crossings near a signalized crossing.

However, Ekman of the University of Lund in Sweden found in 1988 that "a pedestrian experiences approximately a double risk of being injured when crossing on a zebra crossing compared to a crossing location without any signs or road markings, presupposed that all other conditions are equal." Ekman contrasted his results with those from a similar Norwegian study, which reported that pedestrian risk associated with Norwegian zebra crossings was significantly lower than on the Swedish counterparts.

In 1985, Yagar reported the results of introducing marked crosswalks at 13 Toronto, Ontario, intersections. The basis for selecting the intersections was not described. A before-after study was carried out and it was found that crashes had been increasing during the before period and continued to increase at the same pace after crosswalks were installed. It would appear that marking the crosswalks did not have much of an effect. However, the author pointed to an increase in tailgating crashes after crosswalk painting. He also reported that the increased crashes during the after phase seemed to be explained by involvement of out-of-town drivers.

It is difficult to summarize these disparate findings, but it can be said that marked crosswalks have little or no association with pedestrian crash risk on two-lane roads and also on multilane roads with ADT less than approximately 10,000. However, for multilane facilities with ADT greater than 10,000, a significant crash risk is associated with using marked crosswalks alone without other, more substantial pedestrian safety treatments.

Behavioral Studies

It is logical to expect behavioral studies of driver and pedestrian reaction to marked crosswalks in view of the counterintuitive crash results reported in the literature. In his 1972 study, Herms stated: "Evidence indicates that the poor crash record of marked crosswalks is not due to the crosswalk being marked as much as it is a reflection on the pedestrian's attitude and lack of caution when using the marked crosswalk."

Figure 25. Unsafe motorist behavior at marked crosswalks is one of the causes of pedestrian crashes at marked crosswalks.

No behavioral data were presented in that study, however. Other authors advanced similar assertions with regard to pedestrian behavior in marked crosswalks (*Public Works*, 1969) (Los Angeles County Road Department, 1967). In a 1994 study, Gibby et al. provided a thorough review of the literature including behavioral studies. Some are reviewed here in a separate consideration of pedestrian vs. motorist behavior.

PEDESTRIAN BEHAVIOR

In 1999, Knoblauch and his colleagues carried out a study intended to directly observe incautious or reckless pedestrian behavior, such as Herms and others postulated to exist, and that might account for the negative crash results reported in some studies. They found no such behavior (Knoblauch, 1999).

The research team collected data at eleven sites before and after crosswalks were marked. They measured vehicle speed and volume, pedestrian volume, and recorded pedestrian and motorist behavior. Their study addressed three hypotheses related to pedestrian behavior:

Hypothesis: Will pedestrians, perhaps feeling more protected, act more aggressively when crossing a marked crosswalk compared to one not marked?

No difference was seen in blatantly aggressive pedestrian behavior whether the crossing was marked or not.

Hypothesis: Will pedestrians keep in the corridor defined by the stripes?

Pedestrians walking alone tended more to use marked crosswalks, especially at busy intersections. Pedestrians in groups tended not to use the marked crosswalks. Overall, crosswalk usage increased once markings were in place.

Hypothesis: Will marked crosswalks result in less pedestrian "looking behavior," perhaps because they feel more protected?

Looking behavior increased significantly after crosswalk markings were installed. No evidence was seen that the pedestrians were less vigilant in a marked crosswalk compared to one not marked.

The findings are generally consistent with an earlier study that likewise addressed pedestrian looking behavior and how well they kept within the area defined by the markings (Knoblauch et al., 1987). Of one case study, these authors said, "The analysis of behavioral data indicates that there were little or no changes in pedestrian behavior resulting from the installation of the pedestrian crosswalk markings." (p. 21)

Of a second case study, the authors said, "...pedestrians tended to stay in the crosswalk. There was no change in the number of pedestrians looking before entering the roadway; fewer pedestrians continued to look during the first half of the crossing. There was no change in looking behavior during the second half of the crossing. (pp. 25-26)

Hauck (1979) reported a before-after study done in Peoria, IL, in which 17 crosswalks at traffic signals were re-painted. Operational evaluation at the sites showed a general decrease in both pedestrian and motorist violations when comparing "before-and-after results. It was found that the percentage of pedestrians who stepped out in front of traffic during the after period decreased at 12 of the 17 locations; crossing against the DON'T WALK phase (signalized intersections) decreased at 13 of the 17 locations, though jaywalking was unchanged.

These studies show pedestrian behavior to be generally better in the presence of marked crosswalks. Certainly there is no indication of incautious or reckless pedestrian behavior associated with the marked crosswalks. What would be of interest, however, would be a study of pedestrian behavior at the kind of high ADT multilane facility where crashes at marked crosswalks were significantly higher than at unmarked. A study under those circumstances might not be advisable, however. It should be noted that the study by Zegeer and colleagues found that much of the increase in pedestrian crashes at marked crosswalks on multilane roads (above 10,000 ADT) involved "multiple-threat" crashes, where a vehicle stops in the curb lane to let a pedestrian cross and the pedestrian steps into the street and is struck by a vehicle in the adjacent lane (whose view of the pedestrian is blocked by the stopped vehicle). Some agencies have used an advance stop bar with the sign STOP HERE FOR PEDESTRIANS to improve sight distance (i.e., when stopping vehicles stop further back from the crosswalk) and reduce the risk of this type of crash.

MOTORIST BEHAVIOR

Motorist behavior changes at marked (vs. unmarked) crosswalks, have been studied by looking at speed (with and without pedestrians present), yielding, and other factors.

In 1998, Knoblauch reported results of speed measurements at six locations before and after crosswalk markings were applied. Some measurements were made with no pedestrians present, some with a pedestrian present and looking at traffic (the pedestrian was a member of the research team) and another condition in which the pedestrian approached and stood at the edge of the curb, looked straight across the road and not at traffic. The results were not clear-cut. Traffic behavior at the sites was not consistent. One site showed a considerably slower speed after the markings were painted even though no pedestrian was present. This speed change was unexpected and could not be explained; such changes were not seen at other crossings.

When the pedestrian was present and looking at traffic, the result summed over all six sites was a small speed decrease of less than 1 kph (.6 mph), which was not statistically significant. However, one site showed a significant decrease in speed and one showed a significant increase. The author pointed out that given the overall speed of the vehicles and the point at which the measurements were taken, a reasonable driver would assume that a pedestrian looking at traffic would not begin to cross. The driver would therefore see no need to slow down.

When the driver was present and not looking, however, overall the speeds were about 4 kph (2.5 mph) lower after the markings were applied; a statistically significant change. The author concluded that drivers are aware of and respond to the crosswalk markings in most cases, particularly when a pedestrian is present but does not look toward the motorist.

In a 1999 study, Knoblauch and colleagues observed motorist behavior to address two questions:

1. Did crosswalk markings affect the ways drivers respond to pedestrians? The differences were small, but drivers appear to drive slightly slowly when approaching a pedestrian in a marked crosswalk compared to one that is unmarked.

2. Might crosswalk markings disrupt vehicle flow by causing drivers to stop and yield to pedestrians? No change was observed. Drivers were neither more nor less likely to yield to pedestrians in a marked crosswalk than they had been when the crosswalk was not marked. It should be mentioned that all sites used in Knoblauch's 1999 study were two or three lanes (no four-lane roads) and all had speed limits of 56-64 kph (35 or 40 mph).

Ekman reported in 1988 that motorists in Sweden did not reduce their speeds when approaching zebra crossings. Insofar as this study measured vehicle speed when no one was present in the crosswalk or at the curb, one might expect speed to change little or not at all.

In another 1996 Swedish study, Varhelyi measured motorist behavior at non-signalized zebra crossings. He reported that in 73 percent of "critical" cases, the vehicle maintained or even increased speed and in only 27 percent of cases did they slow down as required. Despite what the motorists actually do, it was found in a separate survey that motorists in 67 percent of the cases say they "always" or "very often" slow down.

In 1992, Van Houten studied factors that might influence motorists to yield for pedestrians in marked crosswalks. He measured several behaviors at intersections in Dartmouth, Nova Scotia, where a series of interventions was sequentially introduced to increase the vividness of crosswalks. First signs were added, then a stop line, and then amber lights activated by pedestrians and displayed to motorists. The percentage of vehicles stopping when they should do so increased by amounts up to 50 percent. Conflicts dropped from 50 percent to about 10 percent at one intersection and from 50 to about 25 percent at another. The percentage of motorists who yielded increased from about 25 percent up to 40 percent at one intersection and from about 35 to about 45 percent at another.

Malefant and Van Houten studied in 1989 ways to increase the percentage of drivers who yield to pedestrians. An experiment was conducted in St. John's, Newfoundland, and Fredericton and Moncton-Dieppe, New Brunswick, Canada. Countermeasures included additional markings, feedback to the pedestrians as to compliance, warning signs for motorists, and enforcement. Associated with these multiple interventions were large increases in the proportion of motorists who yielded to pedestrians, ranging from 50 percent (before) to 70 percent (after) in one city; from 10 to 60 percent in another, and from 40 to 60 percent in the third.

In 1975, Katz et al. carried out an experimental study of driver-pedestrian interaction when the pedestrian crossed. The pedestrians in question were members of the study team and they crossed under a variety of conditions in 960 trials. It was found that drivers stop for pedestrians more often when the vehicle approach speed is low, when the pedestrian is in a marked crosswalk, when the distance between vehicle and pedestrian is greater rather than less, when pedestrians are in groups, and when the pedestrian does not make eye contact with the driver.

Cynecki and Associates, 1993 reported the results after rumble strips were installed in advance of marked crosswalks. The strips were placed at 19 uncontrolled locations. After installation, there was little change in vehicle speed. The authors also reported that 85th percentile speeds showed essentially no change. Presumably most of the time when the motorist encountered the rumble strip, the marked pedestrian crosswalk ahead would have been empty.

Assessment of Literature

It appears that there is a greater crash risk associated with marked crosswalks alone (i.e., if no other substantial improvement also is present) on multi-lane facilities with ADT greater than approximately 10,000. Otherwise, it appears that marking a crosswalk has no clear effect one way or another on pedestrian crashes. The apparent large negative effect reported by earlier authors disappears on two-lane roads and multi-lane roads having ADT's below approximately 10,000. The pedestrian behavior hypothesized to account for the negative results was not observed under the circumstances discussed.

Alternative Crossing Treatments

Innovative approaches to pedestrian crossing protection were tested in Detroit, MI (Malo et al., 1971). Combinations of signing, marking, lighting, and pedestrian signal actuation were installed. The alternative configurations included overhead signs with internal illumination, flashing beacons, and pedestrian signals.

Thirteen sites were chosen on the basis of poor crash records and/or judgment that indicated an unusual hazard. Implementation of the devices was preceded by a considerable educational and publicity effort by the Traffic Safety Association of Detroit, using leaflets, demonstration installations, press releases, and other public information methods. Field measurements included approach speeds, gaps, volumes, driver response (slowing), pedestrian attributes, gap acceptance, and behavior. In addition to the engineering studies, opinion surveys were conducted of both pedestrians and drivers as well as evaluations by experts.

Figure 26. Crosswalk treatments such as lighted signs have been used in an attempt to affect pedestrian and/or motorist behaviors

The engineering studies led to the following findings:

- There was a significantly greater relative use of crosswalks following installation of devices, primarily during daylight hours.

- The speed distribution of free-flow vehicles in the vicinity of the crosswalk did not change substantially.

- Many more drivers slowed for pedestrians waiting to cross the street.

- Pedestrian use of push buttons increased but not to the level expected.

Interviews of pedestrians and drivers showed drivers were usually satisfied with the devices, but pedestrians were not satisfied with driver response. It was concluded that drivers did not expect to have to stop or slow down significantly unless a traffic signal or stop sign were in use. Pedestrians expected traffic to slow down when the device was activated.

A study of special crosswalks was conducted in five major Canadian cities (Braaksma 1976). Four evaluation criteria were used—safety, delay, aesthetics, and cost. Special crosswalks were defined as those with some extra features in the form of overhead signs and lighting, pavement markings, parking prohibitions, or, in some cases, special laws. The best system of performance rating per unit cost was in Toronto. Excluding cost, the Calgary system performed best.

The Toronto system consisted of pavement markings and roadside signs. Large "Xs" were marked on the pavement in each lane 30.5 m (100 ft) back on the approach to the crosswalk. The stripe widths were between 304.8 mm and 508 mm (12-20 in), and the X was 6.1 m (20 ft) long. A standard advanced pedestrian crossing warning sign was mounted adjacent to the X at the roadside. The crosswalk was marked no less than 2.44 m (8 ft) wide with two 152.4-mm to 203.2-mm (6-8 in) stripes, 2235.2 mm (88 in) apart, delineating each side of the crosswalk.

The Calgary system employed a large overhead sign bearing the word PEDESTRIAN with two large “Xs” on either side of the word. On either side of the "Xs" were mounted 203.2-mm (8-in) flasher units. Below the word PEDESTRIAN a smaller flasher was mounted for pedestrian viewing. The flashers were activated by a pedestrian button having an appropriate sign instructing the pedestrian to push the button and cross with caution. Standard crosswalk markings were employed. A sign was post mounted at the roadside 45.75 m - 76.25 m (150 ft to 250 ft) before each approach, containing the words WHEN LIGHT FLASHING-MAXIMUM 20*-DO NOT PASS-HERE TO CROSSWALK. A flasher was placed above the sign. The flasher was also activated by the pedestrian button.

Before-and-after studies in Toronto showed a marked decline in pedestrian fatalities, although two hazardous behavior patterns were noted. First, some pedestrians would step off the curb without signaling their intention to cross the roadway; they apparently expected vehicles to stop instantaneously. Second, pedestrians noted that vehicles passed each other just before the crosswalk. The need for consistent laws regarding crosswalks, pedestrian, and driver education in this regard, and improved enforcement, were also cited.

Illuminated crosswalk signs were installed and evaluated at 20 locations in Tokyo, Japan, using before-after comparisons of crashes (*Accident Prevention Effects*, 1969). Findings show both pedestrian crossing–related and other unrelated crashes increased after the installation of the signs by 4.8 and 2.4 percent, respectively, in 200-m (218-yd) sections on either side of the installation. Both crash types increased 11.4 percent in 50-m (55-yd) sections. It was concluded that the illuminated crosswalk signs did not seem to be effective in reducing crashes; whether this type of device increases crashes, however, is unclear, as the average annual rate of crash growth on major streets in Tokyo is approximately 24 percent.

Crosswalk Illumination

A two-stage study of floodlighting of pedestrian crossings was conducted in Perth, Australia (Pegrum, 1972). A pilot study showed sufficient success to initiate a broader scale lighting program. Sixty-three sites were studied. The illumination consisted of two floodlights, one on each side of the roadway, on either side of the crosswalk, mounted about 3.66 m (12 ft) from the crosswalk at a height of 5.185 m (17 ft), and aimed at a point .915 m (3 ft) above the pavement. The luminaire was a 100-watt sodium lamp. The ambient lighting was not from sodium luminaires. The author found sodium floodlighting resulted in a significant decrease in nighttime pedestrian crashes, as shown in table 25.

A combined illumination and signing system for pedestrian crosswalks was developed and tested in Israel (Polus and Katz, 1978). The nighttime crash change at the 99 illuminated study sites and 39 unilluminated control sites is shown in table 26 on the following page. The reductions were concluded to be primarily due to the illumination, since daylight crashes were relatively unchanged. Other threats to validity were checked, including changes in pedestrian and vehicle flow, weather differences, and national crash trends. None of these showed any effect on the results.

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*The sign indicating “maximum 20" refers to kph.

Table 25. Crash effects of providing sodium floodlights at pedestrian crossings (Perth, Australia).

	Pedestrian Crashes			Crashes Involving Vehicles Alone		
	Day	Night	Total	Day	Night	Total
Pilot Test: 6 crossings						
5 years before	19(1)	7(1)	26(2)	5	1	6
5 years after	21(1)	2	23(1)	9	0	9
Follow On Test: 57 additional crossings						
2 years before	57(2)	32(1)	89(3)	19	2	21
2 years after	58(2)	13(1)	71(3)	18(1)	1	19(1)

Fatalities shown in parentheses.
Source: Pegrum, 1972.

Table 26. Effects of crosswalk illumination on pedestrian crashes (Israel).

	Number of Night Crashes	
	Before	After
Illuminated Sites	28	16
Unilluminated Control Sites	10	16

Source: Polus and Katz, 1978

A study in Philadelphia assessed the impacts of installing improved lighting at seven sites (Freedman et al., 1975). The impacts were evaluated on the basis of behavior as measured for 728 pedestrians and 191 drivers at the 7 study sites and 7 control sites. The study sites were high-crash locations, while the control sites were low-crash locations. The illumination improvement consisted of 90-watt low-pressure sodium lamps. Each system was controlled by a photocell that energized the circuit at sundown and turned it off at sunrise. Experimenter override was possible.

The evaluation was conducted using two primary comparisons of pedestrian attribute changes. One approach used five basic factors—search behavior, crossing path, concentration, erratic behavior, and clothing brightness. The results of comparing the five basic factors before and after lighting improvements showed that "perceived clothing brightness" increased significantly on the basis of all comparisons for high-crash locations with the installation of the special illumination. Observers searching the street in a fashion similar to drivers perceived the general appearance of pedestrians as brighter. There was significant improvement in the apparent concentration of pedestrians to the crossing task at all signalized locations. Search behavior was found to improve significantly under all conditions. Drivers appeared more aware of approaching hazardous crosswalks when the illumination was present. It should be noted that the crash data changes in both groups moved as if toward the mean, consistent with what would be expected since one group consisted of high-crash sites and the other low-crash sites. However, the behavioral measures should not have been influenced by regression to the mean.

Barriers, Signals, and Signage to Restrict Pedestrian Movements

Median Barriers

As part of a test of various countermeasures, median fence barriers were installed at two sites (Washington, D.C., with a 1.22-m- [4-ft-] high fence, and New York City, with a 1.83-m- [6-ft-) high fence) (Berger, 1975). One site had two gaps at intersecting minor streets. After installation of the barrier, 61 percent of the pedestrians identified the barrier as the reason for using the crosswalk. When asked whether the barrier affected the manner in which they crossed the street, 52 percent stated it had no effect, while 48 percent indicated the only effect was to force them to cross at the intersection.

Of those who were crossing midblock before the installation, 61 percent did so out of convenience. About one-third indicated they would use the crosswalk only if midblock traffic were "very heavy." After the fence was installed, 32 percent of the 22 pedestrians interviewed who previously made midblock crossings stated inconvenience as the major factor, with high turning volume at the intersection as a close second (23 percent). Older pedestrians were generally concerned with the intersection turning-traffic problem. Many cited recent crash experience. Almost one-quarter of those interviewed indicated they had walked along the median to the end of the barrier, or an opening, before completing the crossing. While merchants at a control site did not indicate anticipating much effect from a median barrier, 58 percent of those at the experimental sites indicated their belief that its major effect was to discourage customers from shopping both sides of the street. Most residents accepted the barrier. Only 7 percent wanted it removed. A few complained about inconvenience and its unsightly appearance.

Freeway Barriers

As part of the analysis of freeway pedestrian crashes, attempts were made to estimate the maximum national impact of right-of-way fencing and/or median barriers on freeway crashes if these pedestrian barriers were employed and were completely effective in controlling crashes identified as related to this countermeasure (Knoblauch et al., 1978). The field investigators estimated that 14 percent of freeway pedestrian crashes were susceptible to this countermeasure. One analysis of the crash types and the contributing factors suggested that these countermeasures could address between 160 and 222 of these usually severe nationwide crashes per year.

Roadside/Sidewalk Barriers

Chains, fences, guardrails, and other similar devices have been proposed in several studies as a means for channelizing and protecting pedestrians (Knoblauch, 1977; Snyder and Knoblauch, 1971; Knoblauch et al., 1978; *Model Pedestrian Safety Program*, 1987 edition).

Parking meter post barriers were tested at three sites in urban areas (Berger, 1975). All involved use of chains that connected parking meter posts. The barrier was .9 m (3 ft) high and involved 1, 2, or 3 chains. In Washington, DC, 6 parking meter post barriers were created on one side of a street, resulting in a series of 3.66-m (12-ft) long single chain sections. In New York City, 19 posts were utilized, 9 on one side of the street and 10 on the other. These were 3.66-m- (12-ft-) sections with 2 chains. The third site was a section of one-way street along which three-chain sections were installed on eight posts. The results were mixed. A vandalism problem (stolen chains) interfered with the experiment, a noteworthy concern. Twenty-six percent of those interviewed who crossed at the intersections after the installation mentioned that a factor in their choice of crossing location was the illegality of crossing elsewhere. Since only 12 per- cent had mentioned this before the change, the barriers may have reminded pedestrians that it is illegal to jaywalk. While 65 percent of merchants perceived no negative effects from the countermeasure, 15 percent noted interference to street crossing, and 18 percent cited a problem when loading or unloading goods.

In London, research was done on a 548.4-m (600-yd) road segment that had been provided with pedestrian barriers on both sides (Jacobs, 1966). The access openings were not directly across from each other. Pedestrian crossing movements were mapped and crash data were compiled. Crashes during the previous 8 years were shown as a ratio to 4-hour pedestrian volume, fewer than 20,000 people. The result- ing risk ratio was compared with that for 11 other sites in London that did not have pedestrian barriers. The only significant differences occurred at points within 45.7 m (50 yds) of a signalized intersection (more than twice the risk ratio with the pedestrian barrier) and at other midblock locations within 18.28 m (20 yds) of an intersection where controlled crossings were not present and approximately 10 times the risk ratio. The overall risk ratio was lower at the test site but was not found to be statistically significant.

The longitudinal path taken by each pedestrian was studied. This was the distance between barrier openings used to get on and off the roadway, measured parallel to the curb. The results indicate most pedestrians would cross away from the crosswalk when the longitudinal distance between barrier openings on either side of the street was less than 9 m (10 yds). It was suggested by the author that longitudinal distances between the openings on opposite sides of a street be greater than 9 m (10 yds).

Pedestrian barrier fences were installed along 18 sections of road in Tokyo (*Accident Prevention Effects*, 1969). Crashes were analyzed before and after the installation. Crashes related to crossing pedestrians declined by nearly 20 percent. An overall 4-percent reduction was observed, including non-pedestrian crashes. It had been thought that even though crashes related to pedestrians' crossing out of crosswalks might decrease, crashes related to pedestrians crossing in the crosswalks might increase. The results indicated both types of pedestrian collisions were reduced equally by 20 percent.

Signalization

Signals are widely employed to direct and assist pedestrians at crossings. A study of 30 locations in Tokyo where pedestrian-activated signals were installed showed that crashes declined by 37.5 percent (*Accident Prevention Effects*, *1969*). Little difference was noted in the severity of crashes between the before and after periods. The effective range of the signal influence seems to be between 25-50 m (27-55 yds) on either side of the signal. The pedestrian-activated signals were found to be much more effective in reducing night crashes than daylight crashes. Rear-end vehicular crashes, which are usually expected to increase after signalization, decreased by 12 percent.

Several behavioral studies of pedestrian signals have been conducted in the U.S. Most have found pedestrian compliance to be poor. One study compared pedestrian crossing behavior at sites with and without standard pedestrian signals (Mortimer, 1973). Observers noted specific behaviors twice on different days. A total of 24 sites in Detroit, MI, were analyzed, 12 of which had pedestrian signals. More than 3,200 pedestrians were observed. Illegal starts on amber/DON'T WALK were about 4 percent less at sites with pedestrian signals. The percent arriving at the far side of the green/WALK was 20 percent higher at the sites with pedestrian signals.

An observational sampling study of pedestrian behavior at a site in Brooklyn, NY, noted any change occurring with the installation of a pedestrian signal (Fleig and Duffy, 1967). A before-after crash analysis was also performed on 11 additional sites at which pedestrian signals had been installed. Neither the behavioral analysis nor the crash analysis showed any significant difference between the before and after periods.

As part of a behavioral analysis at a variety of intersections in Washington, DC, San Francisco and Oakland, CA (Petzold, 1977), observations were made of compliance with pedestrian signals at six intersections. Based on four intersections with pedestrian signals displaying a flashing WALK indication (550 pedestrians) and two intersections having steady WALK indications (139 pedestrians), no difference was observed between flashing and steady WALK signals in terms of pedestrian usage of the cycle. A very large portion of the users paid little, if any, attention to the pedestrian signal. This same study demonstrated that few pedestrians understand the meaning of flashing WALK and DON'T WALK pedestrian signals, whereas symbolic pedestrian signalization such as the walking pedestrian and upheld hand offers an improved understanding over word messages. One study showed that, at most, only about half of the pedestrians pressed the button to activate the WALK light (Palamarthy et al., 1994).

A comparison was made in Massachusetts of the behavior of pedestrians at intersections with flashing and solid WALK segments of the pedestrian signals (Sterling, 1974). The sites were controlled by vehicle-actuated signals having a fixed pedestrian phase length. Sites with high pedestrian and traffic volumes were chosen. Pedestrians at the sites with flashing WALK were found to cross in a legal manner only 29 percent of the time compared with 51 percent who did so at the sites with a steady WALK indication. The percentage of crossings for which a vehicular conflict occurred was 6 percent for the steady indication and 8 percent for the flashing indication. This difference was statistically significant.

An area-wide, centralized computer-controlled signal system was installed in West London. The impact on pedestrian safety and other impacts were studied (Crook, 1970). A significant 5-percent reduction in pedestrian crashes occurred in the experimental area while a 20-percent increase in pedestrian crashes occurred in a comparison (control) area.

Studies in the U.S. and Israel have quantified the effects of pedestrian signals and signal timing on pedestrian crashes. The most comprehensive study involved the collection and analysis of pedestrian crashes, traffic and pedestrian volume, signal timing, roadway geometrics, and other data at 1,297 signalized intersections (2,081 total pedestrian crashes) in 15 U.S. cities. The following pedestrian signal strategies existed (Zegeer et al., 1982, 1983):

- Concurrent (standard) timing allows pedestrians a WALK interval concurrently (parallel) to traffic flow, while vehicles are generally permitted to turn right or left on a green light across the pedestrian's path. These represented 658 intersections, or over 50.7 percent of the sample, and is by far the most common type of pedestrian signal timing in the U.S.

- Exclusive timing refers to a pedestrian signal timing where pedestrians are given an exclusive interval each signal cycle while traffic is stopped in all directions. "Scramble" or "Barnes Dance" timing is exclusive timing where pedestrians are also permitted to cross the street diagonally. There were 109 such intersections, or 8.4 percent of the total, in the database.

- Other timing patterns include early release, where pedestrians are given a head start in the cycle before motor vehicles are permitted to turn behind pedestrians. Late-release timing holds pedestrians until motor vehicles make their right (and/or left) turns before pedestrians are allowed to cross. Only 22 intersections, or 1.7 percent of the total, had one of these timing patterns.

- Pedestrian signal indications were not present at 508, or 39.2 percent, of the sample intersections.

The study found that the factors significantly related to increased pedestrian crashes include higher pedestrian and traffic volumes, street operation (two-way streets have higher pedestrian crashes than one-way streets), wider streets, higher bus use, and greater percentage of turning movements. The presence of concurrently timed pedestrian signals had no significant effect on pedestrian crashes when compared with intersections with traffic signals alone. Sites with exclusive pedestrian signal timing had significantly lower pedestrian experience (about half as many) as sites with either standard timing or with no pedestrian signals. This exclusive timing scheme was effective, however, only at intersections with more than 1,200 pedestrians per day. The authors controlled for pedestrian volume, traffic volume, intersection geometrics, and other factors in their analysis. A summary of results for various signal timing schemes is given in table 27.

Of possible relevance to the issue of early or late release timing is a study of pedestrian traffic conflicts at T intersections (Lord, 1996). This study confirmed earlier work that showed more pedestrian conflicts with left-turning vehicles at T intersections than at standard X intersections. Because left-turning traffic at T intersections has no oncoming vehicle traffic to cause a delay, the driver can initiate the turn immediately and may intercept a pedestrian who starts at the same time. At an X intersection, left-turning traffic may have to wait for oncoming vehicle traffic to pass, which may amount to an early release for the pedestrians.

Zegeer and colleagues (1982, 1983) cite these explanations for the possible lack of effectiveness of concurrent signal timing:

- The possibility that many pedestrians of pedestrians misunderstand pedestrian signal messages, such as the flashing DON'T WALK (i.e., pedestrian clearance interval meaning don't start, but finish crossing if already in the street)

- The false sense of security that some pedestrians may have regarding the WALK interval (e.g., they sometimes incorrectly believe that a WALK interval protects them by stopping traffic in all directions including turns, such as with exclusive signal timing)

- Poor compliance by many pedestrians to pedestrian signals in the 15 test cities (65.9 percent of pedestrians were found to begin crossing during the flashing or steady DON'T WALK at 64 intersection approaches)

- Reluctance by many pedestrians to activate the push-button pedestrian signals (e.g., the study found that 51.3 percent of all crossing pedestrians pushed the button to activate the signal)

The study concluded that highway agencies should not indiscriminately install pedestrian signals at all traffic signalized locations. Instead, the cost of pedestrian signals should be weighed against their effectiveness at a given location. On the other hand, the authors cite a need for pedestrian signals at some signalized locations (e.g., within established school crossings, wide street crossings, or where vehicle signals are not visible to pedestrians) as discussed in the *Manual on Uniform Traffic Control Devices* (1988).

In a 1987 study from Israel by Zaidel and Hocherman, pedestrian crashes were used to compare the safety of various types of pedestrian signal options at signalized intersections in Tel Aviv, Jerusalem, and Haifa. These included sites with a concurrently-timed pedestrian signal, an exclusively timed pedestrian interval, and no pedestrian control. Extensive control data were collected for use in the analysis.

A total of 1,310 pedestrian crashes and 5,132 vehicle crashes were analyzed at 320 intersections. The factors most strongly associated with higher pedestrian crashes include increased pedestrian and traffic volume and greater intersection complexity (as evidenced by number of intersection legs or number of conflict points). The type of pedestrian crossing provision was found to have only a slight effect on pedestrian crashes, and no effect on vehicle injury crashes, particularly where vehicle volumes were relatively low (i.e., less than 18,000 vehicles per day). Exclusively timed pedestrian signals showed evidence of crash reduction where high vehicle and pedestrian volumes existed.

Table 27. Summary of effects of pedestrian signal timing on pedestrian crashes.

Comparison	Dependent Variable	Adjusted Means (Sample Sizes in Parentheses)	Control Variables	Significant Difference (at the 0.05 level)	Level of Significance
1. All Ped. Signal Alternatives	A. Mean Pedestrian Crashes per Year	No Ped. Signal: 0.36 (508) Concurrent: 0.40 (658) Exclusive: 0.22 (109) Other: 0.38 (22)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/Two-Way) Ped. Signal Alternatives	Yes	0.001
	B. Mean Pedestrian Turning Crashes per Year	No Ped. Signal: 0.13 (508) Concurrent: 0.17 (658) Exclusive: 0.01 (109) Other: 0.20 (22)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	Yes	0.001
2. No Ped. Signal Indication vs. Concurrent Ped. Signal Timing	A. Mean Pedestrian Crashes per Year	No Ped. Signal: 0.36 (508) Concurrent: 0.40 (658)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	No	0.130
	B. Mean Pedestrian Turning Crashes per Year	No Ped. Signal: 0.12 (508) Concurrent: 0.15 (658)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	Yes	0.048
3. No Ped. Signal Indication vs. Exclusive Ped. Signal Timing	A. Mean Pedestrian Crashes per Year	No Ped. Signal: 0.33 (508) Exclusive: 0.15 (109)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	Yes	0.001
	B. Mean Pedestrian Turning Crashes per Year	No Ped. Signal: 0.11 (508) Exclusive: 0.00 (109)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	Yes	0.001
4. Concurrent Ped. Signal Timing vs. Exclusive Ped. Signal Timing	A. Mean Pedestrian Crashes per Year	Concurrent Timing: 0.43 (658) Exclusive: 0.27 (109)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	Yes	0.001
	B. Mean Pedestrian Turning Crashes per Year	Concurrent Timing: 0.17 (658) Exclusive: 0.03 (109)	Pedestrian Volume (AADT) Total Traffic Volume (AADT) Street Operation (One-Way/ Two-Way) Ped. Signal Alternatives	Yes	0.001

Source: Zegeer et al., 1983

*Average Annual Daily Traffic (AADT)

A 1984 study by Robertson and Carter examined the safety, operational, and cost impacts of pedestrian signal indications at signalized intersections. The study was based on information obtained from existing literature, an analysis of pedestrian crashes, a delay analysis, and a benefit-cost analysis. The authors concluded that pedestrian signal indications appear to reduce pedestrian crashes at some intersections, have little or no effect at others, and even increase such crashes at other intersections. Also, while the presence of pedestrian signals apparently did not significantly offset pedestrian and vehicle delay, the operation of pedestrian and vehicular signals (i.e., signal timing) had a profound effect on delay. The authors recommended that further efforts be made to determine intersection conditions for effective use of pedestrian signals.

As stated above, many pedestrians do not fully understand the meaning of pedestrian signals and markings, nor the legal obligations underlying them, and that may explain, in part, the less-than-perfect performance associated with these devices. A 1995 study by Tidwell and Doyle reported survey results based on data collected in 48 states. The following survey responses were reported:

- 86-94 percent say crossing should be at intersections or marked midblock crossings.
- 92-97 percent understand that motorists should give way to pedestrians in a marked crosswalk.
- 79-87 percent know that RTOR vehicles should yield to pedestrians in the crosswalk.
- 59-61 percent did not know that motorists are not obliged to stop when a pedestrian is waiting on the sidewalk.
- 42-46 percent erroneously believe the DON'T WALK signal means return to the original curb.
- 47 percent think a WALK signal means there will be no conflict with turning vehicles.

Signing

A variety of pedestrian-related signs are used by state and local agencies. Examples of regulatory signs include PEDESTRIANS PROHIBITED, WALK ON LEFT FACING TRAFFIC, NO HITCHHIKING, and others. Warning signs for pedestrians include the advance pedestrian crossing sign, school warning sign, and others. Guide signs provide travel information and can direct pedestrians to sidewalks, walkways, hiking trails, overpasses, and other facilities. Criteria for the design and placement of signs are contained in the *Manual on Uniform Traffic Control Devices* (MUTCD) (1988) and supplemented by the *Traffic Control Devices Handbook*, (1988). A 1988 study for the Transportation Research Board summarizes experiences from 48 state and local agencies regarding traffic and roadway conditions where certain signs are most (and least) effective (Zegeer and Zegeer, 1988).

An experiment was conducted using a novel flourescent yellow-green sign warning motorists of pedestrians (Clark et al., 1996). A before-and-after study was done, including a comparison group where no such sign was deployed. An increase was found in the proportion of vehicles slowing or stopping for pedestrians. However, no decrease was seen in conflict events.

Right Turn on Red

The effects of RTOR on pedestrian safety was investigated in a 1981 study by Preusser and Associates. Right turn crashes increased from 1.47 percent before RTOR to 2.28 percent of all pedestrian crashes after RTOR went into effect. A common RTOR pedestrian crash resulted when a motorist was stopped at the intersection looking for approaching vehicles from the left and failed to see a pedestrian crossing from the right side. Directional movements related to RTOR crashes involving pedestrians and bicyclists are illustrated in figure 27. The study concluded that there was a small but clear safety problem for pedestrians because of RTOR. A 1994 NHTSA report to Congress said that about two-tenths of 1 percent of all fatal pedestrian and bike crashes result from RTOR (Compton and Milton, 1994).

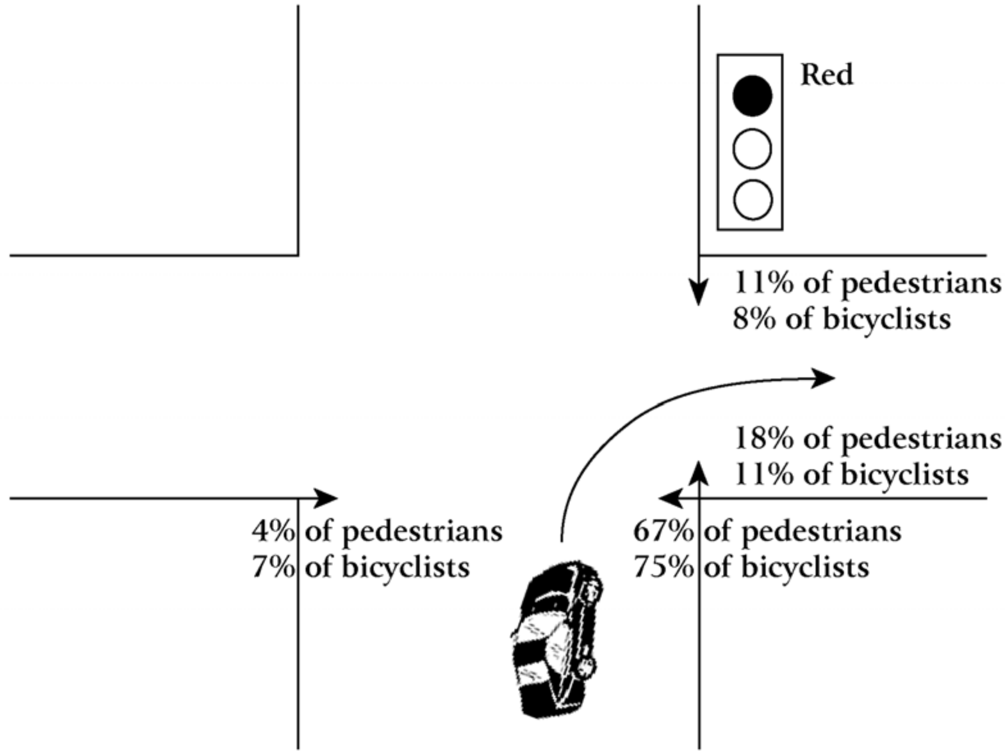

Figure 27. Directional movements of pedestrians and bicyclists involved in right-turn-on-red crashes.
Source: Preusser et al., 1981.

A 1986 study by Zegeer and Cynecki investigated motorist violation rates related to NO TURN ON RED (NTOR) signs and resulting pedestrian-vehicle conflicts. Observational data for more than 67,000 drivers at 110 intersections were collected at intersections in Washington, DC, Dallas, Austin, Detroit, Lansing, and Grand Rapids. It was found that 3.7 percent of all right-turning motorists at RTOR-prohibited intersections violate the NTOR signs. However, approximately 21 percent violate the NTOR signs if given an opportunity (e.g., first in line at the intersection with no pedestrians in front of them and no vehicle coming from the left). A summary of motorist violations and resulting conflicts at RTOR-prohibited sites is shown in table 28.

According to Zegeer and Cynecki's findings, approximately 23.4 percent of all RTOR violations result in a conflict with a pedestrian. These types of conflicts are summarized in table 29 for the near and far crosswalks. At intersections where RTOR is allowed, 56.9 percent of motorists fail to make a full stop before turning right on red. This compared with 68.2 percent of vehicles that failed to make a complete stop at other intersections with stop-sign control. The higher violation rate (i.e., not fully stopping) at stop sign intersections was attributed in part to the greater opportunity for a rolling stop or no stop (because of lower side street volumes and pedestrian activity at stop-sign locations compared with signalized locations). Based on locational factors, 30 candidate countermeasures were developed to improve pedestrian safety relative to RTOR.

A follow-up evaluation of promising countermeasures was conducted for RTOR pedestrian crashes. Seven countermeasures were tested at 34 intersection approaches in six U.S. cities on the basis of motorist violations and pedestrian-vehicle conflicts related to RTOR and right turn on green (RTOG).

Table 28. Violations and conflicts related to right turn on red.

	Total Number of Hours	Number of Intersection Approaches	Number of RTOR Maneuvers (No. per Hour)	Number of RTOR Conflicts (No. per Hour)		Percent of RTOR Vehicles Involved in Conflict			Number of RTOR Conflicts Plus Interactions (No. Per Hour)	Percent of RTOR Vehicles Involved in Conflicts or Interactions	
				Cross Street Vehicles	Pedestrians	Cross Street Vehicles	Pedestrians	Total	Pedestrians	Pedestrians	Pedestrians Plus Cross Street Traffic
RTOR-Allowed Sites	496.7	108	8,507 (17.13)	324 (0.65)	428 (0.86)	3.8	5.0	8.8	792 (1.59)	9.3	13.1
RTOR-Prohibited Sites	435.8	91	2,225 (5.11)	133 (0.31)	135 (0.31)	6.0	6.0	12.0	222 (0.51)	10.0	16.0
Total Sites	932.5	199	10,732 (11.51)	457 (0.49)	563 (0.60)	4.3	5.2	9.5	1,014 (1.09)	9.4	13.7

Source: Zegeer and Cynecki, 1986.

Table 29. Summary of traffic conflicts related to right-turn-on-red pedestrian crashes.

Types of Sites	Hours of Data Collected	Type of Conflict	Near Crosswalk			Far Crosswalk			Total Crosswalks		
			Conflicts	Interactions	Totals	Conflicts	Interactions	Totals	Conflict	Interactions	Total
RTOR-Allowed	496.7	RTOG	118 (0.24)	161 (0.32)	279 (0.56)	5,018 (10.10)	2404 (4.84)	7,422 (14.94)	5,136 (10.34)	2,565 (5.16)	7,701 (15.50)
		RTOR	151 (0.30)	185 (0.37)	336 (0.67)	277 (0.56)	179 (0.36)	456 (0.92)	428 (0.86)	364 (0.73)	792 (1.59)
		Totals	269 (0.54)	346 (0.70)	615 (1.24)	5,295 (10.66)	2,583 (5.20)	7,878 (15.86)	5,564 (11.20)	2,929 (5.90)	8,493 (17.10)
RTOR-Prohibited	435.8	RTOG	181 (0.42)	140 (0.32)	321 (0.74)	5,234 (12.01)	2,654 (6.09)	7,888 (18.10)	5,415 (12.43)	2,794 (6.41)	8,209 (18.84)
		RTOR	40 (0.09)	44 (0.10)	84 (0.19)	95 (0.22)	43 (0.10)	138 (0.32)	135 (0.31)	87 (0.20)	222 (0.51)
		Totals	221 (0.51)	184 (0.42)	405 (0.93)	5,329 (12.23)	2,697 (6.19)	8,026 (18.42)	5,550 (12.74)	2,881 (6.61)	8,431 (19.35)

Source: Zegeer and Cynecki, 1986.

The results showed that the NTOR sign with the red ball was more effective than the standard black and white NTOR signs. For RTOR motorists, an offset stop bar was found to increase compliance (i.e., making a full stop before turning right on red) and also reduced conflicts with cross-street traffic. An electronic NTOR/ blank-out sign (actuated only during critical times, such as during school crossing times) was slightly more effective, although considerably more costly than traditional signs. In general, driver compliance was improved when the RTOR restriction was limited to the peak pedestrian times instead of full-time restrictions. The NTOR WHEN PEDESTRIANS ARE PRESENT sign was found to be effective at intersections having moderate or low RTOR volumes. Several of these countermeasures are illustrated in figure 28. The study also showed that generally the likelihood of an RTOG collision was higher than a RTOR collision. In some cases, prohibiting RTOR may lead to a greater RTOG collision potential.

Innovative Traffic Control Devices

Various problems have been identified in recent years regarding traffic controls for pedestrians, particularly related to the ineffectiveness and confusion associated with pedestrian signal messages. A 1982 study by Zegeer et. al. developed and tested alternatives to warn pedestrians and/or motorists of potential problems between pedestrians and turning vehicles at intersections. Field testing was conducted at selected intersections in several cities (Washington, DC, Milwaukee, Detroit, Ann Arbor, and Saginaw, MI). The results revealed that:

- A red and white triangular sign, 914 m (36 in) on each side and inscribed YIELD TO PEDESTRIAN WHEN TURNING was effective in reducing turning conflicts between vehicles and pedestrians. It was recommended that this sign be added to the MUTCD for optional use at locations with a high incidence of pedestrian crashes involving turning vehicles.

- A PEDESTRIANS WATCH FOR TURNING VEHICLES warning sign with black letters on a yellow background was significantly associated with reduced vehicle turning crashes involving pedestrians. This sign was also recommended as an optional sign to be incorporated into the MUTCD.

- A pedestrian signal explanation sign had no detectable effect at two sites where pedestrian violations were not a problem before the signs were installed (Saginaw), but was associated with lower pedestrian violations and turning conflicts at two other sites where pedestrian violations had been a serious problem (Washington, DC).

- A three-section pedestrian signal with the message WALK WITH CARE displayed during the crossing interval was tested at four sites in three cities to warn pedestrians of possible turning vehicles and/or vehicles that run red lights. The signal message was associated with significantly fewer pedestrian signal violations and also fewer turning-related conflicts. This special message was recommended as an addition to the MUTCD for use only where pedestrian collisions were high, especially since overuse was believed to result in its decreased effectiveness.

Previous research has also shown a general misunderstanding by pedestrians of the flashing DON'T WALK interval (Robertson and Carter, 1984). As part of the 1982 Zegeer et. al. study, several devices were developed as alternatives to the flashing DON'T WALK, including:

- A three-message DON’T START display (to be used with the standard WALK and DON’T WALK where the DON’T START is a steady yellow message) resulted in a significant

Figure 28. Examples of treatments that have been tested to reduce pedestrian crashes related to right-turn-on-red (RTOR) motorists.

reduction in pedestrian violations and conflicts compared with the flashing DON’T WALK without the DON’T START message. This finding prevailed at three of four test sites. It’s further testing was recommended for possible eventual adoption nationwide.

- A steady DON'T WALK message for the clearance and pedestrian prohibition intervals provided no improvement over the flashing DON'T WALK interval and was not recommended.

An illustration of some of these innovative traffic control alternatives is shown in figure 29.

Huang, Zegeer, and Nassi conducted an evaluation of innovative pedestrian signs at unsignalized locations in conjunction with marked crosswalks to improve the crosswalk visibility and increase the likelihood that motorists would yield to pedestrians. Their study evaluated three such devices: (1) an overhead CROSSWALK sign in Seattle, WA; (2) pedestrian safety cones with the message, “STATE LAW - YIELD TO PEDESTRIANS IN CROSSWALK IN YOUR HALF OF ROAD” in NY State and Portland, OR; and (3) pedestrian-activated “STOP FOR PEDESTRIAN IN CROSSWALK” overhead signs in Tucson, AZ. The signs were used under different traffic and roadway conditions.

The New York cones and Seattle signs were effective in increasing the number of motorists who stopped for pedestrians. At one location in Tucson, the overhead sign increased instances of motorists’ yielding to pedestrians. The signs in Seattle and Tucson were effective in reducing the number of pedestrians who had to run, hesitate, or abort their crossing. None of the treatments had a clear effect on whether people crossed in the crosswalk.

The authors concluded that these devices by themselves cannot ensure that motorists will slow down and yield to pedestrians, and that it is essential to use such devices together with education and enforcement. Finally, the authors recommended that traffic engineers should use other measures, including designing “friendlier” pedestrian environments at the outset.

Figure 29. These innovative pedestrian crossing signs had mixed results.

Figure 30. Examples of innovative pedestrian signalization alternatives.

A novel overhead illuminated crosswalk sign and high-visibility ladder style crosswalk were evaluated in Clearwater, FL by Nitzburg and Knoblauch (2000) using an experimental/control design. The effect of the novel treatments on driver and pedestrian behavior was determined. A significant 30-40 percent increase in daytime driver yielding behavior was found. A smaller (8 percent) and insignificant increase in nighttime driver yielding behavior was observed. A large (35 percent) increase in crosswalk usage by pedestrians was noted along with no change in pedestrian overconfidence, running, or conflicts. It was concluded that the high-visibility crosswalk treatments had a positive effect on pedestrian and driver behavior on the relatively narrow low-speed crossings that were studied. Additional work was recommended to determine whether they also have a desirable effect on wider roadways where speeds are greater.

Figure 31. The Clearwater pedestrian crossing treatment resulted in a positive influence on pedestrian and driver behavior.

At many intersections, pedestrians must push buttons to activate the WALK phase. However, they often do not know whether the button has been pressed and whether it is functional. If the WALK phase does not appear soon after the button has been pressed, they may believe that it does not work and start crossing early, while the steady DON'T WALK is still being displayed. When a pedestrian presses an illuminated push button, a light near the button turns on, indicating that the WALK phase has been activated and will appear. Huang and Zegeer conducted in 2000 a study to evaluate the effects of illuminated push buttons on pedestrian behavior. In general, illuminated push buttons did not have a statistically significant effect on how often the pedestrian phases were activated, how many people pushed the button, how many people complied with the WALK phase, or such pedestrian behaviors as running, aborted crossings, and hesitation before crossing. Only 17 and 13 percent of pedestrians pushed the button in the "before" and "after" periods, respectively. In both the before and after periods, someone pushed the button in 32 percent of signal cycles with pedestrians. The majority of pedestrians (67.8 percent with, and 72.3 percent without illuminated push button) who arrived when parallel traffic had the red and who pushed the button complied with the WALK phase.

Automated pedestrian detection systems provide the means to detect the presence of pedestrians as they approach the curb before crossing the street, and then "call" the WALK signal without any action required on the part of the pedestrian. Hughes, Huang, Zegeer, and Cynecki conducted a study to determine whether automated pedestrian detectors, when used in conjunction with standard pedestrian push buttons, would result in fewer overall pedestrian-vehicle conflicts and fewer inappropriate crossings

Figure 32. Illuminated pedestrian push buttons were not found to alter pedestrian crossing behavior.

(i.e., beginning to cross during the DON'T WALK signal). "Before" and "after" video data were collected at intersection locations in Los Angeles, CA (infrared and microwave), Phoenix, AZ (microwave), and Rochester, NY (microwave). The results indicated a significant reduction in vehicle-pedestrian conflicts as well as a reduction in the number of pedestrians beginning to cross during the DON'T WALK signal. The differences between microwave and infrared detectors were not significant. Detailed field testing of the microwave equipment in Phoenix revealed that fine tuning of the detection zone is still needed to reduce the number of false calls and missed calls.

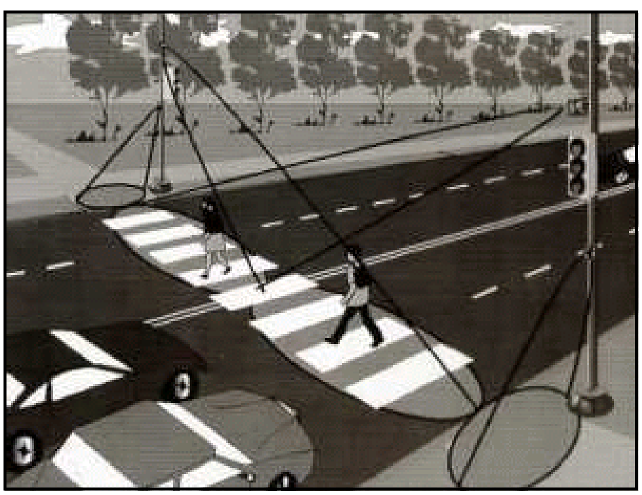

Figure 33. Automatic pedestrian detectors have been found to significantly reduce pedestrian violations of the DON'T WALK indication and reduce pedestrian vehicle conflicts.

Pedestrian Refuge Areas

Some pedestrians cannot cross an intersection within the signal time provided, and some midblock crossings are too wide for the available gaps. Running across intersections has been shown to be a common cause of pedestrian crashes. Pedestrian refuge areas between traffic lanes offer a place where pedestrians may pause while crossing a multilane street. They also allow pedestrians to cross one direction of travel at a time. Refuge areas may be delineated by markings on the roadway or raised above the surface of the street.

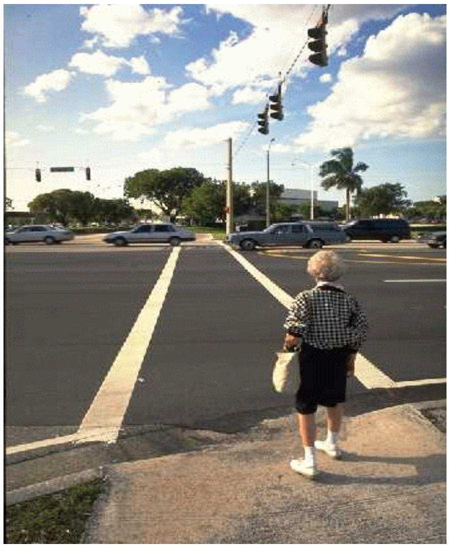

Figure 34. Some pedestrians are not able to cross an intersection within the signal time provided.

The use of central refuge islands, or medians, for pedestrians is often proposed but seldom studied. One analysis reports before-after comparisons of personal injury crashes at sites where pedestrian refuges were installed (Lalani, 1976). "Double-D" shaped islands were installed at 120 sites in London. The installations were in conjunction with other roadway improvements, including anti-skid surfacing, illuminated bollards, bus lanes, and cross-hatch markings. The crash records for comparable before-and-after periods were subjected to statistical tests to determine significant changes. It was found that provision of refuges, thought of as a facility for pedestrians, reduced vehicle crashes but increased pedestrian crashes. Significant pedestrian crash reduction at intersections could be identified only where the purpose of the refuge was very clearly established, such as: provision of the refuge specifically on the basis of safety, reinforcement of the refuge with cross-hatch markings, or provision of the refuge for channelization or vehicular traffic. For single refuges not at junctions, it was possible to identify significant reductions in vehicle crashes when the refuges were fitted with fully illuminated bollards. It was possible to identify overall significant reductions in crashes where the refuges were provided in the vicinity of active pedestrian areas.

Additional studies do not fully remove the ambiguity cited above. Bowman and Vecellio (1994A, 1994B) reported comparisons of several kinds of medians, including undivided multi-lane roadway, TWLTL, and raised curb medians. Raised curb facilities seem to be associated with lower pedestrian crash rates, as might be expected. But the authors say, " . . . it appears that both raised and TWLTL medians significantly reduce the number and severity of vehicular crashes . . . . The literature did not provide a conclusive indication that medians improved pedestrian safety," (Bowman and Vecellio, 1994B, p. 186).

Figure 35. Raised medians and pedestrian islands may provide a measure of safety to pedestrians.

In general, raised curb medians may be better than TWLTL medians which are, in turn, better than undivided highways (Bowman and Vecellio, 1994A). The data were broken down several ways, and recombined several ways. Some differences were significant and others were not.

The need for refuge areas is presumably related to street widths, pedestrian walking speed, and vehicle gaps. The *Manual on Uniform Traffic Control Devices* (MUTCD) requires clearance intervals to be based on a walking speed of 1.2 m/s (4 ft/s); however, this may not be sufficient for pedestrians with mobility impairments. Knoblauch and colleagues measured pedestrian start-up and walk times in 1996. The measures varied according to many factors, but the differences, though statistically significant, were mostly too small to matter from the design standpoint. The authors recommend, however, use of a walking speed of 0.91 m/s for elderly pedestrians and 1.22 m/s (4 ft/s) for a typical pedestrian.

Further indications of variability of possible relevance to designers are two studies of pedestrian walking speeds in the tropical countries of Thailand and Sri Lanka.(Tanaboriboon and Guyano, 1991; Morrall et al., 1991), where walking speeds are slower than typical in the U.S. Thus, when the temperature is high and when pedestrians may be encumbered with loads, walking speed may be slower.

Provisions for Pedestrians with Disabilities

A study of collisions involving pedestrians with disabilities in Atlanta, GA led to conclusions regarding various countermeasures for reducing elderly and handicapped pedestrian crashes (Templer, 1979). A telephone interview was used to determine information not available from the collision report or hospital records of 989 pedestrian crash reports. Field reconnaissance was made of the crash sites. The number of crashes in the sample that might have been prevented by each of the following countermeasures is noted below:

- Design and operate pedestrian facilities to accommodate the handicapped: 5 crashes
- Design traffic facilities for the safety of vehicular traffic *and* pedestrian traffic: 17 crashes
- Provide appropriate separation between pedestrian and non-pedestrian areas: 5 crashes

- Use traffic engineering measures to ensure each street is used for its intended purpose: 2 crashes

- Provide a safer school trip for young pedestrians: 3 crashes

- Encourage parents to take more responsibility for the supervision and education of their children in pedestrian safety: 24 crashes

- Provide information to school children and safety personnel about safe and proper pedestrian behavior: 17 crashes

- Provide information to elderly people about safe and proper pedestrian behavior: 11 crashes

- Prosecute drivers for repeated violations of traffic regulations: 14 crashes

- Keep the pedestrian environment clean and free from debris: 2 crashes

- Remove objects that obstruct visibility between drivers and pedestrians: 3 crashes

- Provide information about the dangers of alcohol overconsumption : 1 crash

In addition to those crashes analyzed for Atlanta, the same study sampled reactions to environmental hazards by handicapped people in five U.S. cities. Four elements of the pedestrian system were identified as accounting for 81 percent of the crashes they reported:

Walks and corridors	36 percent
Streets and crosswalks	17 percent
Curbs and curb ramps	11 percent
Stairs	17 percent

Countermeasures for Pedestrians with Vision Impairments

Crossing the street is a major hazard for people with vision impairments. A non-visual system to assist the vision-impaired has two distinct aspects, according to Hulscher (1975).

- Making the person with vision impairments aware of any special facility so it can be used properly

- Conveying the information normally displayed by visual means

From a series of interviews with 10 persons with vision impairments in Washington, DC, Hulscher showed the need for careful consideration of this impairment when widening streets and intersections, or accomplishing other physical changes. Major recommendations by those interviewed included:

- Greater separation between vehicle and pedestrian facilities, such as grade-separated crossings
- Use of textured pavements
- Angular, instead of round, corners (better for directional orientation)
- Braille maps at strategic points

Figure 36. Without adequate facilities, vision-impaired pedestrians are at increased risk..

Particular problems were noted for pedestrians with vision impairments at signalized crossings, including their difficulty in finding the pedestrian push buttons at actuated signals. Another problem for visually impaired pedestrians was in determining when the WALK and clearance intervals were displayed. Conveying signal information under such circumstances has been achieved by both tactile and audible means. These may be used to provide information regarding signal status as well as crossing guidance (Hulscher, 1975; Roberts, 1972). One study reported that, in Japan, sound equipment was used to generate bird calls or little songs to indicate signal status (Van Der Does, 1976). These have been found least disturbing to others and can be installed to vary in loudness depending on ambient sound levels.

Combinations of buzzers and beepers have been used in Australia (Chalis et al., 1976). These were combined with a vibrator, which the pedestrian with a vision impairment must touch at the curb to determine when it is safe to walk. The beeper then provides information on the clearance interval. Disturbance to others and masking due to ambient noise were noted as problems. Interviews with pedestrians with vision impairments uncovered a pronounced mistrust of mechanical aids at intersections, based upon experience with the vibrating signal. Several new designs were evaluated on the basis of behavior on the part of pedestrians with a vision impairment. The recommended mechanism employed an audible DON'T WALK sound device mounted on a pole to which the pedestrian could go and wait for the WALK signal. The signals were automatically adjusted to ambient noise level.

An evaluation of audible pedestrian signals was conducted in 1988 by the San Diego Association of Governments. The study estimated that as many as 100 cities in the U.S. use audible pedestrian signals, and they were reported to be used in Australia, Japan, Canada, Great Britain, and other countries in Europe. One aspect of the study involved a review of pedestrian crashes at 60 intersections in San Diego, CA, where pedestrian signals had been installed. No differences were found in the number of pedestrian collisions before and after installation of the audible devices. Drivers were at fault in more than half of the pedestrian collisions, and most crashes occurred between 9 a.m. and 6 p.m. in clear weather with the vehicle going straight. In spite of the signals' lack of a measurable effect on pedestrian crashes, the authors developed specific criteria for their use.

Tactile strips have been laid down to assist pedestrians with a vision impairment in crossing the street. In San Diego, tests at three sites showed tactile guide strips made of epoxy cement and pea gravel to be effective and durable under sustained traffic and weather conditions (Herms et al., 1975). They reported no evidence that the raised strip (102 mm [4 in] wide with 6-mm [0.25-in.] gravel) caused any subsidiary problems for motorists, bicyclists, or other pedestrians. The authors cautioned that these tactile strips should not be applied on an areawide basis but rather at selected locations of proven need, under joint supervision of a traffic engineering specialist and a trained mobility expert. This will help insure that such devices are provided consistently and to warn visually-impaired pedestrians where it is appropriate to do so.

Research was done by Gallon and colleagues on the use and utility of tactile surfaces in the traffic environment for people with visual impairments (Gallon et al., 1991; Gallon, 1992). The 1991 report included four study parts:

1. A review of literature, and usage practices current in England during the late 1980s
2. A survey of the walking habits of people with visual impairments
3. An experimental search among 20 different surfaces for a subset whose members were mutually distinguishable
4. An evaluation of how well people with visual impairments could distinguish among the selected surfaces, and how well they learned the intended uses

Five or six surfaces were found to be reliably distinguished, though none was "perfect," and color differences were important for people with some sight. The study also called for training people with visual impairments and consistent deployment of the various surfaces. In the 1992 study, Gallon reported that the selected surfaces posed no problems for those with mobility impairments. In contrast, O'Leary et al. (1995) cite some concerns by people with mobility impairments to the surfaces that assisted people with visual impairments.

Another device for pedestrians with a visual impairment, tested in Japan is a radio receiver carried by the vision-impaired pedestrian to receive information on traffic signal status from the signal installation (Van Der Does, 1976). For the color-blind, red and green are most often difficult to distinguish, so blue has been included in the green signal, or replaced green, for easier identification.

These "system" approaches can augment motorist behavior in response to seeing a handicapped pedestrian. In one experiment, a member of the research team crossed traffic with and without carrying a cane (Harrell, 1992). Drivers stopped more often when the cane was carried, but even under this condition, an average of three cars passed by before one stopped.

Safety Measures for Pedestrians with Hearing Impairments

A survey of 60 people with hearing impairments in Washington, DC, emphasized the visual dimension of travel on foot (Roberts, 1972). These pedestrians indicated the need for better, clearer signs at more appropriate locations; the use of audible crossing signals at various frequencies for the hearing impaired; more and better lighting facilities along pedestrian routes; and support structures, such as handrails, at critical locations such as bus boarding areas.

Guides and Manuals for Accommodating Pedestrians with Disabilities

Several published reports, guides, and manuals provide guidance on the selection and use of facilities for pedestrians with physical or mental impairments. For example, Earnhart and Simon in 1987 prepared a manual entitled, *Accessibility for Elderly and Handicapped Pedestrians - A Manual for Cities*, written to provide guidance to planners and other officials in the development of a program for improved accessibility. The manual includes information on planning, programing, and design of such facilities, and also provides example problems and solutions along with a checklist that can be used to solve various problems. Design details are provided relative to walkways and sidewalks, curb ramps, crosswalks, refuge islands, parking and loading areas, ramps and stairs, handrails, signing, street furniture, lighting and illumination, traffic signals, and tactile surface treatments.

Several FHWA reports address efforts to improve accommodation for elderly and handicapped pedestrians in U.S. cities. They involve the priority accessible network (PAN) approach, which is based on planning principles designed to provide for the special needs of these pedestrian populations. (Larsen, 1984; Hawkins, 1984). The goals of the PAN approach are to:

- Provide continuous accessibility to all desired pedestrian destinations.
- Provide a transportation network tailored to the special needs of all handicapped users (e.g., wheelchair users, and those with vision impairments).
- Efficiently use resources so the highest priority routes are constructed first.

The PAN process has been applied successfully and documented in, among other cities, Seattle, WA; New Orleans, LA; and Baltimore, MD (Larsen, 1984; Hawkins 1984; Zegeer and Zegeer, 1989). A summary of the various types of roadway and engineering improvements for elderly and handicapped pedestrians has been documented in a 1989 publication by Zegeer and Zegeer, which discusses the many possible measures related to traffic signals, sidewalks, signs, and design features.

The FHWA's two-part *Designing Sidewalks and Trails for Access* report provides further guidance on designing sidewalks and walkways for people with disabilities. *Part I: Review of Existing Guidelines and Practices* looks at existing sidewalk and trail conditions for people with disabilities. By conducting a literature search and site visits around the U.S., the authors compiled data and reviewed designs to identify factors that affect accessibility for all populations (Axelson et al., 1999). Building on the foundation of Part I, *Part II: Best Practices Design Guide* was created to improve understanding among city planners, urban designers, and transportation engineers with respect to how sidewalks and trails can be developed to promote pedestrian access for all users, including people with disabilities (Kirschbaum et al., 2001).

Bus Stop Location

Two percent of all pedestrian collisions in urban areas can be classified as pedestrian collisions at bus stops. Most do not involve a pedestrian's being struck by a bus; rather, the bus creates a visual screen between approaching drivers and pedestrians crossing in front of the bus. In rural areas, pedestrian crashes related to school bus stops were identified in 3 percent of all pedestrian crashes. The countermeasure proposed for the urban crashes involved bus stop relocation to the far side of the intersections to encourage pedestrians to cross behind the bus instead of in front. This allows the pedestrian to be seen and to see oncoming traffic closest to the bus. To determine the effect of such relocation on pedestrian crossing behavior, two studies addressed before-and-after bus stop relocation. One was a site in Miami, FL, on a two-way, four-lane street intersecting with a two-way, two-lane street at an unsignalized location. The other was in San Diego, CA, on a two-way, four-lane street intersecting with a one-way, three-lane street at a signalized location that included pedestrian signals (Berger, 1975). The relocation of the bus stops to the far side eliminated the undesired crossing behavior; previously, half those crossing after disembarking were crossing in front of the bus.

An analysis of pedestrian crashes in Sweden found school bus stops were not located with the greatest care regarding pedestrian safety factors (Sandels, 1979). They concluded bus stops should be located:

- So as not to be hidden by vegetation or other obstacles
- Away from roadway curves or superelevated locations
- To provide adequate standing and playing area for the waiting passengers
- So that each location provides maximum sight distance to all critical elements

A U.S. study of crashes involving trips to and from schools investigated the location of school bus stops and developed guidelines for planning, routing, and scheduling school buses (Reiss, 1975A).

School Trip Safety

Pedestrian safety dealing with the school trip has received much attention from the public and researchers. It is therefore treated as a separate entity here, referencing a variety of traffic guidance and control countermeasures.

An inventory of crashes in 1,335 U.S. cities revealed that 25.4 percent of 220 child pedestrian deaths reported for 1967 occurred as the children were en route to or from school (AAA Special Study, 1968). Among 1,854 child pedestrian injuries, 18.6 percent took place en route to or from school. From this study, a national estimate was made of 500 fatalities and 11,000 injuries resulting from the walk to school. The highest proportion of these occur at ages 12 to 14. This is the junior high school age when the student is usually without the presence of student crossing controls for the first time. Further analysis showed about 93 percent of all children involved were struck at locations where no school safety patrols, adult guards, or police officers were stationed. (This study was carried out many years ago and may now be out of date.)

An intensive study of the school trip was conducted at sites in New York, Maryland, and Virginia (Reiss, 1975A), surveying both students and drivers. Crashes were also analyzed. The student surveys sought information on knowledge, behavior, and possible means for modifying these. Driver surveys sought data regarding perceptions, motivational factors, and reactions to the school zone environment and their correlation to actual behavior.

Figure 37. Studies have found that uniformed crossing guards are safer than other control devices such as signs or markings alone.

The four sites studied employed school warning and speed limit signs. Walking to school accounts for between 10 and 20 percent of the annual young-pedestrian crashes in the U.S. Significantly more younger students than older ones indicated they are unaware of or do not differentiate among various traffic control devices. They consider uniformed crossing guards safer than other control devices. They would vary their route to school on the basis of parental instructions.

Zegeer and Deen in 1978 conducted an evaluation in Kentucky of the 25 MPH WHEN FLASHING sign at 48 high-speed school-zone locations with yellow flashing beacons. Speeds were predominantly 56-73 km/h (35-45 mi/h) without the flasher. Vehicle speeds overall were an average of only 5.8 km/h (3.6 mi/h) less during the flashing periods compared with the non-flashing periods. Speed reductions of 16 km/h (10 mi/h) or more were found at only two sites, and only 18 percent of all motorists complied with the 40 km/h (25 mi/h) flashing limit. The regulatory flashing signs were not considered effective in reducing vehicle speeds to 40 km/h (25 mi/h). At rural school zone locations, the 40 km (25 mi) flashers during school periods resulted in an increase in speed variance and thus, they created the potential for increased rear-end vehicle crashes. The presence of crossing guards and/or police speed enforcement, however, contributed to improved speed compliance

Another discouraging note is added in a 1990 study by Burritt et al. in which yellow flashers were added to existing 24 km/h (15 mi/h) school zone signs at a school crossing on a highway in Tucson, AZ. The flashers, installed over the objections of the Arizona highway authorities, were then evaluated in December before the flashers and in May after the flashers. Speed was somewhat worse after the flashers were installed, increasing from 26 to 32 km/h (16-20 mi/h) at one site and from 24 to 27 km/h (15-17 mi/h) at the other. The authors provided no behavioral data.

Figure 38. School regulatory flashes have been found to have only limited success in reducing vehicle speeds in school zones, unless adult crossing guards are also helping to control traffic.

Alternatives to Signalization for School Crossings

A school pedestrian signal design concept has been used with stop signs on the minor approach and traffic signals on the major approach. Some western states have used these devices to create adequate pedestrian crossing gaps across high-speed, high-volume facilities used by school children, the elderly, and/or those with disabilities where full signalization was not warranted.

A 1977 study by Petzold was directed at identifying and evaluating alternatives to full signalization at school pedestrian crossings. These crossings were located at the intersection of a high-volume arterial street and a low-volume residential street where traffic gaps are inadequate to allow pedestrians to cross the arterial street safely without an unreasonable delay. These locations would not otherwise warrant full signalization.

The following five school pedestrian crossing designs were selected for field testing at installations in six U.S. cities:

- Sign and beacon: Sign and beacon on the major street approach and stop sign on the local residential street

- Flashing yellow signal and flashing red beacon: Standard traffic signal dwelling in flashing yellow on the major street and a flashing red beacon on the local residential street

- Flashing green signal and stop sign: Standard traffic signal dwelling in flashing green on the major street and stop signs on the local residential street

- Signal and stop sign: Standard traffic signal dwelling in solid green on the major street and stop sign on the local residential street

- Crossing guard: Crossing guard on the major street and stop signs on local residential street

The five school pedestrian crossing designs were evaluated in a time series, matched experimental-control design. Six measures of effectiveness were used: compliance, behavior, and volume, for both pedestrians and vehicles; vehicle delay; gaps in the major street vehicular traffic stream; and driver understanding. In all experiments, a fully signalized intersection was used as a control site. Based on the data analysis and observations at each school pedestrian crossing design, Petzold (1977) listed the following advantages as compared with full signalization:

- Increased pedestrian compliance with the pedestrian signal

- Reduction in the percentage of vehicles stopping on the major street approach

- Reduction in the stop time per vehicle on the major street approach

- Reduction in installation costs

Disadvantages to the full signal alternatives as found by Petzold include:

- Reduction in both pedestrians' and drivers' understanding of how the traffic control devices operate

- Increase in conflicts between vehicles approaching at a right angle (not significant).

Based on the comparison between each school pedestrian crossing design and its fully signalized control site, the authors made these conclusions:

- The sign and beacon design revealed many undesirable characteristics, especially concerning vehicle compliance with the flashing red beacon. It was concluded that full signalization is more desirable than the beacon and stop sign design

- The flashing yellow signal and flashing red beacon show characteristics similar to those obtained at the fully signalized control site. The flashing yellow signal and flashing red beacon are judged equivalent to full signalization, except full signalization could generate through traffic on the minor street approach

- The remaining three school pedestrian crossing designs (crossing guard, signal and stop sign, and flashing green signal and stop sign) were judged to have operating characteristics more desirable than those measured at the fully signalized control site

Based on the comparison of mean rank scores among the five school pedestrian crossing designs, the crossing guard had significantly better operating characteristics than the beacon and stop sign or the flashing yellow signal and flashing red beacon designs. The crossing guard operating characteristics were not significantly different from the operating characteristics observed at the signal and stop sign and flashing green signal and stop sign designs.

Reflectorization and Conspicuity

Research has identified reflectorization as a highly effective means of improving visibility (Allen et al., 1969; Hazlett and Allen, 1968; Jacobs, 1968b). In a survey of safety specialists, reflectorization countermeasures were identified as having the highest overall rating to reduce school children crashes occurring during darkness (Reiss, 1975). The key issue is attaining proper usage. A study of reflectorization treatments showed that a person dressed in black wearing a thumb-sized retroreflective tag is detected at greater distances than a person completely dressed in white (Rumar, 1966). Maintaining the retroreflective power of the tag was also shown to be important to achieve good results, thus highlighting the need to regularly replace or clean the tag.

A 1984 study by Blomberg et al. investigated countermeasures to improve the conspicuity of pedestrians and bicyclists. Nighttime field tests were conducted for baseline pedestrians (i.e., wearing a white tee shirt and blue jeans), compared with pedestrians with dangle tags, a flashlight, jogger's vest, and retroreflective material on head band, wrist bands, belt, and ankle bands ("rings"). On average, the flashlight was detected by a driver at 420.5 m (1,379 ft). This was slightly more than 183 m (600 ft) further away than rings, which were the next best target (at 231.8 m [760 ft]) and jogging vest (227 m [744 ft]), as shown in figure 40. The average detection distance of the baseline pedestrian was 68 m (224 ft).

Owens and Antonoff in 1994 conducted an experiment in which retroreflective materials were placed on different body locations. Pedestrians with reflective materials on knees, waist, elbows, and shoulders were seen more readily than when placed on a pedestrian (e.g., chest or back) where no movement was evident. Authors said "biological motion" was an important part of detection and recognition. Seen at night, such motions of the reflectorized materials are more pronounced and are more readily interpreted as characteristic of human motion.

As an engineering countermeasure, retroreflective materials are used for roadway markings such as crosswalks, stop lines, and lane markings. These materials reflect light from vehicle headlights and from roadway illumination. Reflective vests and other clothing for pedestrians have also been made with

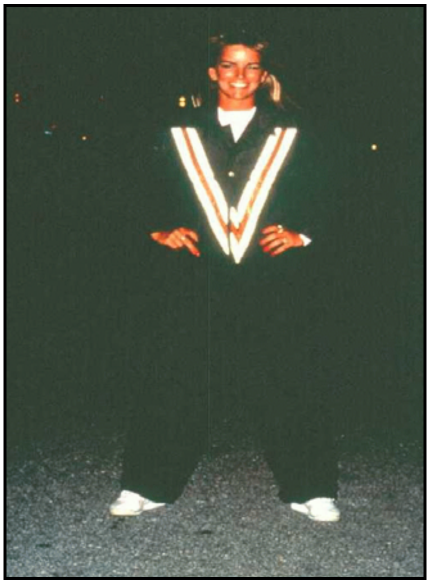

Figure 39. Reflectorization has been shown to result in a major increase in the visibility of a pedestrian at night.

reflective materials. Reflectorization has been shown to increase the visibility of a pedestrian by a factor of five. The difficulty is making retroreflective clothing that can last more than a few wash cycles.

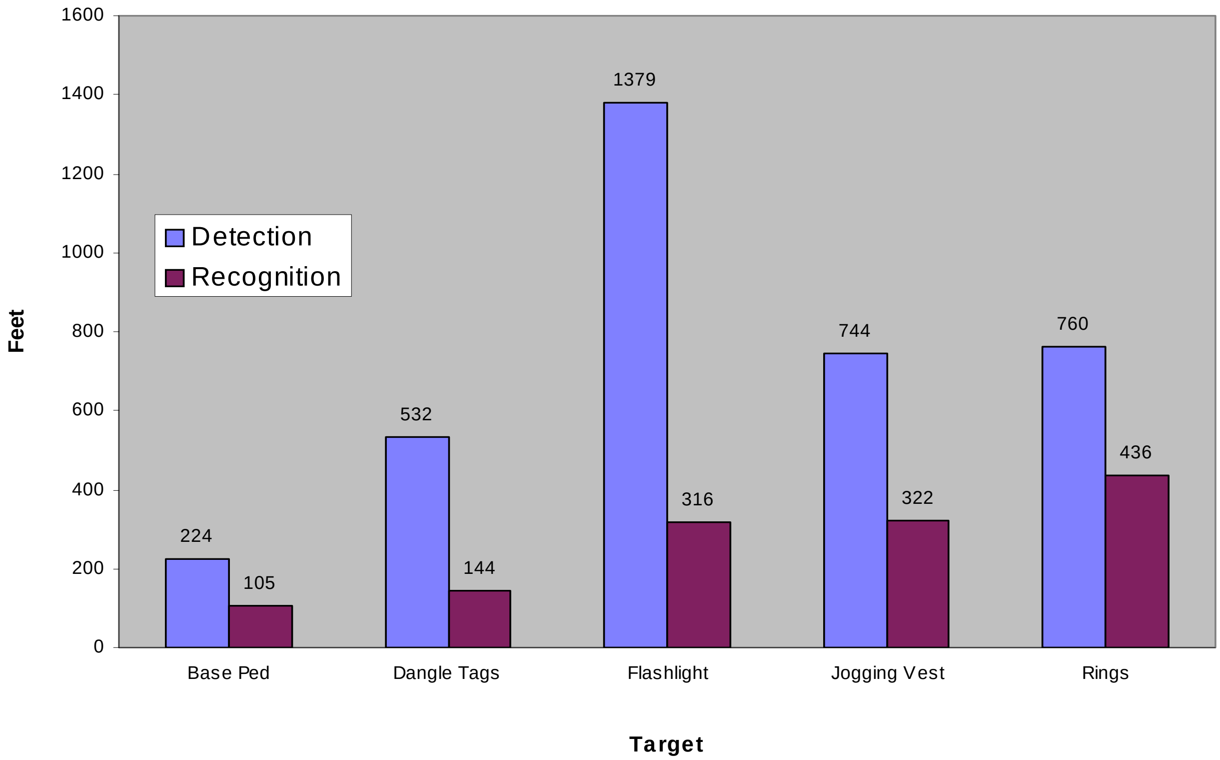

Figure 40. Nighttime detection and recognition distance of pedestrians. Source: Blomberg et al., 1984.

One-Way Streets as a Pedestrian Crash Countermeasure

A comprehensive study of pedestrian and bicycle crashes in several Canadian cities found fewer crashes on one-way streets in the core of a city than on two-way streets (Lea, 1978). Thus, conversion to a one-way street system may also be a relatively low-cost pedestrian countermeasure, having as high as 40-60 percent effectiveness on amenable crashes. However, the applicable crashes were estimated to represent only about 10 percent of the city total.

A study in Manhattan, NY highlighted the aspects of one-way street grids that tend to provide safer traffic operation (Fruin, 1973). The simplification of the crossing and turning conditions, which has been noted to occur for vehicles at the intersection of two one-way streets, is also helpful to pedestrians. Two-hundred fifty-three pedestrian crashes, occurring over a 5-year period in an 8-by-4 grid, were studied. Almost 70 percent of these occurred at intersections. Only five fatalities occurred in the area during the 5 years; all were males over age 60.

The four crosswalks at each intersection were divided into two groups, two where there was a conflict with a vehicle completing a turn (conflict side), and two with no turning conflict. The results of that study showed that crossings on the turning conflict side of the intersection accounted for 69.7 percent of the intersection crashes. This total consisted of 44.7 percent turning crashes, 17.5 percent straight crashes, and 7.5 percent backup crashes. A pedestrian is more than twice as likely to be struck by a vehicle when crossing on the turning conflict side than when crossing on the non-turning conflict side.

Short vehicle and pedestrian counts were taken at the intersections in the study area. While the conclusions were not statistically significant, the results offer some useful perspectives. Although vehicle turning movements averaged only 14 percent of the total intersection volume, turning crashes were almost 45 percent of the total. Left-turn crashes exceeded right-turn crashes by a ratio of two to one. The front left vehicle window post was suggested as a factor, blocking the driver's view of a critical part of the crosswalk area. Of course, the left turn is inherently a more complex task for the driver.

In many cases, converting two-way streets to one-way streets may not be justified solely by pedestrian safety considerations. Several concerns such as capacity, traffic circulation, and overall traffic safety are the major considerations. Vehicle speeds may also increase after conversion from two-way to one-way street patterns. However, one-way streets can greatly simplify the task of crossing a street and in some cases may improve safety for pedestrians.

Pedestrian Overpasses and Underpasses

An analysis was made of reported pedestrian crashes for 6 months before and 6 months after the installation of pedestrian overpasses at 31 locations in Tokyo, Japan (*Accident Prevention Effects*, 1969). The overall results are shown in table 30. The table shows data for 200-m (218-yd) sections and 100-m (109-yd) sections on either side of each site. The “related” crashes (assumed to be pedestrian crossing crashes) decreased substantially after overpass installation, but non-related crashes (not defined) increased by 23 percent in the 200-m (218-yd) sections. There was also a greater reduction in daylight pedestrian collisions than in those occurring at night.

The effectiveness of pedestrian overpasses depends largely on the amount of use by pedestrians. A 1965 study by Moore and Older found that use depended on walking distances and convenience of the

Table 30. Comparison of crashes before and after installation of pedestrian overpasses (Tokyo, Japan).

Type of Crashes	200-M Section Before	200-M Section After	200-M Section Reduction	100-M Sections Before	100-M Sections After	100-M Sections Reduction
Related Crashes	2.16	0.32	85.1%	1.81	0.16	91.1%
Non-related Crashes	2.26	2.77	22.9%	1.65	1.87	-13.7%
Total	4.42	3.09	29.9%	3.46	2.03	41.1%

Source: ***Accident Prevention Effects***, 1969

facility. A convenience measure (R) was defined by the authors as the ratio of the time to cross the street on an overpass divided by the time to cross at street level. As illustrated in figure 41, the study found that approximately 95 percent of pedestrians will use an overpass if the walking time in using the overpass is the same as crossing at street level (i.e., R = l). However, if crossing the overpass takes 50 percent longer than crossing at street level (R = l.5), almost no one will use the overpass. Usage of pedestrian underpasses (subway) was not as high as overpasses for similar values of R.

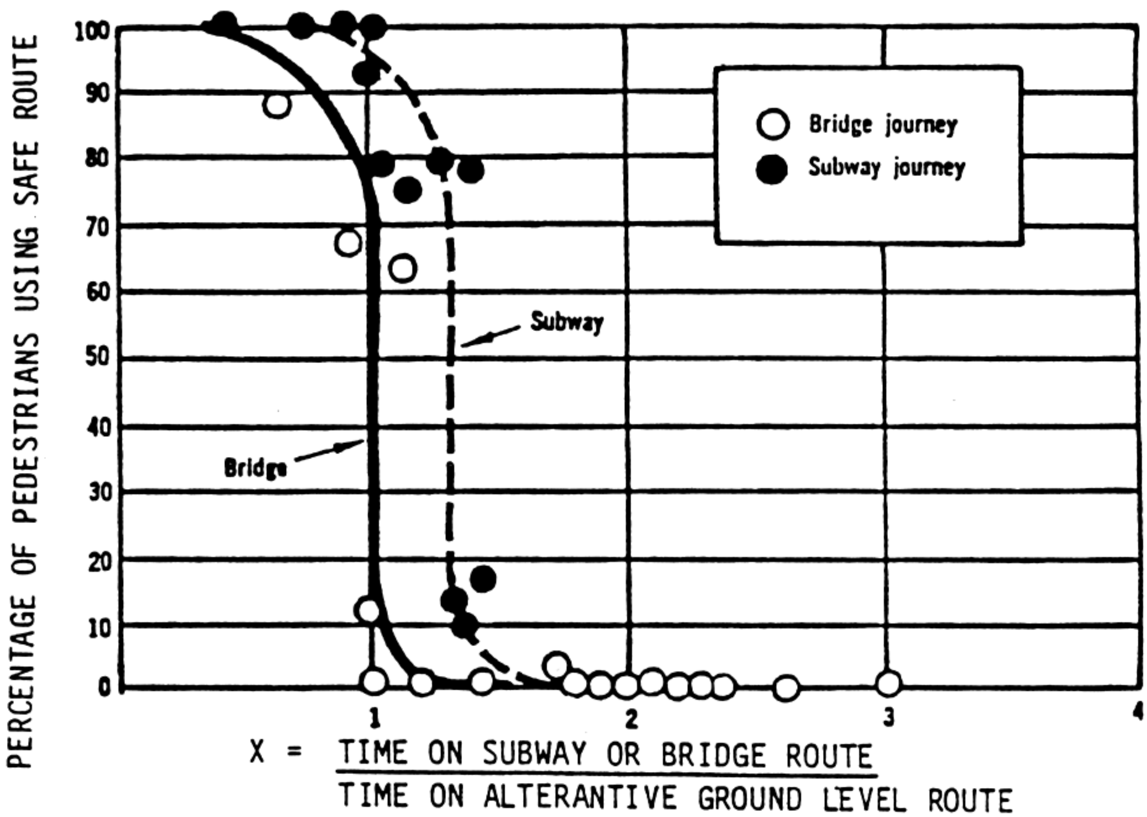

Figure 41. Expected usage rate of pedestrian bridges and underpasses, relative to time needed to cross at street level.
Source: Moore and Older, 1965.

Problems have also been identified relative to pedestrians' use of overpasses. A panel of people with disabilities was asked to comment on problems after using three pedestrian overpasses in San Francisco, CA (Swan, 1978). The major elements identified as creating a barrier or hazard to the user with disabilities included:

- Lack of adequate or no railings to protect pedestrians from dropoffs on the bridge approaches
- Greater than acceptable cross slopes
- No level area at terminals of bridge ramps on which to stop wheelchairs before going into the street
- Lack of level resting areas on spiral bridge ramps
- Railings difficult to grasp for wheelchair users
- Lack of sight distance to opposing pedestrian flow on spiral ramps
- Use of maze-like barriers on bridge approaches (to slow bicyclists) that create a barrier to those who use wheelchairs or who are visually impaired
- Lack of sound screening on the bridge to permit people with visual impairments to hear oncoming pedestrian traffic, and otherwise more easily detect direction and avoid potential conflicts

A study in 1980 by Templer et al. investigated the feasibility of accommodating pedestrians with physical disabilities on existing overpass and underpass structures. A review of 124 crossing structures revealed that 86 percent presented at least one major barrier to the physically handicapped, the most common being:

- Stairs only (i.e., no ramps for wheelchair users) leading to the overpass or underpass
- Ramp or pathway to ramp that is too long and steep
- Physical barriers along the access paths on structure
- Sidewalk on the structure that is too narrow
- Cross slope on the ramp that is too steep

Various solutions to these access problems were developed and compared based on cost-effectiveness.

The Americans with Disabilities Act (ADA) law of 1990 has since required the barriers to wheelchair users to be removed, requiring more gentle slopes. While these gentle slopes make it easier for bicyclists and other users, it has also greatly increased the length of ramps, which may discourage usage. Methods such as carefully planned fencing have been used to channel pedestrians to the overpasses and underpasses to increase usage.

Grade separations such as overpasses and underpasses for pedestrian crossing can be beneficial under certain circumstances if the pedestrian can be persuaded to use the grade-separated crossing (i.e., perceive it as safer, convenient). However, they are very costly and may not be used by pedestrians if not planned properly.

Figure 42. Grade-separated crossings can be beneficial to pedestrians under certain situations but are very costly and may not be used by pedestrians if not planned properly.

Traffic Calming

What is Traffic Calming?

At an Institute of Traffic Engineers (ITE) meeting attended by traffic calming experts, the following definition was prepared:

> "Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-vehicular traffic." (Lockwood, 1997, page 22)

The need for a definition process grew out of the fact that a variety of activities are called traffic calming by one person or another. Lockwood (1997) said:

> "...traffic calming could mean anything from lowering motor vehicle speeds to an all-encompassing transportation policy." (page 22) and "... everything from slowing down motor vehicles to changing tax laws." (page 24)

According to Lockwood, the term "mainly physical measures" is meant to include the supporting political environment, policy, and legislation. The "negative effect of motor vehicle use" refers to speeding, neighborhood intrusion, energy consumption, pollution, urban sprawl, etc. Many traffic calming measures typically create an improved environment for pedestrians by reducing vehicle speeds or volumes, and/or shortening the crossing distances for pedestrians.

Traffic-Calming Measures

Many measures can be considered traffic calming. A 1995 document prepared by the Institute of Traffic Engineers (ITE) (Kemper and Fernandez, 1994) discusses "neighborhood traffic control measures" and lists 13 types, and other initiatives are not included on the ITE list. :

1. Street closures
2. Cul-de-sacs
3. Diverters (diagonal or semi-diagonal)
4. Traffic circles
5. Woonerfs
6. Chicanes
7. Flares, chokers
8. Speed humps
9. Speed limit signs and speed zones
10. Speed watch and enforcement programs
11. Walkways
12. Parking controls
13. Other signage

Other measures include traffic diversion, which involves moving traffic onto other streets, while still others, such as speed limit signs and enforcement, fall into traditional traffic engineering approaches. Figure 43 illustrates some of the above.

A study in 2000 by Huang and Cynecki evaluated the effects of a variety of traffic-calming measures on pedestrian and motorist behavior at midblock and intersection locations. "Before" and "after" data were collected in Cambridge, MA (bulbouts and raised intersection), Corvallis, OR (pedestrian refuge island), and Seattle, WA (bulbouts). Data were also collected at "treatment" and "control" sites in Durham, NC (raised crosswalks), Greensboro, NC (bulbouts), Montgomery County, MD (raised crosswalks), Richmond, VA (bulbouts), and Sacramento, CA (bulbouts). The key findings include:

- Overall vehicle speeds were often lower at treatment than control sites.

- The combination of a raised crosswalk with an overhead flasher increased the percentage of pedestrians for whom motorists yielded. It is not known what part of the improvement was attributable to the raised crosswalk and what part was attributable to the flasher. None of the other treatments had a significant effect on the percentage of pedestrians for whom motorists yielded.

- The treatments usually did not have a significant effect on average pedestrian waiting time.

- Refuge islands often served to channelize pedestrians into marked crosswalks. The raised intersection in Cambridge also increased the percentage of pedestrians who crossed in the crosswalk.

In conclusion, these devices have the potential for improving the pedestrian environment. However, these devices by themselves do not guarantee that all motorists will slow down or yield to pedestrians.

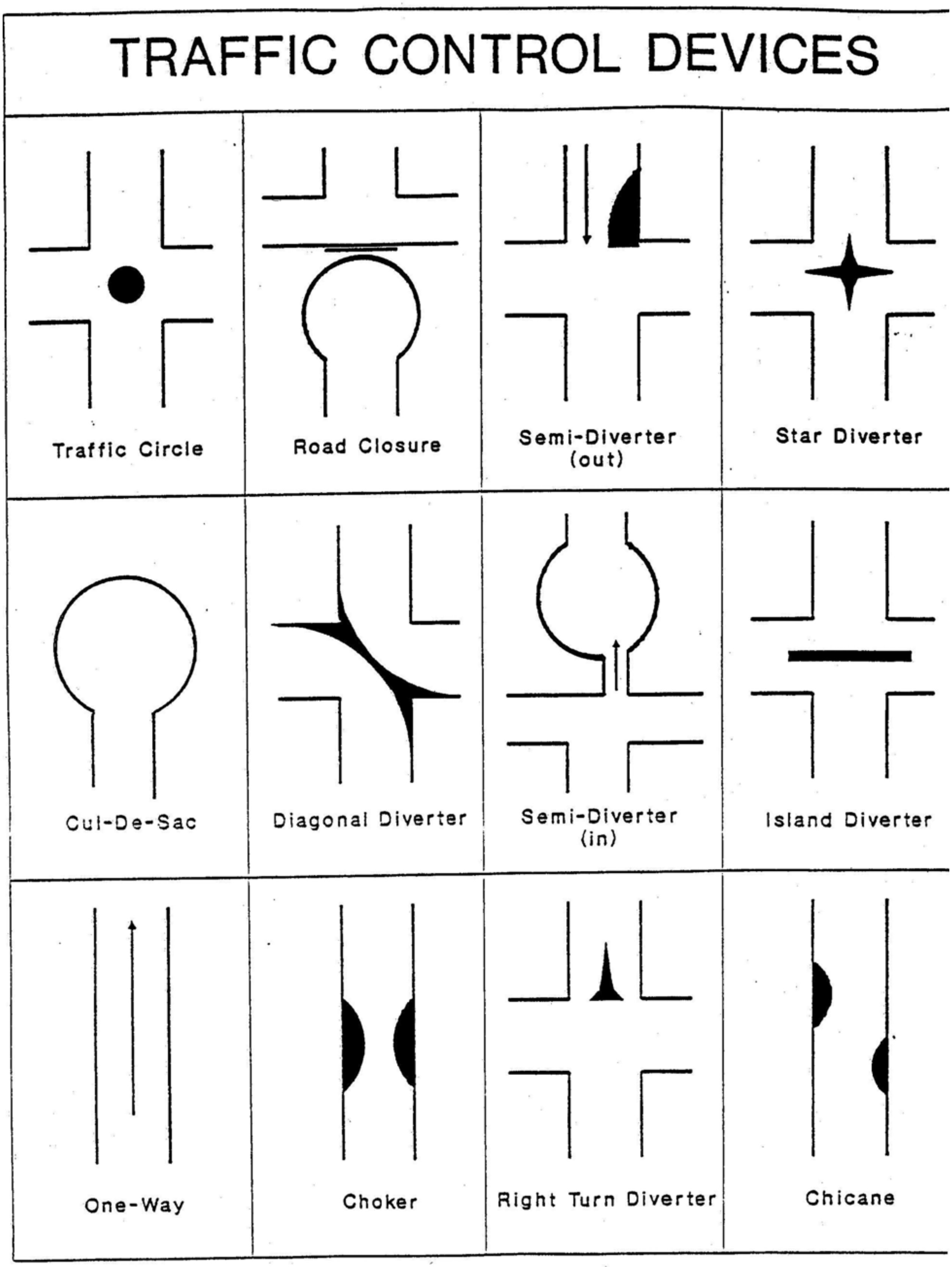

Figure 43. Illustrative neighborhood traffic control devices.

1. Play Streets

Play streets have been employed in the United States in center-city neighborhoods to provide safe play areas in or near residential areas. A play street is a residential street closed to vehicular traffic during specific hours to permit a supervised program of recreational activities in the roadway. A series of interview studies was performed at 20 sites in Philadelphia and New York City. The interviews sought behavioral and opinion data regarding play streets from users, residents, merchants, play street supervisory staff, and city officials (Reiss, 1975B).

Play streets were found to be effective in eliminating traffic and parking. The streets drew 67 percent of the users from among those who live along the street. The remainder came from within a radius of three blocks. Ninety-six percent of the residents and merchants interviewed believed the play street reduces the likelihood that children will be hit by cars. Eighty-eight percent noted no problems to them because of the 1 p.m. to 8 p.m. street closure. However, only 12 percent of the play supervisors interviewed perceived a safety benefit. It was recommended that signing and barricades be judiciously used to control vehicular access to a play street. The authors recommend that appropriate traffic engineering studies should be made before selecting a play street site. Guidelines were developed for the creation and operation of urban play areas. No evaluations of the safety benefits of play streets were conducted.

Figure 44. Many traffic-calming measures create an improved environment for pedestrians by reducing vehicle speeds or volumes, and/or shortening crossing distances for pedestrians.

A study of the effect of recreational facilities on child pedestrian crashes was made in Philadelphia (Bartholomew, 1967). Traffic crash records were analyzed for 2 years before and 2 years after the opening of seven different recreational facilities in various parts of the city. Service areas for each were defined on the basis of population density and physical barriers. There was a significant reduction in pedestrian crashes involving children ages 5-14 for the combined areas after facilities were opened. Outside the seven areas, there was a city-wide trend of an increase in child pedestrian collisions. The greatest impact was noted within a radius of one-quarter mile of each facility. This occurred even though more children were using the facilities and crossing streets going to and from the sites.

2. *Community Streets*

Japan's traffic-calming strategies have been directed toward community streets. Community streets rely on treatments such as speed humps, bulbouts, chicanes, and other devices to slow down motor vehicle traffic (Replogle, 1992). In addition, motorists and pedestrians are separated. Community streets are most appropriate when traffic volumes are 200 vehicles per hour or less.

Road-pia are neighborhood-wide installations of community streets that give priority to pedestrians and cyclists. In the Koraku district of Nagoya, a road-pia scheme introduced community streets to connect schools and transit stations to homes. The number of car-pedestrian crashes resulting in injury or death fell from 32 in the 4 years before the road-pia scheme was installed to only 2 in the 2 years after. While the effects of individual components such as speed humps or bulbouts was not known, the combination of these devices was effective in reducing traffic, vehicle speeds, and collisions (Replogle, 1992).

3. *Woonerf*

The Netherlands is one of the leaders in traffic calming. They developed the “woonerf” based on the concept of the residential yard (Kraay, 1976). These are areas where the physical and visual treatments of the public right-of-way create a pedestrian-oriented area. Only local traffic is allowed to use the roadway and all modes are “forced” to travel almost as slow as the slowest mode (the pedestrian) through design features. The residential yard's function differs from a conventionally designed residential street. The paved area is used in common for various functions, including driving, playing, cycling, walking, and parking. This is intended for application only along low-volume streets having minimal parking demand.

Special legal and behavioral rules apply to traffic in the residential yard:

- Roads located within a designated residential yard may be used over their entire width by pedestrians and children at play.

- Drivers must move with the greatest caution, being intruders within the residential yard.

- The speed of all modes is limited to about 11.3 km/h (7 mi/h).

- Pedestrians must not unnecessarily obstruct vehicle progress.

- Motor vehicles with more than two wheels can park in a residential yard only at places with a parking sign or a letter "P" in spaces on the road surface.

- A new traffic sign indicates residential areas designated as residential yards.

4. *Transit Malls: Shared Use of Pedestrian-Oriented Space*

The use of transit malls is common in Europe, and is increasing in U.S. cities.

Studies were conducted of crashes occurring before and after implementation of transit malls in Philadelphia and Minneapolis (Edminster and Koffman, 1979). Analysis showed non-pedestrian collisions decreasing sharply on transit malls with no evidence of an increase on nearby streets. Total pedestrian crashes appear stable with the only increase related to an increase in the exposure rates of pedestrian and vehicular volumes. Bus-pedestrian conflicts are much higher on transit malls than on other streets. Fortunately, creating the malls has not resulted in a higher number of bus-pedestrian collisions. Factors related to pedestrian crashes in Philadelphia include:

- Change from a one-way street to a two-way bus flow appears to cause confusion and carelessness on the part of pedestrians.

- Illegal pedestrian behavior, particularly jaywalking, results in more collisions in which pedestrians are at fault.

- Jaywalking is partly encouraged by a low volume of buses.

- Inadequate mall design included roadways that were too narrow, and the lack of barriers to discourage jaywalking.

- Jaywalking was encouraged by certain amenities such as phone booths used by pedestrians and placed too close to the curb.

- Construction of bus shelters too far away from crosswalks encouraged bus riders to cross the roadway outside the crosswalks.

- Midblock pedestrian crossings caused the entire roadway to be viewed in a casual manner by pedestrians.

- Operational problems may contribute to pedestrian crashes.

Although some people believed speeding buses, encouraged by the freedom from other traffic, were a danger to pedestrians, there was no evidence of buses speeding.

As a result of a review of studies involving shared use of pedestrian-oriented space, it was concluded that plans that restrict private vehicles from small sections of the roadway but allow other public service vehicles have only marginal or small positive safety benefits (Edminster and Koffman, 1979; Katz, 1978). Other pedestrian measures, such as pedestrian delay, are improved.

5. Area-wide Traffic Restrictions

Area-wide traffic restriction plans have been employed in town centers and residential areas. Observations of pedestrian risk were made in Upsala, Sweden, both before and after the implementation of an area-wide traffic restriction plan in the center of town (Lovemark, 1974). This involved closing streets to vehicular traffic, institution of one-way flow on bypass routes, and bus-only streets. Risk was defined as the probability of a collision occurring that would result in personal injury and was predicted from serious traffic conflicts for various types of pedestrian and driver behaviors. Risk for pedestrians in the restricted area declined by 29 percent. Risk for pedestrians on surrounding streets outside the restricted area, which experienced a 30-percent increase in volume after the restrictions were implemented, increased 12 percent.

In similar traffic management efforts in London, the impact of street closures and a few other devices on pedestrian safety was analyzed for 19 areas (Brownfield, 1980). Ten sites showed declines in pedestrian collisions and two sites remained the same. The overall result was a pedestrian crash decline of 24.4 percent. However, this decline was not statistically significant.

6. Speed Humps and Speed Tables

Also known as road humps, undulations, or "sleeping policemen," speed humps were developed by the Transport and Road Research Laboratory in Great Britain. The purpose of speed humps is to promote the smooth flow of traffic at slow speeds, around 32-40 km/h (20-25 mi/h). The speed hump is an elongated bump with a circular-arc cross-section, rising to a maximum height of 76 mm (3 in) above the normal pavement surface and having a length of 3.7 m (12 ft) in the direction of vehicular travel. Speed humps usually extend the full width of the road.

Speed tables are flat-topped or trapazoidal speed humps. When used in conjunction with crosswalks, the flat top of the hump can extent the width of the crosswalk. Speed tables are generally the same height of speed humps, and the raised portion can be built with brick pavers. Speed tables are more common in Europe and Australia than in the U.S.

The ITE notes that,

> Speed humps have the advantage of being largely self-enforcing and of creating a visual impression, real or imagined, that a street is not intended for speeding or 'through' traffic. Some items to consider before speed hump installation are their initial construction and continuing maintenance costs, any potential negative impact on emergency and service vehicles, increases in vehicle noise, inconvenient access, and to some, their unsightliness. They must be appropriate for use at all hours, day and night. In addition, it is mandatory that they be supplemented with a combination of signs and/or pavement markings to warn motorists. (ITE Technical Council, 1993)

Other concerns related to speed humps and speed tables include the effect on drainage, snow removal, and the effect on emergency access of fire trucks and ambulances.

7. Effects of Speed Humps

According to the ITE, speed hump research and testing have found that:

- Traffic speeds decrease at the humps and at locations between properly spaced successive humps. Speeds of the fastest drivers are affected as well as those of average drivers. The speed distribution generally narrows, with the greatest effect on higher vehicle speeds.

- A single hump will only act as a point speed control. A series of humps is usually needed to reduce speeds along an extended section of street. On long straight streets, speed humps will be needed about every 153 m (1 block) to more uniformly control speeds.

- Speed humps may divert traffic to other streets, especially in those situations where a significant amount of traffic is using the street as a shortcut, detour, or overflow from a congested collector or arterial roadway. Volume reduction is affected by the number and spacing of humps and availability of alternative routes.

- Studies indicate that speed humps do not have the same effect on all vehicles. Humps tend to have a more significant impact on longer wheel-base vehicles such as pickup trucks, buses, and fire trucks, and less of an impact on vehicles with good suspension.

- Speed humps are said not to pose a traffic safety hazard when properly designed and installed. In fact, crash experience generally remains stable or decreases due to reduced speeds and volume (ITE Technical Council, 1993). Surveys of various agencies have failed to identify any clear liability problems associated with the use of speed humps.

8. Experience with Speed Humps

Several agencies have reported on the use of speed humps.

OMAHA, NE (Klik and Faghri, 1993)

- Humps installed on 60 residential streets
- Before-after measurements of 85th percentile speeds at 10 locations showed significant speed reductions (5 percent significance level)
- Personal injury crashes decreased at 19 locations
- Some residents complained about increased noise levels, vehicle damage, and that speeding still existed
- Officials were concerned about emergency vehicle response, potential liability, and need for monitoring signs and pavement markings near speed humps

BELLEVUE, WA (Clarke and Dornfield, 1994)

- Sixteen speed humps installed in five residential neighborhoods
- 85th percentile speeds declined from before level of 58-63 km/h (36-39 mi/h), to 39-43 km/h (24-27 mi/h) after installation
- Traffic volumes declined when alternate routes existed
- Most residents said humps were effective and favored continued use

HOWARD COUNTRY, MD (Walter, 1995)

- Seven humps on Baltimore Avenue lowered 85th percentile speeds from 61 km/h (38 mi/h) to 43-47 km/h (27 to 29 mph) *between* humps, and 24 km/h (15 mi/h) *at* humps; no crashes in 4 years after vs. 4 crashes in the 2 years before
- Four humps on Dogwood Drive reduced the 85th percentile speed from 64 km/h to 45 km/h (40 mi/h to 28 mi/h); volumes fell 24 percent
- On Shaker Drive, 85th percentile speed fell from 69 km/h to 47 km/h (43 mi/h to 29 mi/h) following the installation of two flat-top humps; speed between humps and at humps was essentially the same

AGOURA HILLS, CA (Cline, 1993)

- Five speed humps were built along a 0.8-km (0.5-mi) stretch of Grey Rock Road. The humps were 70 mm (2.75 in) high instead of 76 mm (3 in)
- 85th percentile speeds fell 10-15 km/h (6-9 mi/h) after installation
- Volumes remained constant. Observations indicated motorists did not speed up between the humps, drive in the gutter, or divert to other residential streets

WESTLAKE VILLAGE, CA (Cline, 1993)

- Humps were 67 mm (2.625 in) high
- 85th percentile speed fell 15-23 km/h (9-14 mi/h) after the humps were installed

Several other demonstration projects in Los Angeles used the 67-mm (2.625-in) speed humps, with results similar to Agoura Hills and Westlake Village

CORIO, VICTORIA, AUSTRALIA (McDonald and Jarvis, 1981)

- Two residential streets each had three road humps. The separation between the humps was 110 to 150 m (361 to 492 ft)
- 85th percentile traffic speeds at humps dropped by nearly half
- Volume fell 28 percent on one street and 24 percent on the other

STIRLING, WESTERN AUSTRALIA (Richardson and Jarvis, 1981)

- Eight humps installed, with 115 to 160 m (377 to 525 ft) between humps
- 85th percentile traffic speeds at humps dropped from 65 km/h (40 mi/h) to 21 km/h (13 mi/h)
- Speeds between the humps fell from 70 to 45 km/h (43 to 28 mi/h)
- Volumes fell by roughly half

Other Australian cities conducted evaluations on speed tables. In Croydon, Victoria, the 85th percentile speeds between speed tables fell as much as 36 percent (Hawley et al., 1992). In Mosman, New South Wales, the noise levels after speed tables were installed fell by up to 11 decibels, partly the result of lower traffic volumes (Hawley et al., 1992). With speed tables in place, the character of vehicle noise changes to thumping (as motorists drive over the tables) and acceleration (as motorists speed up between tables). Nearby residents may perceive these changes as increased noise.

A Danish study developed a regression model to calculate expected speed changes associated with speed humps, lateral dislocations, and street narrowing (Engel and Thomsen, 1992). According to their model, every centimeter in height is expected to reduce speed by 1.0 km/h (0.6 mi/h). (Street narrowing is predicted to produce a 4.7-km/h (2.9-mi/h) speed reduction. A single lateral dislocation is predicted to reduce speed by 2.0 km/h (1.2 mi/h), while a double lateral dislocation by 4.7 km/h (2.9 mi/h).)

Zaidel et al. in 1992 surveyed individuals and organizations about speed-reduction devices. Based on 23 responses from 13 countries, they concluded that "many communities in several countries experienced neither vehicle damage nor driver loss of control when passing over humps. Also, no real operational or comfort problems with bus, truck, or emergency vehicles were reported."

9. Guidelines for Speed Hump Use

Drawing upon experiences with speed humps, the ITE proposed the following guidelines:

- A traffic engineering study, including consideration of alternative traffic control measures, should precede any installation.

- Speed humps should only be installed on local two-lane residential streets with less than 3,000 vehicles per day, with a posted speed or prima facie speed of 48 km/h (30 mi/h) or less.

- Hump locations should be coordinated with street geometry and grades.

- Speed humps should not be installed on streets with significant numbers of emergency vehicles, transit, or long wheelbase vehicles.

- Support from a documented majority of affected residents should be obtained before any installation (ITE Technical Council, 1993).

In the United Kingdom, road hump regulations were first issued in 1983, with more flexible regulations in 1986 and 1990 (Road Safety Division, 1993). Among other changes, the 1990 regulations allowed tapered-edge and flat-top humps in addition to the conventional round-top, curb-to-curb hump. The new regulations allow humps at pelican[1] crossings and do not limit the number of humps in a series. When a hump coincides with a crossing, only flat-top humps should be used. Humps may not be placed closer than 30 m (98 ft) from a pelican or zebra crossing. Pavement markings delineating a crossing should be placed along the flat top of the hump, not on the ramps leading to and from the hump. A tactile surface may be necessary to indicate the sidewalk/street edge for pedestrians with vision impairments. At junctions, humps across side streets can be set back 5-8 m (16-26 ft) from the main road to discourage pedestrians from crossing the side street to near the main road and thereby reduce conflicts between pedestrians and turning traffic (Speed Control Humps, 1990).

Although speed humps reduce vehicular speeds and volumes to the benefit of pedestrians, they have their disadvantages. Adjacent residential streets and arterials are likely to experience higher levels of traffic as motorists are diverted from the treated street. The noise caused by vehicle acceleration and “thumping” over humps may disturb residents who live near the humps. Signing and pavement markings can render humps unattractive. Because humps reduce speeds, emergency response time may increase. They can impede maintenance activities such as sweeping and snowplowing and may affect drainage (Clarke and Dornfield, 1994). Speed humps also require extra care when resurfacing of the street is required.

Thus, speed humps are certainly not a cure-all for traffic problems on residential streets. Less restrictive and more passive devices that may address these problems should be considered first. However, where high vehicle speeds create an unsafe environment on local streets, speed humps may be one possible treatment. Care should be taken to inform the residents of the advantages and disadvantages of the humps before they are installed. Residents should provide a show of consensus for the humps, particularly those who will be most directly affected.

10. Bulbouts and Street Narrowing

The purpose of a bulbout, also known as a choker, bulbout, or curb bulb, is to reduce the width of the vehicle travel way at either an intersection or a midblock pedestrian crossing location. It shortens the

[1]As used in England, pelican crossings are midblock crossings controlled by traffic signals and pushbutton pedestrian signals. The pushbutton hardware lights up and conveys specific messages to pedestrians during each interval (walk phase, clearance phase, and don’t walk phase), with dashed (not solid) parallel lines to mark the crosswalk (Zegeer, et al., 1994).

street crossing distance for pedestrians, may slow vehicle speeds, and provides pedestrians and motorists with an improved view of one another, thereby reducing the risk of a motor vehicle-pedestrian collision.

Figure 45. Street narrowing can reduce vehicle speeds and provide pedestrians with a narrower street to cross.

In two Australian cities, Keilor (Queensland) and Eltham (Victoria), "curb blisters" (i.e., bulbouts) had little effect on reducing vehicle speeds (Hawley et al., 1992). However, in Concord, New South Wales, a comparison of a subarterial street with both curb blisters and marked parking lanes versus an untreated street showed that the crash rate on the treated street was only one-third that of the untreated street (Hawley et al., 1992). The number of these crashes involving pedestrians was not stated, nor is it known how the streets compared before treatment.

Australia's "wombat" crossings usually consist of a raised platform with a marked crosswalk on top, and a refuge and curb blisters where space permits. Thus, they combine features of speed tables and bulbouts. They are designed to slow motorists, shorten pedestrian exposure to motor vehicles, and increase pedestrian visibility to motorists. Wombat crossings have generally reduced 85th percentile vehicle speeds by 40 percent (Hawley et al., 1992).

Anne Arundel County, MD, has been using a combination of medians and bulbouts near intersections. The medians narrow the traveled way, while the bulbouts force drivers to make a lateral deflection as they enter the narrowed area. Medians with lateral deflection have reduced the 85th percentile speeds by 3-8 km/h (2-5 mi/h) (Walter, 1995).

The Dutch towns of Oosterhout and De Meern have installed street-narrowing variations. The Oosterhout project consisted of installing two bulbouts so as to require motorists to deviate from a straight path. Both the 85th percentile vehicle speed and the degree of pedestrian-motor vehicle conflict fell after the deviation was installed. De Meern's deviation was created by placing two bulbouts opposite one another to narrow the width of the traveled way. A significant reduction in the 85th percentile vehicle speed was observed at the deviation. Opinions of the deviation in De Meern were mixed. There was not a strong sense of neighborhood improvement among residents. Swerving cars were thought to endanger bicyclists. School teachers thought that children would be confused by the deviation. Retailers were concerned about accessibility and parking. There was little concern about emergency vehicle access (Replogle, 1992).

Macbeth in 1995 reported favorable speed changes seen on five raised and narrowed intersections and seven midblock bulbouts (two raised). The speed limit was also lowered to 30 km/h (19 mi/h). The results of speed changes are given below.

	Percent Exceeding		
	30km/h	40km/h	50km/h
Before	86	54	13
After	20	3	2

11. Roundabouts

In a Toronto traffic engineering workshop, Frederick (1995) reported modest reductions in 85th percentile speed after traffic circles were installed. It was reported that local citizens asked for traffic-calming measures (Herget, 1995). Before the installation, the 85th percentile speed was 43-50 km/h (27-31 mi/h) and 81 percent of traffic was non-local. Two roundabouts were installed and 81 percent of citizens in the area approved. Herget said there was no measurable effect of the application.

More recently, the Insurance Institute for Highway Safety found in 2000 that roundabouts reduce crashes when compared to intersections with signals or stop signs, especially when injuries are considered. Researchers at the University of Maine, Ryerson Polytechnic University, and the Institute studied crashes and injuries at 24 intersections before and after the construction of roundabouts. Though the study found that fewer pedestrian crashes occurred when roundabouts were installed, the numbers were too small to be statistically significant. Accordingly, the topic of roundabouts and pedestrian safety remain controversial, especially for people with disabilities. For motorists, however, the study found a 39-percent overall decrease in crashes, a 76-percent decrease in injury-producing crashes, and a 90-percent decrease in crashes involving fatal or incapacitating injuries.

12. Cul de sacs

In the 1970's, Australia implemented street closures "on the grounds that the problem was caused by excessive connectivity in the network" (Brindle, 1997, page 26), but now latter-day planners want to return to connective local street networks as part of a neotraditional neighborhood design. A disadvantage to cul de sacs is that extra right-of-way is needed to build the turnarounds. If complete closures are built, blocking pedestrian and bicycle access, it may make travel by automobile *more* attractive.

The authors cite the "benefits" of the neotraditional designs as coming from "increased density, a mix of land uses, and a grid transportation system" (Szplett and Sale, 1997, page 42), but they acknowledge the opposing view, saying "The volume of traffic is often a rallying point for the neighbors in an adjoining residential area who are opposed to the project. The authors' experience is that the higher density is another element of citizen complaints" (p. 43).

13. Emergency Vehicles

Some apprehensions about certain traffic-calming measures relate to fears that emergency vehicles will be delayed in responding, and the traffic-calming facilities will make vehicle access more difficult. Atkins and Coleman (1997) report the results of their study of several types of emergency vehicles, with several drivers, in negotiating several types of traffic-calming devices including humps and roundabouts. This was carried out as an experiment in non-emergency situations. They report that the delay was 0 or 1 second in some cases, ranging up to 10 seconds, maximum, in others. They did not report the duration of the typical emergency run, but an additional 10 seconds is within the variation imposed by random factors encountered on such runs. Despite this, many emergency service providers may be opposed to certain traffic-calming projects; some that involve street closures, medians, chokers or other street-narrowing projects may make it more difficult for large fire trucks to negotiate the streets. It is always a good practice to have the local fire officials review the project to make sure that essential emergency services will not be unnecessarily disrupted. Implementing traffic-calming projects on streets that provide primary access to fire stations, hospitals, and other emergency services should be carefully evaluated.

14. Traffic Diversion

Traffic diversion can be accomplished by street closures, diverters, and signs restricting access, either during the peak travel hours or on a 24-hour basis. Traffic diversion projects are designed to shift

Figure 46. Traffic diversion projects are designed to shift traffic off neighborhood streets.

traffic off of a neighborhood street that is suffering from cut-through traffic onto other streets. If these "other streets" are major streets or arterial roads, the project generally can be considered successful. If the traffic is shifted onto adjacent neighborhood streets, the problem is merely transplanted, not solved.

Parent in 1995 reported that certain roads were closed for a year. When reopened, various traffic-calming measures had been installed such as chicanes and narrowing. He reports that ADT was diminished from 3,865 to 1,850. Speed was reduced by 14 percent. Local citizens in the neighborhood rated the changes as good. He did not discuss what happened to the 2,000 vehicles per day that “disappeared.” Where did they go? Were they safely diverted? Was the total system better?

When considering traffic diversion projects, the entire neighborhood area must be included in the decisionmaking process. This will allow input from the entire affected area and will prevent one part of the neighborhood’s being sacrificed to benefit another part. The boundaries of the affected neighborhood should be broadened to include more than one or two streets that may be currently suffering from cut-through traffic.

Traffic diversion projects often limit resident access, as well as access for their guests and service vehicles. The affected residents should provide input into the change or loss of access to ensure that the tradeoffs will be acceptable. Often, the traffic restrictions can be tested and evaluated before they are made permanent. A test period can be used to identify potential problems to residents and emergency and school access, and to allow for adjustments to accommodate those problems that were not readily apparent at the outset of the project.

Traffic Calming in Original Construction

Many residential streets have been designed to provide the most convenient automobile access, with little thought of the high traffic levels and speeds that may result. In some cases, the curb returns and street widths are designed to allow easy access to the largest moving van that may serve an area. While it is important to provide access to fire trucks and school buses, some communities may be able to make significant changes to the layout and design of their neighborhood streets as a part of the design and review process to eliminate the potential for cut-through traffic or speeding before the neighborhood streets are built.

This can include narrowing streets, providing smaller turn radii at corners, and preventing long straight streets that are unobstructed. Roundabouts and discontinuous street paths can be supplemented with connective bike and pedestrian paths to provide ideal access to transit, schools, and adjacent shopping areas. Access to a large neighborhood should not be limited to one or two entry points, and an adequate system of arterial and collector streets should be provided to diminish the attractiveness of using local streets.

West and Lowe make the point that traffic-calming measures are often thought of as modifications to an existing facility, but they urge consideration for traffic-calming designs in original construction (1997).

Effectiveness Evaluation

Some documents on traffic calming report numerical changes in before-versus-after analyses. In many cases, it appears that the traffic calming measures had the desired effect of slowing or diverting traffic. Likewise, fewer “after” crashes are reported in many cases. In some instances, little or no change is noted. In many of these reports, it is not clear just how the evaluation was conducted.

Leonard and Davis (1997) cite a lack of evaluation of traffic calming installations (page 36) and list some indicators they say should be used in evaluation:

- Annual use of all urban modes
- Spot monitoring of vehicle emissions and noise
- Network-based highway capacity
- Route choice and travel time
- Crash rates involving pedestrians, bikers, and motor vehicles
- Speed attainment by functional classification

Spielberg (1994) spells out research needs:

- What are the true safety issues?
- Does neotraditional neighborhood design result in slower operating speeds?
- Are dart-out crash rates and severity from on-street parking a real problem?
- Are there compensating benefits from slower speeds and fewer driveways?
- How are travel patterns influenced?
- Does the mixed-use design result in lower trip-generation rates?
- Are destinations changed, resulting in shorter trips and lower vehicle miles traveled?

The report also provides a good list of references.

Skene et al. (1997) comment that much is done in the name of traffic calming, but they say effectiveness is largely unknown. On page 34 they state “there is little information available regarding the applicability, effectiveness, and geometric characteristics of various traffic-calming devices." They also say there is little information on the adverse effects of traffic-calming initiatives.

Nevertheless, before-and-after data are reported for many projects. In "Traffic Calming in Practice" prepared by the County Surveyors Society in England and published by Landor Publishing Limited in November, 1994, a total of 85 case studies is reported; in 74 cases, before-and-after-crash data are cited. In 69 of those cases, the crashes after were fewer than before; in three cases, crashes were more numerous, and in two cases there was no change. The sheer number of projects that experienced safety benefits is persuasive to a degree, especially when the very nature of the traffic-calming measures was intended to reduce speeds and in some cases to induce traffic to go elsewhere. However, one cannot know the study designs used, most notably what factors dictated the particular intervention at the particular site, and therefore the possible role of regression to the mean.

Sidewalks and Pedestrian Paths

The 1992 Uniform Vehicle Code defines a sidewalk as "that portion of a street between the curblines, or the lateral lines of a roadway, and the adjacent property lines, intended for use by pedestrians."

Figure 47. Pedestrians are safer in areas with sidewalks than in areas without them.

Several types of pedestrian walkways have been defined (*Work Zone Traffic Management*, 1989; Zegeer and Zegeer, 1988):

- Sidewalks: Walkways that are paved (usually concrete) and separated from the street, generally by a curb and gutter. Sidewalk widening may be used to facilitate pedestrian travel.

- Pathway: Temporary or permanent walkways that may or may not be placed near a roadway and are usually made of asphalt or gravel.

- Roadway shoulder: In rural or suburban areas where sidewalks and pathways are not feasible, gravel or paved highway shoulders provide an area for pedestrians to walk next to the roadway.

A study by Tobey et. al. (1983) investigated the safety effects of sidewalks. Sites with no sidewalks or pathways were the most hazardous for pedestrians, with pedestrian hazard scores of +2.6 and a PxV exposure score (i.e., exposure measure equals pedestrian volumes [P] times traffic volume [V]) of +2.2. This indicates that crashes at sites without sidewalks are more than twice as likely to occur than expected. Sites with sidewalks on one side of the road had pedestrian volume and PxV hazard scores of +1.2 and +1.1, compared with scores of -1.2 and -1.2 for sites with sidewalks on both sides of the road. Thus, sites with no sidewalks were the most hazardous to pedestrians, and sites where sidewalks were present on both sides of the road were least hazardous. A later study by Knoblauch et al. (1987) developed guidelines for sidewalk installation separately for new and existing streets.

A variety of factors are widely acknowledged to have an impact on the risk of pedestrian motor vehicle injuries. Those most extensively researched are geometric characteristics of the road, including the presence of sidewalks. However, until recently, factors relating to demographics and neighborhood characteristics have been mentioned but not sufficiently researched. To address that problem, McMahon, et al. (2000) used a case-control methodology and applied conditional and binary logistic models to determine the effects of cross-sectional roadway design attributes and socioeconomic and other census block group data on the likelihood that a site is a crash site. A total of 47 crash sites and 94 comparison sites were analyzed. Physical design factors found to be associated with significantly higher likelihood of being a crash site are higher speed limit, the lack of wide grassy walkable areas, and the absence of sidewalks. When these roadway factors are controlled for, non-geometric factors associated with significantly higher likelihood of being a crash site are high levels of unemployment, older housing stock, and more single parents. This information suggest that some neighborhoods may, due to increased exposure or specific types of exposure, be especially appropriate sites for pedestrian safety measures such as sidewalks, lower speed roadway designs, and the addition of wide grassy shoulders. That FHWA study also developed guidelines and priorities for installing sidewalks and walkways, as shown in table 31.

Table 31. Recommended guidelines for new sidewalk/walkway installation.

Roadway Classification/Land Use	Sidewalk/Walkway Requirements	Future Phasing
Rural highways (<400 average daily traffic [ADT])	Shoulders preferred, with a minimum width of 0.9 m (3 ft)	Secure/preserve right-of-way (ROW) for future sidewalks.
Rural highways (400 to 2000 ADT)	1.5-m (5-ft) shoulders preferred, and minimum of 1.2-m (4-ft) shoulders required.	Secure/preserve ROW for future sidewalks.
Rural/suburban highway (ADT >2,000 and less than 1 dwelling unit (d.u.)/.4 hectares (ha)	Sidewalks or side paths preferred; minimum of 1.8-m (6-ft) shoulders required.	Secure/preserve ROW for future sidewalks.
Suburban highway (1 to 4 d.u/.4 ha)	Sidewalks on both sides required.	
Major arterial (residential)	Sidewalks on both sides required.	
Urban collector and minor arterial (residential)	Sidewalks on both sides required.	
Urban local street (residential—less than 1 d.u /.4 ha)	Sidewalks on both sides preferred; minimum of 1.5-m (5-ft) shoulders required.	Secure/preserve (ROW) for future sidewalks.
Urban local street (residential—1 to 4 d.u./.4 ha)	Sidewalks on both sides preferred.	Both sides required if density becomes greater than 4 d.u./ .4 ha (4 d.u./acre) or if schools, bus stops, etc. are nearby.
Local street (residential—more than 4 d.u./.4 ha)	Sidewalks on both sides required.	
All commercial urban streets (commercial areas)	Sidewalks on both sides required.	
All streets in industrial areas	Sidewalks on both sides preferred; minimum of 1.5-m (5-ft) shoulders required.	

Education Countermeasures

Numerous studies have evaluated efforts of educational programs on pedestrian behavior. For example, the NHTSA film on "Willie Whistle" is aimed at grades kindergarten through 3, and teaches children the safe way to cross streets (Blomberg et al., 1983). It is 7 minutes long and contains live action plus animation. It is directed at reducing midblock dart-out or dash crashes by teaching children always to stop at the curb and look left-right-left before entering the street. After extensive testing in Los Angeles, Columbus, and Milwaukee, the film was reported to reduce dart and dash crashes by more than 30 percent among 4- to 6-year old children, as illustrated in figure 49.

Non-midblock pedestrian crashes were used as a control group, since they were not considered to be affected by the "Willie Whistle" program. Crashes in this group remained relatively unchanged, suggesting that the drop in midblock pedestrian crashes was the result of the educational messages and not a general decline in pedestrian crashes.

A 15-minute follow-up educational film called "And Keep On Looking" (Preusser and Lund, 1988) was later developed by NHTSA to convey street-crossing advice to older children (grades 4-7), such as crossing busy streets, safety in parking lots, and crossing at signalized locations. The effectiveness of this film was examined through testing in Connecticut, Seattle, and Milwaukee. In a 2-year test in Milwaukee of the film's effects, the number of 9- to 12-year olds involved in pedestrian crashes decreased by more than 20 percent. Positive results were also found in Seattle in terms of children's observed behavior and in Connecticut through retained information after viewing the film.

Other less formal evaluations of pedestrian educational programs have been conducted in the past 20 years, including:

- Pittsburgh, PA. A short film was shown and discussed with grade school students; it improved "looking behavior" but no significant improvement in slowing or stopping before crossing (Blomberg and Preusser, 1975).

Figure 48. "Looking behavior" is encouraged in pedestrian education programs.

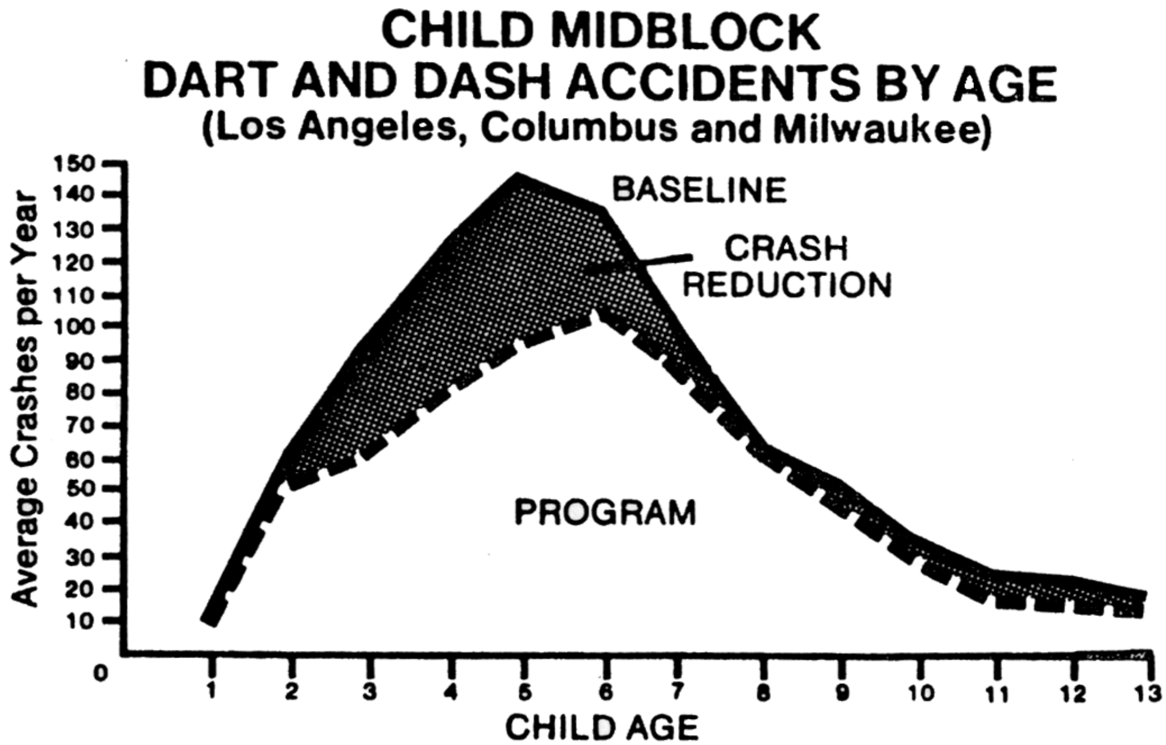

Figure 49. Effects of "Willie Whistle" educational campaign on pedestrian crashes. Source: Blomberg et al, 1983.

- Stamford, CT. When informed through a question-and-answer pamphlet of correct crossing behavior, adults showed a small improvement in stopping and searching behavior at crossings. They stopped more often at intersections than at midblock, but looked less often at the intersections (Blomberg and Preusser, 1975).

- New York City. A recorded message in buses advised passengers not to cross in front of the bus when leaving. The message had little effect. Passengers based crossing behavior on the observed degree of hazard without regard to the message (Blomberg and Preusser, 1975).

- Salt Lake City, UT. Public awareness was developed through radio, television, and print information (newspapers). A pedestrian safety contest was begun. Following classroom instruction, students in a primary school who were observed crossing safely were rewarded with praise and a good pedestrian certificate. Correct crossings increased from 20 percent before to 80 percent after instruction (Reading, 1973).

- England. The Tufty Club, organized by the Royal Society for the Prevention of Crashes in England, initiated in 1961, included 2 million children as members by 1971. The Tufty educational program taught crossing safety through graphic aids and stories featuring Tufty, a safety-minded squirrel who does the right thing in dangerous situations. Improved crossing instructions, called the Green Cross-Code, were introduced in 1974. Over a 3-month period, the pedestrian crash rate declined 11 percent. The greatest reduction in crashes was observed between the ages of 5 and 9, the target audience (Firth, 1975; Sargent and Sheppard, 1974).

- Sweden. On the basis of an elaborate program of developmental and educational research in safety-relevant behavior, the researcher found that children of pre- and primary-school age do not have the perceptual, motivational, and judgmental maturity to learn and meet the demands of modern traffic (Sandels, 1975).

In recent years, a number of other pedestrian educational programs have been developed in the U.S. and abroad, although no formal evaluations are available for many of these. Most were directed at helping various pedestrian age groups, but a few were intended for either the parents or teachers of young children. As discussed in the *WALK ALERT Program Guide*, some of these pedestrian educational materials include the following (National Safety Council, 1988):

Figure 50. Preschool and elementary school children are the target of many pedestrian education programs.

- For preschool children, various programs are directed at children, their parents, and/or teachers regarding the need to recognize and avoid streets and traffic hazards. The programs include:

    - Walking in Traffic Safely (WITS)
    - Watchful Willie
    - "Children in Traffic—Why Are They Different?" (a West German film)
    - Child and Traffic
    - Parents, Children and Traffic

- Elementary children (grades kindergarten to 3) represent the age group most at risk, and more than half of all pedestrian deaths and injuries to children ages 5 to 9 involve crossing or entering residential streets. These educational programs emphasize safe street crossing behavior and include:

    - Willie Whistle Safe Street Crossing Program (discussed earlier)
    - I'm No Fool As a Pedestrian
    - Walk Safely
    - AAA Poster Contest

- Elementary children (grades 4-6) need more complex safety messages, such as crossing at signalized intersections, multiple threat situations, right turn on red, walking in parking lots, and others. Examples of educational programs include:

    - And Keep on Looking (discussed earlier)
    - Walk Safely
    - Safety on Streets and Sidewalks
    - The National Student Traffic Safety Test
    - Guidelines for a K-12 Traffic Safety Educational Curriculum

- Junior high and high school students should also be taught about more complex street situations, but also about being seen at night, dangers of alcohol use and walking, recreational walking, commercial bus stops, and others. Examples of programs include:

    - Guidelines for a K-12 Traffic Safety Educational Curriculum
    - *WALK ALERT—A Pedestrian Safety Booklet for Junior High Students*
    - Driver Education
    - Substance Abuse Programs
    - Teaching About the Child

- Adult (including older adults) educational programs are more commonly in the form of:

    - Walking tours led by traffic safety officers or civic leaders
    - Public service announcements
    - Print media
    - Work place programs
    - Hospitals and health-related print material

Since driver education is also an important component of pedestrian safety, numerous programs directed at drivers are also available, including:

- AAA's School's Open Drive Carefully

- Parents Can Be Serious Traffic Hazards
- About Children and Traffic
- Give Older Pedestrians a Break at Crossings

Education is certainly an essential ingredient of pedestrian safety programs along with engineering and enforcement. Cities that historically have had a low incidence of pedestrian crashes have typically had active pedestrian-education programs. More information on various educational programs for pedestrian safety and specific messages is available (National Safety Council, 1988; Preusser, 1988).

Media campaigns are one form of education, and they are sometimes accompanied by the promise of intensified law enforcement. Two studies carried out in Canada are illustrative. In one, a multimedia campaign targeted left turns, aimed at increasing the proportion of drivers who yield to pedestrians (Koenig and Wu, 1994). No enforcement emphasis was mentioned. Failure to yield was 25 percent before and 17 percent after. No change was seen in right-turn behavior, which was not targeted.

Another study, in Seattle, reported little success (Britt et al., 1995). These authors evaluated a 4-year study in Seattle. Driver behavior at crosswalks was observed; compliance with the yield law was not great (15 to 20 percent). A media campaign accompanied the enforcement effort, but it is not clear whether the intensity of either was maintained during the full 4-year period. Enforcement seemed to produce a slight improvement in compliance, but the authors said they were " . . . unable to demonstrate that law enforcement efforts directed at motorists' violations of crosswalk laws significantly or consistently increase drivers' willingness to stop for pedestrians." (p. 166)

It seems reasonable to believe that many pedestrian collisions are the result of poor behavior on the part of pedestrians and drivers. This would indicate that educational countermeasures could improve pedestrian safety. Many public information and education campaigns have been conducted to improve pedestrian and driver behavior. However, there is a clear need for further development and widespread use of effective pedestrian-safety programs that are targeted at children of various ages, parents, and drivers.

Enforcement and Regulations

In addition to engineering and education, enforcement of traffic laws and regulations is another important element in safe pedestrian activity. This means curtailing dangerous motorist actions that relate to pedestrians. Motorists who exceed the speed limit, fail to yield the right of way to pedestrians when turning, run a red light or stop sign, and/or drink and drive can place pedestrians in jeopardy. Strong police enforcement programs are needed to help reduce these violations (National Safety Council, 1988). Giving citations to pedestrians (for jaywalking, etc.) has not been shown to be effective in improving behavior, and can create a public-relations problem for local police departments.

Unfortunately, no quantitative studies could be found that determined the specific effects of various types of police enforcement on pedestrian crashes and injuries. However, many U.S. cities with exemplary pedestrian safety achievements (such as Milwaukee, Seattle, and San Diego) have maintained active enforcement programs along with other pedestrian safety measures (National Safety Council, 1988). The effect of enforcement alone is difficult to quantify because so many factors affect pedestrian crash experience over a given time period.

Several model pedestrian ordinances have been developed by NHTSA that have the potential to reduce certain types of pedestrian crashes. These include the following (National Safety Council, 1988;

Development of Model Regulations, 1974; *Model Ice Cream Truck Ordinance*, 1979, Enforcement-Policing Pedestrian Protection, 1988):

- Model ice cream truck ordinance: This type of regulation is needed in many areas to deal with the problem of children who walk or run into the street to or from ice cream or other vending trucks. This ordinance has several components, including: (1) requiring drivers to stop before overtaking a vending truck, (2) requiring "stop then go if safe" swing arms and alternately flashing lights on vendor trucks, and (3) restricting the locations where vending trucks are allowed. According to a 1979 NHTSA study, such an ordinance went into effect in Detroit in June, 1976. During the first partial vending season, related crashes dropped 54 percent. In the first full vending season, related child crashes declined 77 percent (from a 3-year average of 48.7 crashes per year to 11 in 1977) (*Model Ice Cream Truck Ordinance,* 1979).

- Model bus stop ordinance: This measure requires that bus stops be relocated from the near side to the far side of an intersection. It also prohibits pedestrians from crossing in front of a stopped bus unless allowed to do so by a traffic control device or police officer. This ordinance can increase the visibility between an approaching motorist and crossing pedestrians and thus decrease bus-related pedestrian crashes.

- Multiple vehicle-overtaking ordinance: One of the common types of pedestrian crashes on multi-lane roadways is termed a "multiple-threat" crash, which involves pedestrians who step into a traffic lane, often in a crosswalk, in front of a stopped vehicle and then into the adjacent lane without looking and are struck by an oncoming vehicle. This ordinance would require drivers to yield to pedestrians in a crosswalk and to stop before passing a vehicle stopped at a crosswalk.

- Disabled vehicle ordinance: To reduce pedestrian crashes on freeways, this ordinance requires that motorists move their vehicle as far as possible off the road and place a warning device behind it. Reflective materials must also be carried in the vehicle for occupants to wear when walking along access-controlled roads at night. It also prohibits standing in roadways during vehicle repairs.

- Parking near intersections or crosswalks ordinance: This ordinance provides that vehicles should not park within 15 m (50 ft) of a marked crosswalk or within 18 m (60 ft) of an intersection without a marked crosswalk on that approach. Access ramps and other provisions for people with disabilities are included. This ordinance should help drivers approaching an intersection to see pedestrians more easily and will give pedestrians a better view of approaching motorists.

The above ordinances can help reduce pedestrian crashes when implemented and followed by local jurisdictions. Effective police enforcement may be needed to help ensure reasonably high compliance with these and other ordinances. Enforcement efforts have been most effective when they are long term and consistent, have strong support from top management, and are upheld by the local judicial system (National Safety Council, 1988).

PART 4. SUMMARY AND DISCUSSION

This synthesis report reviewed existing pedestrian research, particularly as it relates to pedestrian crash characteristics and the effects of various engineering and roadway safety treatments (much less attention was given to educational and enforcement measures related to pedestrians). Emphasis was placed on pedestrian research conducted in the past 10 years.

In addition to reviewing research published in U.S. literature, this report features a limited number of research studies from other countries, and authors in five other countries were hired to conduct similar summaries of pedestrian research in the United Kingdom, Canada, the Netherlands, Australia, and Sweden. This process resulted in the consideration of non-English articles and reports from those countries, with key results given in the research summary. These summaries are provided as separate attachments to this report and are found at the following Web site: http://www.walkinginfo.org/rd/international.htm

Introduction

Part 1 of this report provides an introduction to the pedestrian safety problem. Guides and model pedestrian programs developed in the U.S. in recent years are also discussed, along with illustrations of some of the major pedestrian crash types and countermeasures.

It is clear that pedestrian safety has emerged in recent years as a topic of growing interest and concern. As far back as the 1920s, pedestrian collisions resulted in about 40 percent of all traffic fatalities, annually reaching more than 15,000 pedestrian deaths in the 1930s.

As motorization advanced, that proportion fell, and pedestrian deaths now annually number approximately 5,000 to 6,000 and represent approximately 12-15 percent of traffic deaths each year. This decline is presumably the product of: increased attention to pedestrian control and safety measures and pedestrian safety education; and a change in exposure factors on trips that formerly would have been made on foot that came to be made in a motor vehicle. Other factors also may play a role. Detailed pedestrian exposure data are not available that illuminate pedestrian trip choices and amount of walking on a nationwide basis.

Pedestrian Crash Experience

Part 2 of this report deals with pedestrian crash characteristics. Research since the 1970s of pedestrian crash databases has given us a better understanding of crash causes and related factors. For example, night conditions greatly increase pedestrian crash risk, and, while pedestrian collisions primarily occur in urban areas, higher speed rural collisions more often result in pedestrian deaths. Fridays and Saturdays are the most common days for pedestrian collisions, perhaps because of increased drinking by pedestrians and motorists and more walking exposure on these days.

We know that children are over-involved in pedestrian collisions per population. This is particularly true for males age 5-9. Older pedestrians (particularly above age 65) are much more likely to be killed as pedestrians, possibly because of their increased frailty. Alcohol consumption by the pedestrian is a factor in 40 percent or more of pedestrian deaths, and is a particular factor for male pedestrians age 25-44.

The most common pedestrian crash types include dart-outs, intersection dash, and turning-vehicle collisions. Pedestrians are cited as being solely at fault 43.2 percent of the time, compared with

34.8 percent solely motorist fault. Of course, the assignment of fault depends to an extent on the judgment and biases of the reporting police officers.

Overview of Pedestrian Crash Countermeasures and Safety Programs

The U.S. is the most motorized nation on earth (motor vehicles per capita), and priorities have skewed in favor of the motorist and against the pedestrian. In recent years, however, some attempts have been made to give more consideration to pedestrians. Sometimes this is addressed directly in terms of increased safety for pedestrians accomplished through a variety of traffic calming and other measures. Sometimes the effort is framed as creating a more pedestrian-friendly walking environment in the interest of an improved quality of life, but increased safety is clearly a benefit.

Traffic professionals have had to proceed with less comprehensive knowledge than is desirable about the effectiveness of some measures. While many evaluation results are reported in the literature, it is not always possible to know with sufficient confidence what works and what does not, particularly under specific traffic and roadway situations, because of difficulties in conducting crash evaluations of pedestrian treatments. Low crash samples and threats of regression to the mean, among other difficulties, confound firm conclusions. Thus, when reviewing dozens of published articles and papers on pedestrian research for this report, efforts were made to summarize the results of the best available information and studies.

Many studies were excluded from this synthesis because of questionable research methods or insufficient sample sizes, or because they did not specifically address the safety effects of pedestrian treatments. While this does not imply that every study mentioned in this report is of the highest possible quality, there is a considerable amount of valuable information on the effectiveness of roadway and other treatments for pedestrians. In addition to pedestrian crash data, numerous studies use pedestrian and motorist behavior, vehicle speeds, conflicts, and other measures when analyzing the effects of different pedestrian treatments.

Some major findings are:

- There is evidence that substantially improved nighttime lighting can enhance pedestrian safety in certain situations.

- At uncontrolled crosswalks (i.e., no stop sign or traffic signal on the approach roadway) on a two-lane road, the presence of a marked crosswalk is associated with no difference in pedestrian crash rate, compared to an unmarked crosswalk. On multi-lane roads with traffic volumes above 12,000 vehicles per day, having a marked crosswalk alone, without other substantial improvements, is associated with a higher pedestrian crash rate (after controlling for other site factors) compared to an unmarked crosswalk. More substantial improvements are recommended to provide for safer pedestrian crossings at many such pedestrian crossings, such as adding traffic signals with pedestrian signals when warranted, providing raised medians, initiating speed-reducing measures, and/or others.

- Providing raised medians on multi-lane roads can substantially reduce pedestrian crash risk and can help pedestrians cross the street.

- At intersections with traffic signals, adding a WALK/DON'T WALK signal with a standard timing scheme (i.e., motorists move parallel to pedestrians and may turn right or left on a green light across pedestrians' path) has no significant effect on pedestrian crashes. Providing an exclusive pedestrian interval (i.e., motorists are stopped in all directions during the same interval each cycle while pedestrians cross in any direction) reduces pedestrian collisions by half. However, exclusive timing schemes can increase pedestrian and motorist delay and are most appropriate at downtown intersections with a combination of heavy pedestrian volumes, good pedestrian compliance, and low vehicle volumes.

- Allowing vehicles to make a RTOR maneuver appears to result in a small but clear safety problem for pedestrians. In fact, 21 percent of motorists violate NTOR signs if given the opportunity, and 23 percent of RTOR violations result in a conflict with a pedestrian. Countermeasures that have been effective in reducing pedestrian risks related to RTOR include illuminated NTOR signs, offset stop bars at intersections where RTOR is allowed (i.e., motorists are more likely to make a full stop often), variations in NTOR signs, and others.

- Various innovative pedestrian and motorist warning signs have been found to reduce vehicle speeds or conflicts between pedestrians and motorists. These devices include the "strong yellow green" pedestrian warning sign, YIELD TO PEDESTRIANS WHEN TURNING sign, PEDESTRIANS WATCH FOR TURNING VEHICLES sign, three-section WALK WITH CARE signal head, a DON'T START display to replace the flashing DON'T WALK display, and others.

Figure 51. Undivided highways had the highest crash risk for pedestrians.

- Curb medians provide a safer environment for pedestrians compared with two-way left-turn lanes (TWLTLs). Undivided highways present the highest crash risk for pedestrians.

- Numerous treatments can address the needs of pedestrians with disabilities: textured pavements, audible and vibrating pedestrian signals, larger signs and pedestrian signals, wheelchair ramps, and others. While formal safety studies are very difficult to conduct on such treatments, certain benefits may result from such devices, depending on site conditions and pedestrian needs.

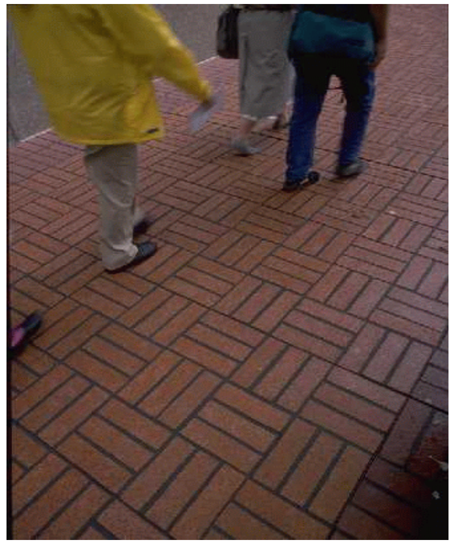

Figure 52. Textured pavements at crosswalks may help vision-impaired pedestrians to cross streets.

- Careful placement of bus stops can affect pedestrian safety. It is clearly beneficial to put bus stops on the far side of an intersection and at locations with good sight distance and alignment (e.g., not on steep grades or on horizontal curves).

- School trip safety can be enhanced by sidewalks and proper signalization, but also by well-trained adult crossing guards and selective police enforcement. Certain warning signs (e.g., flashing school speed limit signs) and markings (e.g., school crosswalks) are also appropriate and beneficial to pedestrians in many school zones.

- Pedestrian safety and mobility are enhanced by sidewalks and walkways. This is a critical component of a pedestrian transportation network in urban and suburban areas. Rural roads should have shoulders for pedestrian travel.

- Overpasses and underpasses can substantially improve safety for pedestrians needing to cross freeways or busy arterial streets at certain locations. However, such facilities must be carefully planned and designed to encourage pedestrians to use the facilities and not continue to cross at street level.

- Pedestrians can make themselves more visible by using a flashlight, jogger's vest, dangle tags, and rings (retroreflective material on the head band, wrist bands, belt, and ankle band). Such measures can increase a pedestrian's visibility distance up to 397 m (1300 ft), compared with about 61 m (200 ft) for a "base pedestrian" wearing blue jeans and a white t-shirt.

- Several studies have shown that converting from two-way to one-way streets can substantially reduce pedestrian collisions. However, converting from two-way to one-way streets may not be solely justified by pedestrian safety considerations. More often, several concerns such as capacity, traffic circulation, and overall traffic safety are major considerations. One-way streets can greatly simplify the task of crossing a street, particularly if the one-way street conversion does not result in increased vehicle speeds.

- While traffic-calming measures are primarily intended for neighborhood streets to reduce vehicle speeds and/or reduce cut-through vehicle traffic, such measures as street closures, speed humps, chicanes, traffic curbs, diverters, and others are in use in various U.S. cities. While controversial, many of these measures have been found to be effective in improving safety for pedestrians and/or traffic as a whole based on reductions in crashes, vehicle speeds, and/or reductions in cut-through traffic on neighborhood streets.

- Education for pedestrians has been found in a few studies to reduce crashes involving child pedestrians. However, most U.S. educational programs were found to have received little if any formal evaluations or to have had only limited measurable effects.

- Enforcement of traffic laws and regulations represents another important element in safe pedestrian activity in a roadway environment. This includes not only enforcing pedestrian regulations (e.g., jaywalking, crossing against the signal) but also motorist actions related to pedestrians (e.g., speeding, yielding to pedestrians when turning, drunk driving). While a number of U.S. cities (e.g., Seattle, Milwaukee, San Diego) have had active police enforcement programs in recent years, no quantitative studies are known that have determined the specific effects of police enforcement on pedestrian crashes and injuries. Further, such a study would be very difficult to conduct because of the many other contributing crash factors in a city.

Summary reports of pedestrian research are provided at http://www.walkinginfo.org/rd/international.htm for the United Kingdom, Canada, the Netherlands, Scandinavia, and Australia. While much has been learned from pedestrian research over the past two or three decades, there is still much to discover about measures that might affect safety and mobility for those who choose to walk.

Annotated Bibliography on Traffic Calming Measures

Several sources exist with extensive text, illustrations, etc. Some are listed here:

- *Traffic Calming: State of the Practice,* FHWA, Report RD-99-135, August, 1999, Ewing, R.H.

This report looks at the design, impact, and other considerations surrounding traffic-calming measures in the U.S. and Canada. It covers information on traffic-calming in different contexts from urban residential areas to areas where high-speed rural highways transition into rural communities. The report is based on detailed information collected on traffic-calming programs in 20 featured communities, another 30 communities surveyed less extensively, and a parallel Canadian effort by the Canadian ITE (CITE) and the Transportation Association of Canada (TAC).

- *Traffic Calming in Practice*, County Surveyors Society, Landor Publishing Limited, Quadrant House, London, SE11 5RD, November, 1994.

With a considerable list of references and lavishly illustrated, this report claims to be "an authoritative source book with 85 case studies." Among the 85 case studies are 18 different types of interventions. Each case study is laid out in a two-page spread with photos, schematics, speed and crash data, etc. In 72 of the 85 cases, before- and after-crash data are presented, and in 69 of the 72, crashes are lower in the after period than they were before. However, this is not a research document; what might be the nature or strength of the study designs cannot readily be ascertained from the discussions.

- *Towards Traffic Calming: A Practitioner's Manual*, Hawkey, L., Henson C., Hulse, A., and Brindle, R., Federal Office of Road Safety, Canberra, Australia, August, 1992.

This manual shows numerous methods of slowing down vehicular traffic, the presumed beneficiaries being pedestrians and bicyclists, and cites the need for evaluation of effectiveness and lack thereof. It contains good visuals and descriptions: humps, narrowing, mini-roundabouts. There is a section on international references.

- *National Bicycle and Walking Study: Case Study 19: Traffic Calming*, FHWA, Report PD-93-028, January, 1994, Clarke, A. And Dornfield, M.

This report contains a discussion of pros and cons of the "Woonerven" (the Netherlands). Several efforts produced good results: less speed, fewer crashes, lower volume (though of course less speed and volume are good for some and bad for others). This report also addresses U.S. traffic-calming initiatives: speed humps, mini-roundabouts, chicanes, bike boulevards, channelization changes, slow streets, traffic diverters, and corner treatments.

- *FHWA Study Tour for Pedestrian and Bicyclist Safety in England, Germany, and the Netherlands*, October 1994, FHWA, DOT, Zegeer, C., Cynecki, M., Fegan, J., Gilleran, B., Lagerway, P., Tan, C, and Works, B.

Countermeasures discussed include:

England: chicanes, narrowing, humps, roundabouts (humps are sometimes designed to allow wide trucks, buses, or emergency vehicles to pass unimpeded. City dwellers like the restrictions, and country people want to retain the diminished access.

Netherlands: low speed limits, diverters, narrowing, block through-access

Germany: self-enforcing speed control, road narrowing

- "*Traffic Calming, 1995*," Traffic Engineering Committee Workshop, Proceedings from 21 papers, Ontario Traffic Conference, 20 Carlton Street, Toronto, M5B 2H5, November, 1995.

This compilation of papers describes a number of traffic-calming initiatives installed in various cities and towns in Canada. The nature of the interventions is described and, in a number of instances, before-and after-data are presented. Drawings and photographs illustrate the installations.

- *Slow Down You're Going Too Fast: The Community Guide to Traffic Calming,* Public Technology, Inc., 1301 Pennsylvania Avenue, Washington, DC, 1998.

This guide contains 25 case studies designed to meet local government and community demands for information on traffic calming to provide a better quality of life for residents.

- *"Traditional Neighborhood Development Street Design Guidelines,"* Prepared by ITE Transportation Planning Council Committee 5P-8, A Proposed Recommended Practice of the ITE, 525 School St. NW, Suite 140, Washington, DC, June 1997.

This document presents a discussion of the concepts of traditional neighborhood development, also referred to as "The New Urbanism," as they relate to the role of streets in traditional neighborhood development communities. The document also includes a discussion of community design guidelines, specific guidance on geometric street design, and an appendix that summarizes some of the recent findings on the relationship between urban design and travel demand.

- *"Guidelines for the Design and Application of Speed Humps, A Recommended Practice of the Institute of Traffic Engineers,"* ITE Traffic Engineering Council Speed Humps Task Force TENC-5TF-01, Douglas W. Wiersig, Chair, 525 School St. NW, Suite 140, Washington, DC, 1997.

This document provides information on the recommended practice for the guidelines for using speed humps, community relations and administrative procedures, design and construction considerations, monitoring and evaluation of speed humps over time, and other considerations, such as liability, aesthetics, maintenance and enforcement needs. An extensive listing of source materials is also included.

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APPENDIX A

REVIEW OF PEDESTRIAN SAFETY RESEARCH IN AUSTRALIA, CANADA, THE NETHERLANDS, SWEDEN, AND THE UNITED KINGDOM

(Appendix A reports may be found at www.walkinginfo.org/rd/international.htm)