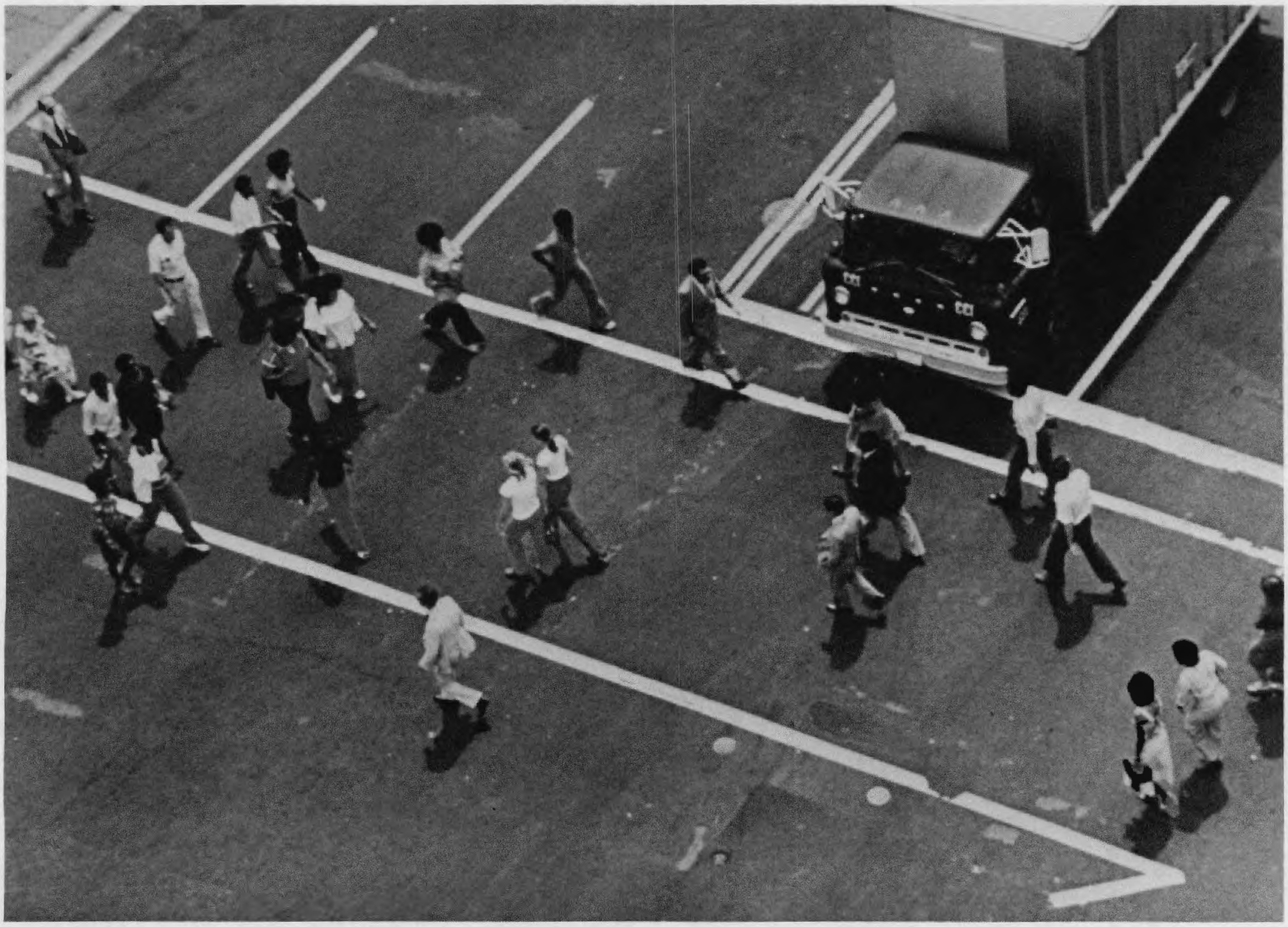
U.S. Department of Transportation

Federal Highway Administration

Synthesis of Safety Research—Pedestrians



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TECHNOLOGY APPLICATIONS

Innovation Through Partnerships

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16. Abstract

This synthesis provides information from past research on pedestrians, with a primary emphasis on pedestrian safety. The topics include characteristics of pedestrian accidents, conflict analyses and hazard formulas, pedestrian safety programs, and countermeasures related to engineering and education. Engineering measures discussed in this report include pedestrian barriers, crosswalks, signs, signals, right-turn-on-red, innovative traffic control devices, refuge islands, provisions for handicapped pedestrians, bus stop location, school trip safety, overpasses, sidewalks, and others. Information is also included on educational considerations and traffic enforcement and regulations related to pedestrians.

Pedestrian accidents account for 15 to 20 percent of all motor-vehicle fatalities in the U.S. and more than 100,000 people injured or killed each year. A considerable amount of research has been conducted over the past 25 years to better define the pedestrian safety problem and to develop and evaluate potential countermeasures. When selectively used, many of the engineering treatments can be effective in reducing pedestrian deaths and injuries. Pedestrian educational programs have been found to reduce 20 to 30 percent of pedestrian accidents involving young children. Model traffic regulations and enforcement programs are also important.

This report is an update of Chapter 16 "Pedestrian Ways" written by R.C. Pfefer, A. Sorton, J. Fegan, and M.J. Rosenbaum, which was published by the Federal Highway Administration in Synthesis of Safety Research Related to Traffic Control and Roadway Elements - Volume 2 in December, 1982.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

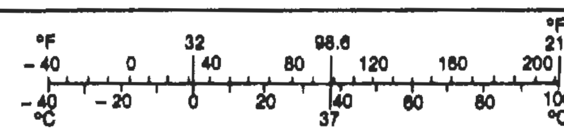
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.093	metres squared	m²
yd²	square yards	0.836	metres squared	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	kilometres squared	km²
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.028	metres cubed	m³
yd³	cubic yards	0.765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
ha	hectares	2.47	acres	ac
km²	kilometres squared	0.386	square miles	mi²
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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INTRODUCTION

While walking is the oldest mode of transportation, it carries with it a relatively high risk of injury or death on our existing networks of streets and highways. Motor vehicles have only been around for about a century, but they have created a vast array of problems for those who still choose to walk.

The relative directional freedom but slow pedestrian movement, as compared to the directionally confined but much more rapid movement of the motor vehicle, results in a large number of conflict locations having great accident potential. The majority of motorists have been trained and tested in observing the "rules of the road" and traffic control devices. However, pedestrians--who represent a wide range of ages and physical abilities--are not as well trained. Some may not be physically and/or psychologically able to adequately cope with a complex street environment, even if pedestrian facilities are provided.

Much of the emphasis on highway transportation has historically focused on increasing the safety and mobility of motor vehicles, with much less attention given to pedestrians. However, an increasing number of detailed studies have been conducted in recent years on various aspects of the pedestrian safety problem. Such studies have attempted to quantify the magnitude and characteristics of pedestrian accidents and identify the traffic and roadway characteristics associated with such accidents. A limited amount of research has also involved attempts to evaluate the effects of various roadway and educational treatments on pedestrian accidents.

The purpose of this report is to provide an overview of some of the research studies on pedestrian safety. This includes details of pedestrian accident characteristics, measures of pedestrian exposure and hazard, and more than a dozen specific roadway improvements and their effects on pedestrian safety. Pedestrian educational considerations are also briefly discussed.

This report is an update of Chapter 16, *Pedestrian Ways,* [1] written 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* in December, 1982. This update includes numerous studies published between 1980 and 1990 and includes foreign as well as domestic studies. Topics have not been revised in cases where no new research was conducted.

EVOLUTION OF PEDESTRIAN ACCIDENT PROBLEMS

Since ancient times, it has been found desirable to separate pedestrians from vehicular roadways. Fruin [2] presents a comprehensive historical perspective of the methodology used in ancient times to limit vehicular intrusion into cities. This included regulations prohibiting heavy wagons within the central city after dusk, vehicle/pedestrian separation by 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. In some cities, building height was limited to two times the street width.

The introduction and accelerated use of motor vehicles in urban areas has resulted in a number of adverse environmental effects. Facilities for pedestrian movement have been restricted by the ever-narrowing sidewalk environment. Both the motorist and the pedestrian are faced with a visual clutter of traffic signals and signs.

The central business district (CBD) of a city includes a variety of land uses such as 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. Walking, because of its infinite diversity, is the only means of transportation satisfying the many short, dispersed trip linkages required within the CBD. Downtown origin and destination surveys in most cities show about 90 percent of all internal trips within the CBD are walking trips.

The traditional urban core is usually superimposed on an archaic street system surviving from the land use and functional scale of the past. The street system of the Manhattan financial district of New York City, for example, is a survivor from colonial times when the tallest structure was 2 or 3 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 a situation like this, maximum use of sidewalk area and flow capacity is a necessity.

In many high density CBD's, the sidewalk width has actually been reduced to facilitate vehicular traffic movement. This results in a reduction of pedestrian traffic capacity, but does not always produce a commensurate increase in vehicular capacity. The wider streets increase the probabilities of pedestrian-vehicle crosswalk conflicts, which limit the vehicular capacity of intersections.

The potential pedestrian capacity of the CBD sidewalks is reduced further by the intrusion of refuse cans, fire hydrants, fire alarm boxes, parking meters, traffic signals and poles, newsstands, telephone booths, mailboxes, planters, sewer and ventilation gratings, and other devices. In addition, building service operations, such as the unloading or loading of trucks, often inconvenience and sometimes endanger the pedestrian. In many instances, no control has been exercised over the location of fixed sidewalk paraphernalia that often appear in clusters at intersections, the most critical points in the pedestrian circulation network.

Space is needed at intersections for the accumulation of pedestrians waiting for traffic signals and the weaving of 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 within a narrow sidewalk near an intersection, excessively narrow subway stairs are provided causing pedestrian queues both in the transit station below and on the surface above.

All of these factors discussed above can add up 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.

The rectangular grid pattern of the typical CBD is not conducive to the 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 straightline trip distance of only 200 feet. Larger midblock buildings with frontages on adjacent streets are often used as through routes so the pedestrian can shorten trip distances. This practice is more common in inclement weather. Depending on city location, one day in four may be too windy, cold, or wet for the pedestrian's comfort. Protection of the pedestrian from the elements is an almost forgotten amenity in most cities.

SUMMARY OF PEDESTRIAN ACCIDENT EXPERIENCE

Pedestrian Accident History

In 1989, a total of 6,552 pedestrians were killed in motor vehicle crashes in the United States, according to the National Highway Traffic Safety Administration's Fatal Accident Reporting System (FARS). [3] In 1975, pedestrian fatalities in the U.S. numbered 7,516 and increased to a peak of 8,096 in 1979. Since then, pedestrian deaths have gradually dropped to a low of 6,552 in 1989, as shown in figure 1. [3] This decrease seems even more substantial when one considers the increased U.S. population in the last decade.

To place the fatality picture in perspective, 1989 data show that pedestrian deaths account for 14.4 percent of the 45,555 motor vehicle traffic fatalities nationwide. Since 1975, pedestrian deaths have accounted for between 14 and 17 percent of traffic fatalities on U.S. highways. Further, of the approximately 2,148,445 non-fatal pedestrian injuries in the U.S. in 1989, 5.2 percent involved pedestrians. [3,4] Thus, although a drop in pedestrian fatalities has occurred in recent years, a serious problem continues to exist in the U.S. relative to pedestrian deaths and injuries.

Pedestrian Age and Sex

As one aspect of their 1984 study, Robertson and Carter [5] analyzed pedestrian risk by age. Based on 2,397 intersection pedestrian accidents, pedestrian risk was calculated by dividing the percent of pedestrian crashes by the corresponding percent of population. Nearly 40 percent of all pedestrians involved in an accident were less than 15 years of age. As illustrated in figure 2, pedestrians over-involved in accidents are young (between 5 and 15) and older adults (more than 64 years old).

A 1988 TRB study [6] computed fatality rates of pedestrians by age. As shown in figure 3, the fatality rate for pedestrians increased sharply for pedestrians 70 years or older. Although younger children are over-involved in number of fatalities, their fatality rate (deaths per 10 million population) is about the same or less than the rate for other pedestrian groups less than age 65. This could reflect their greater ability of the younger pedestrians to survive a crash than some older age groups, and/or be the result of different accident characteristics (e.g. lower vehicle speeds on residential streets where children are more likely to be struck than adults).

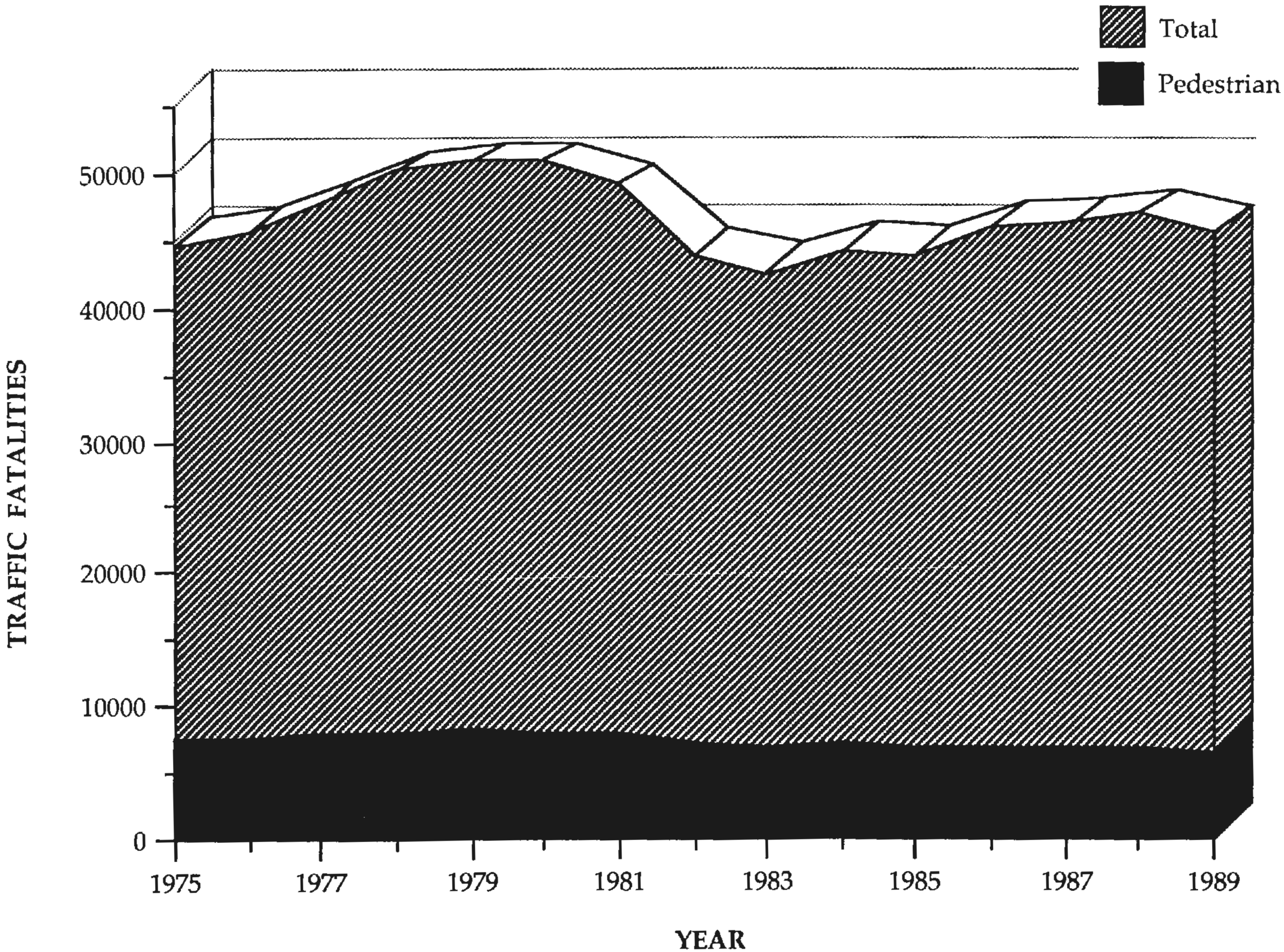


Figure 1. Pedestrian deaths in the U.S. - 1975 through 1989.

Source: Reference 3.

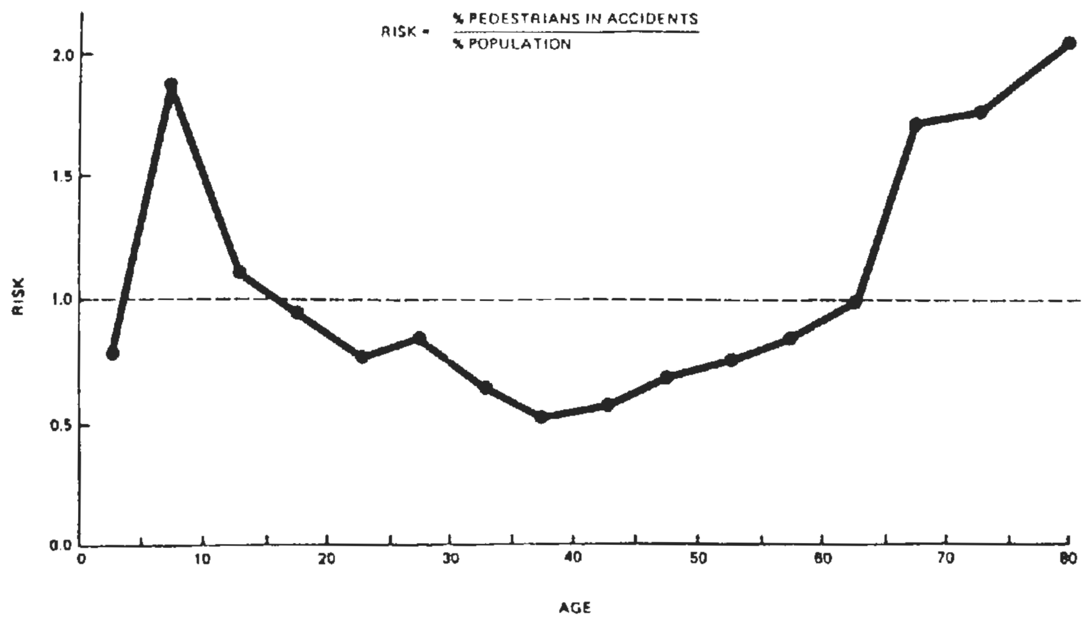


Figure 2. Pedestrian intersection accident risk by age based on exposure.

Source: Reference 5.

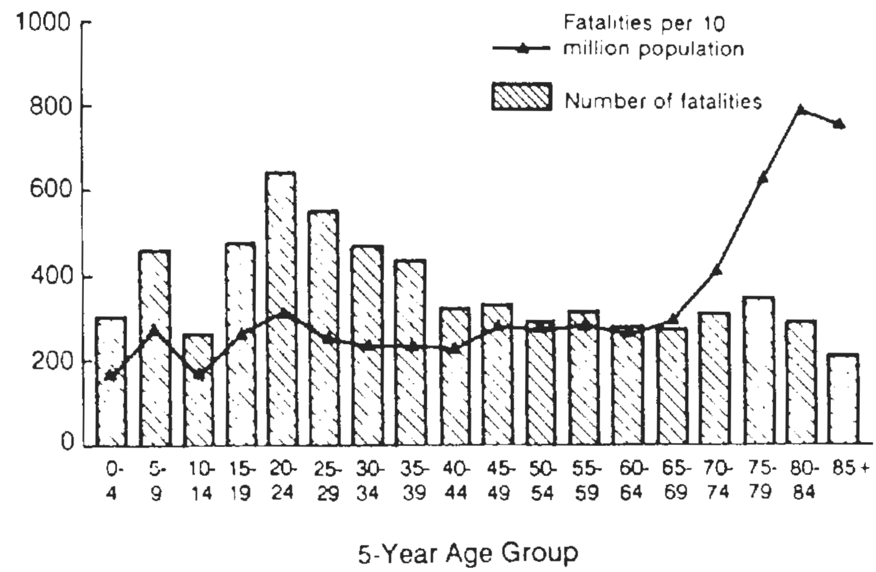


Figure 3. Pedestrian fatalities and fatality rates by age in 1986 (based on NHTSA data).

Source: Reference 6.

Pedestrian accident data from over 2,200 cities were analyzed by the American Automobile Association (AAA). [7] Compared to their proportion of population in the U.S., children ages 2 through 22 were found to be overrepresented in terms of pedestrian deaths and injuries as illustrated in figure 4. The greatest risk involved children aged 5 through 9. Boys were found to be involved in about twice as many pedestrian accidents as girls at ages 5 to 7. A study of pedestrian accident data for Milwaukee, Wisconsin [8], showed children age 9 and less represented 21 percent of all accidents while they represented almost half of the non-intersection accidents.

A more recent study from NHTSA's General Estimate System of pedestrian injury and fatality rate shows a steady drop in rate for pedestrian ages above the 5 to 9 category. [4] As shown in figure 5, the rate of injury or death is 149 for males 5 to 9 years old, and decreases steadily to a rate of 40 (per 100,000 population) for males 65 and over. This trend for older pedestrians differs from the study by Robertson and Carter, but that study involved intersection pedestrian accidents only (where older pedestrians may have particular crossing problems). It should also be remembered that pedestrian exposure (i.e. miles of walking along streets or number of times crossing wide or dangerous streets) is not accounted for in any of these statistics. Exposure is a factor about which little data exists. The amount of walking increases as the elderly make less use of motor vehicles, but the amount of walking may vary widely by age groups.

In a study of pedestrian accidents in Manhattan, New York City [9], a selected sample was compared with a control group whose characteristics were determined in a field survey. The results showed the mean age of those killed was 58.8 years; of those non-fatally injured, 48.4 years; and of those interviewed at the fatal accident sites, 41.6 years. The researcher's interpretation indicated an age associated risk of involvement and an age associated risk of a fatal outcome, once involved.

In a study of rural and suburban accidents [10] comparison with the base rate data showed nearly 10 percent of the accident sample victims were over age 55, but only 3.7 percent of the pedestrians observed at the site were in that age group.

The reason for the general over-representation of elderly pedestrian fatalities may be explained by the greater severity resulting from elderly pedestrian involvement, as suggested by Haddon et al. [9] This is supported by a Canadian study [11], as shown in table 1:

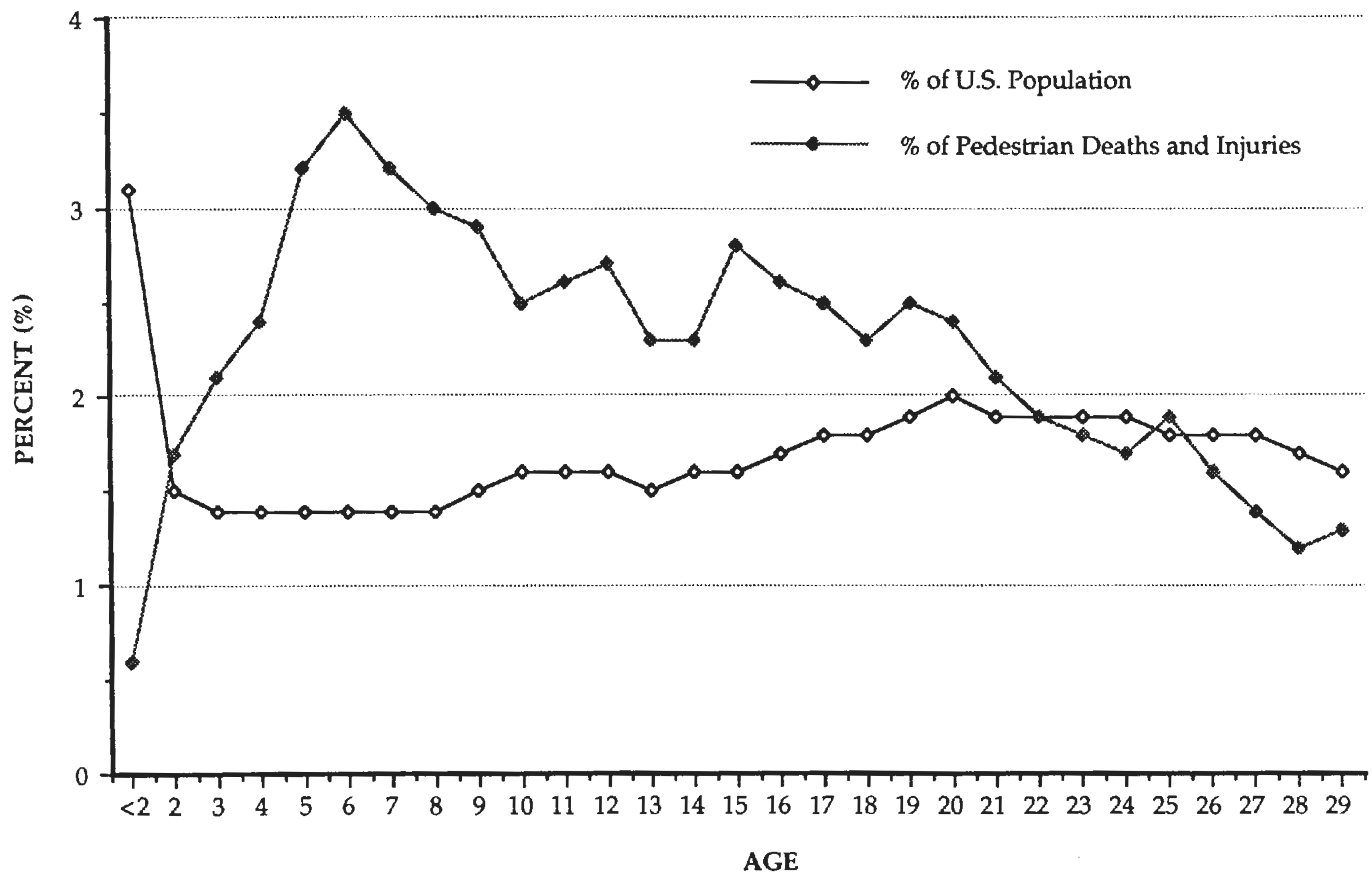


Figure 4. Rate of child pedestrian accidents by age.

Source: Reference 7.

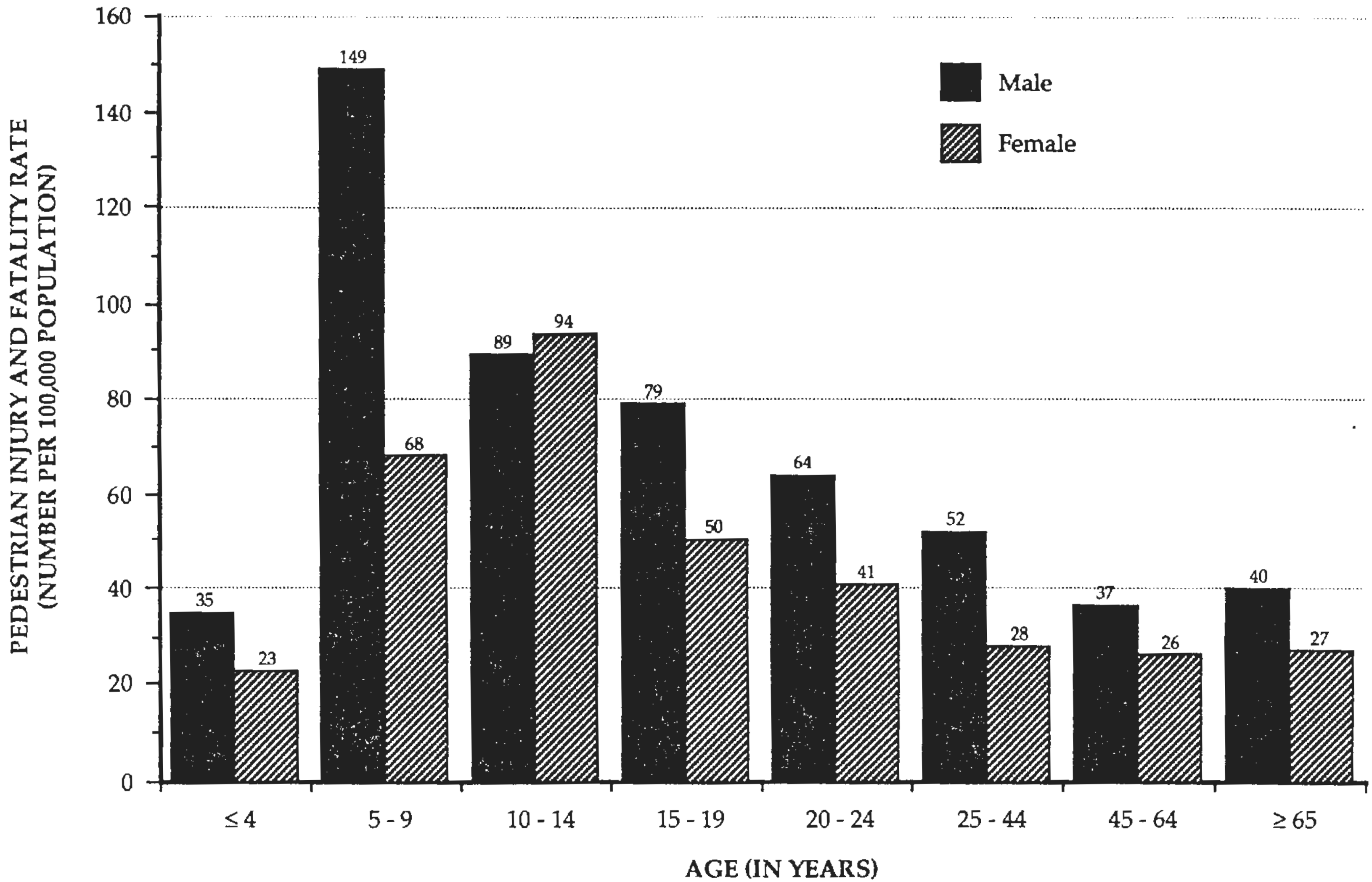


Figure 5. Rate of pedestrian injuries and deaths by pedestrian age.

Source: Reference 4.

Table 1. Pedestrian accident severity by age groups.

Age (Years)	Slight	Serious or Fatal
0 - 14	77%	23%
15 - 55	83%	17%
>55	66%	34%

Source: Reference 11.

Note the serious or fatal pedestrian accident is twice as frequent for those over 55 as for those between the ages of 15 and 55.

An analysis of pedestrian accidents from 172 cities in California [12] shows an increasing injury-to-death ratio up to age 14 and a declining injury-to-death ratio as ages increase above 14 years. Similar results were found in a study of pedestrian accidents in Wayne County (Detroit, Mich. area). [13]

A 1990 FHWA study by Cove [14] compared pedestrian fatalities (from the Fatal Accident Reporting System - FARS), pedestrian injury accidents (from the National Accident Sampling System - NASS), and population census data by age. The study reported that children 5 to 14 represent only 14.2 percent of the population but account for 27.1 percent of all reported pedestrian accidents. While adults had a lower percentage of accidents (7.7 percent) compared to their percentage of the total population (12.5 percent), they account for 22.7 percent of all fatalities. This shows that older pedestrians are much more likely to be killed if struck by a motor vehicle than younger pedestrians.

Handicapped Pedestrians

Data are limited on the extent to which handicapped persons are represented in pedestrian accidents. The study of suburban and rural accidents [10] indicated less than 5 percent of the accidents represented persons handicapped other than by drugs or alcohol. A study by Templer [15] analyzed pedestrian accidents involving his classification of handicapped persons and found four groups experiencing higher accident risks: the developmentally restricted (mostly children), wheelchair users, those with lower extremity impairments who walk using special aids, and the severely visually impaired. He indicated that there are many ways of classifying handicapped people, depending on the disabilities under consideration. He was concerned with the ability of people to function as pedestrians and identified broad groups of people as having difficulty in using the pedestrian environment. Table 2 gives the numbers of these pedestrian types from 1975 population figures.

While indications are that handicapped pedestrians would be few in number, their safety is given significant attention in the pedestrian area because of the many inherent hazards to such persons becoming barriers to their personal mobility.

Alcohol Impaired Pedestrians

Recent studies have found that alcohol impairment is a major problem which involves pedestrians as well as drivers. One 1990 study reported that between 37 and 44 percent of fatally-injured pedestrians had blood alcohol concentrations (BAC's) of .10 percent or greater for the years of 1980 through 1989. These percentages were only slightly less than fatalities involving passenger vehicles and motorcycles but much higher than drivers of tractor trailers. Of adult pedestrians killed in 1989 nighttime collisions with motor vehicles, 59 percent had BAC's of .10 or greater, while only 31 percent had no alcohol in their blood. [16]

It is interesting to note that while the percentage of fatally-injured pedestrians with high BAC's (.10 or more) did not decline in the 1980's, this same trend was not found with motor vehicle drivers. Instead, a 20 percent decrease occurred in high BAC's for drivers of motor vehicles during that period. These results were based on data reported from 29 states. [16,17]

A study of motor vehicle fatalities in North Carolina between 1972 and 1989 showed that between 42 and 61 percent of pedestrian fatalities involved pedestrians under the influence of alcohol (i.e. BAC of .10 or greater). This compared with 53 to 64 percent of drivers of single-vehicle collisions which were under the influence. Of 176 fatally-injured pedestrians tested in 1989, 81 (46 percent) had BAC's of .10 or above, 5 (3 percent) had been drinking, and 90 (51 percent) were sober (had no alcohol). [18]

Table 2. Population of typical groups of handicapped.

HANDICAP	TYPICAL GROUP AFFECTED	ESTIMATED POPULATION 1975
Developmental (Size and Maturity)	1. Children (and others)	67,408,000
Chronic restrictive conditions related to agility, stamina, and reaction time	2. Persons over 65 (and others)	22,170,000
Lower extremity impairment (legs, feet)	3. Wheelchair users	445,000
	4. Those who walk using special aids	5,042,000
	5. Those who walk with difficulty without the use of special aids	2,344,000
Chronic impairment of upper extremities (arms, shoulders, neck)	6. Those with chronic impairment of upper extremities	2,588,000
Severe auditory impairment	7. Those with severe auditory impairment	1,867,000
Severe visual impairment	8. Those with severe visual impairment	482,000
Obvious confusion and/or disorientation	9. Those with obvious confusion and/or disorientation	20,000,000

Source: Reference 15.

TIMES OF ACCIDENT OCCURRENCE

Hour of Day

In urban areas, there is general concurrence in the literature that peak pedestrian accident experience occurs between 3 and 6 p.m. This represents about 30 to 40 percent of the accidents. [3,10,13,14] The proportion drops off on either side of this period. Some exceptions involve much smaller secondary peaks during the 7 to 9 a.m. and 12 Noon to 1 p.m. time periods. [19]

A 1990 study by Cove [14] found fairly similar results for pedestrian injury accidents, with the major peak between 3:00 and 7:00 p.m. and a minor peak between 7:00 and 9:00 a.m. based on data from the National Accident Sampling System (see figure 6). However, fatal pedestrian accidents peak later in the day, between 5:00 p.m. and 11:00 p.m., with several minor peaks, including one from midnight to 2:00 a.m. (see figure 7). [14] This trend in fatalities could be associated partly with rural pedestrian accidents involving high-speed vehicles and pedestrians walking along the road or in some cases lying unconscious in the road. In fact, in North Carolina, 10 percent of all pedestrian fatalities involve a pedestrian lying in the road. [20]

The distribution of pedestrian injuries and deaths under day or nighttime periods was determined by pedestrian age from the 1989 "General Estimate System." [4] Pedestrian accidents involving children 14 years or younger are about twice as likely to occur during the day than at night, as shown in figure 8. For pedestrians aged 15 to 24, crashes were nearly equal during the day and at night. For pedestrians aged 25 to 64, crashes were somewhat less at night than during the day. For pedestrians 65 years and older, accident frequency is about four times higher during the day than at night. [4] These values probably reflect the relatively small percent of nighttime walking by the young and old pedestrian age groups combined by the increased level of risk from walking at night by all ages of pedestrians.

Day of Week

Available data indicate pedestrian accidents are over-represented on Friday and Saturday, with respect to weekly distribution. They are under-represented on Sunday. These trends are likely directly related to the amount of walking by day of the week. A Wayne County, Mich., study [13] indicated 35 percent of the accidents occurring on those two days. This was especially true for children, with Friday being the worst day. Similar patterns were found for urban, suburban, and

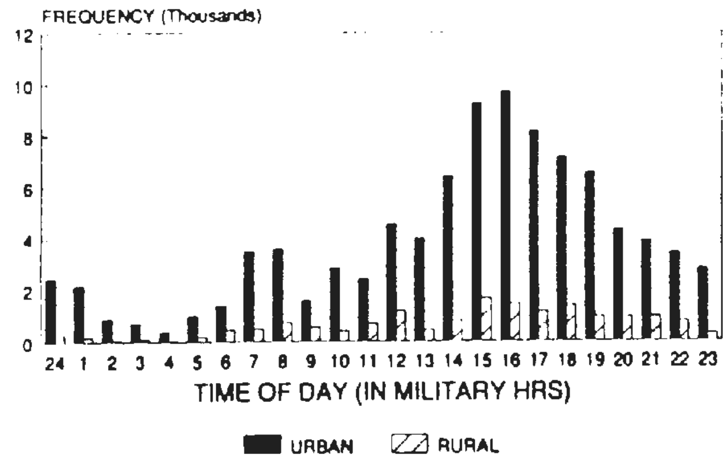


Figure 6. Pedestrian injuries by time of day and rural land use.

Source: Reference 14.

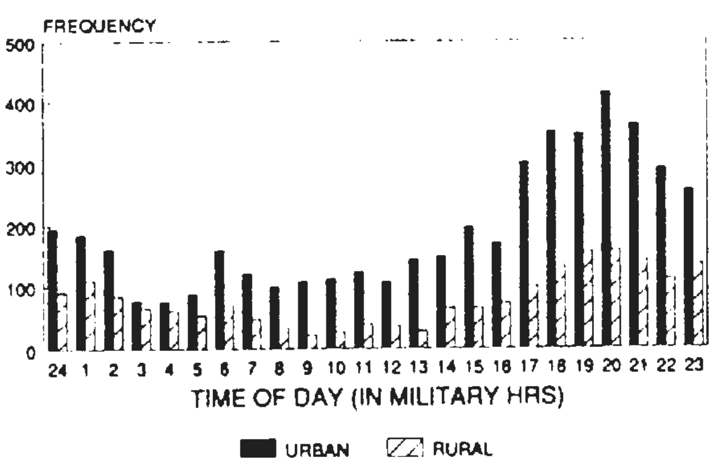


Figure 7. Pedestrian fatalities by time of day for urban and rural land use.

Source: Reference 14.

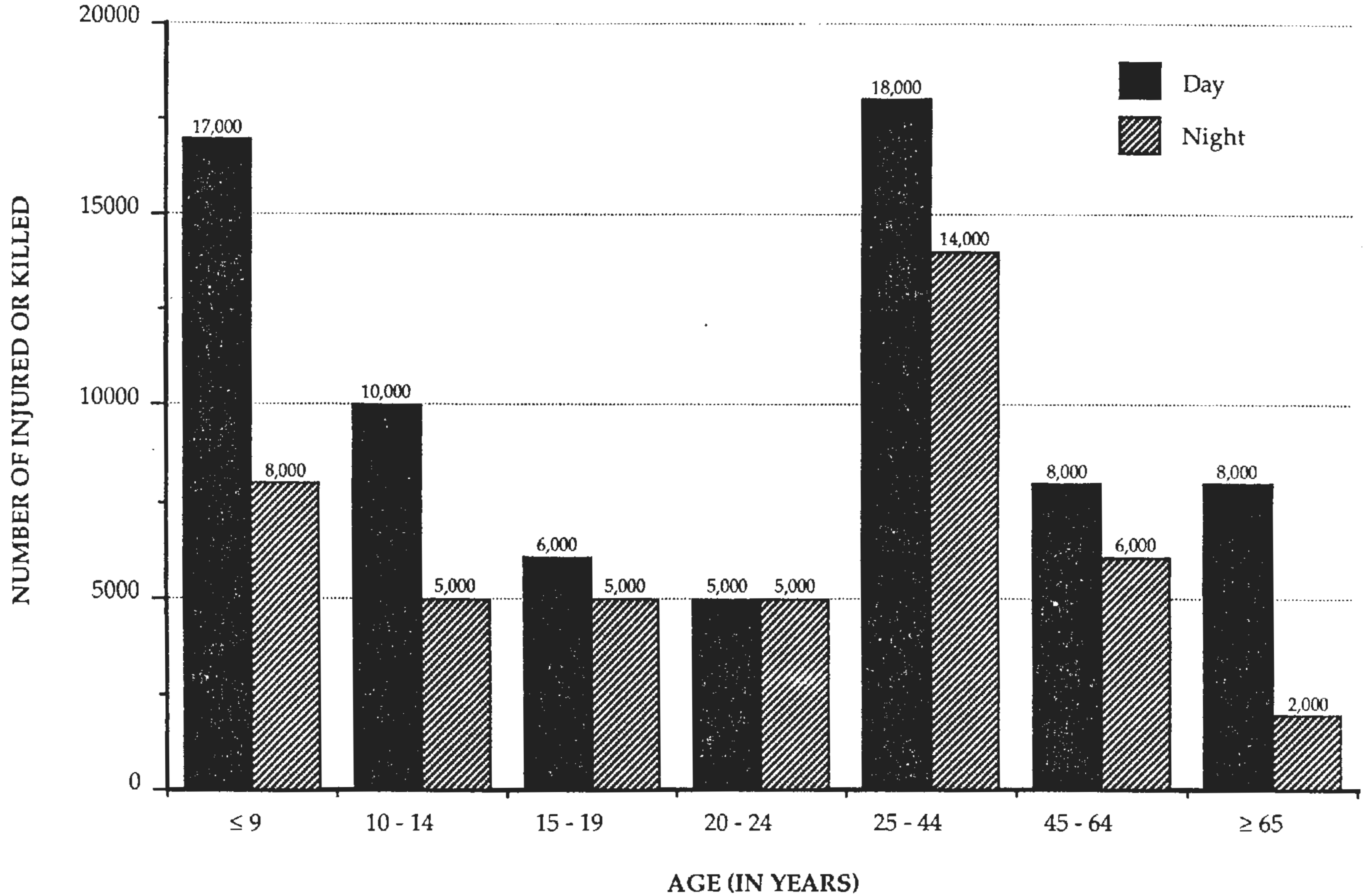


Figure 8. Pedestrian accidents by pedestrian age during day and night conditions.

Source: Reference 4.

rural data samples from a number of U.S. cities and counties. [10] Friday was the day showing the highest over-representation.

More recent data by Cove also reveal that Friday and Saturday have the greatest percentages of pedestrian fatalities for both rural and urban areas, with pedestrian fatalities nearly constant for Sunday through Wednesday (see figure 9). Pedestrian non-fatal injury accidents were most prevalent on Fridays and least frequent on Sundays. [14]

Month

A Wayne County, Mich., study [13] in 1969 showed more pedestrians (13 percent) were killed during December than in any other month. Child fatalities rose sharply in May, June, and July. The study of rural and urban data samples of U.S. areas [10] showed December to be the month having the greatest over-representation. Nationwide, pedestrian fatalities in 1989 were found to be highest in September through January, as illustrated in figure 10. [14] These are the months typically with fewer daylight hours and more inclement weather.

LOCATIONS OF PEDESTRIAN ACCIDENTS

Rural Versus Urban Areas

The rural/urban distribution of pedestrian accidents is given in table 3, based on estimates by the National Safety Council. [21].

Table 3. Pedestrian injuries and fatalities by area type.

Area Type	Non-fatal Injury		Fatal		Totals	
	No. of Accs.	Column Percent (Raw %)	No. of Accs.	Column Percent (Raw %)	No. of Accs.	Column Percent (Raw %
Rural	10,000	14.3	2,200	25.0	12,200	15.5
Urban	60,000	85.7	6,600	75.0	66,600	85.5
Totals	70,000	100.0	8,800	100.0	78,800	100.0

Source: Reference 21.

Of the estimated 78,800 total pedestrian accidents in the U.S. in 1988, 85.5 percent occurred in urban areas. This is due to the great majority of pedestrian activity in urban

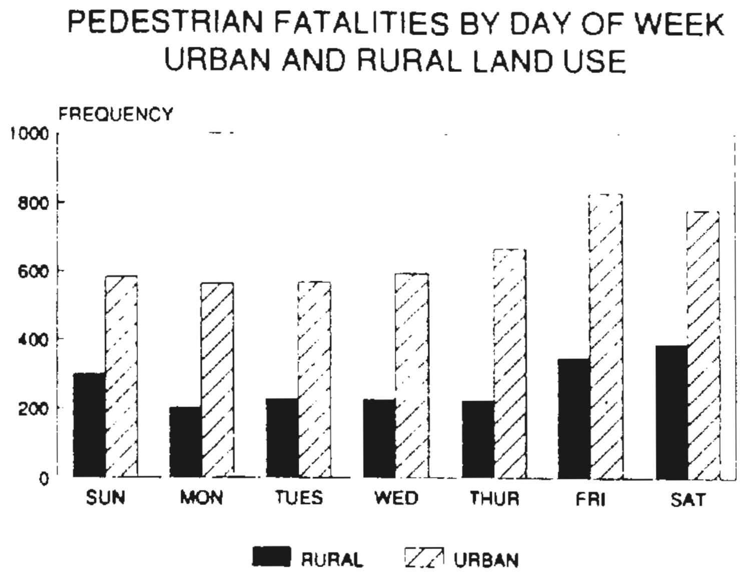


Figure 9. Pedestrian fatalities by day of week for urban and rural land use.

Source: Reference 14.

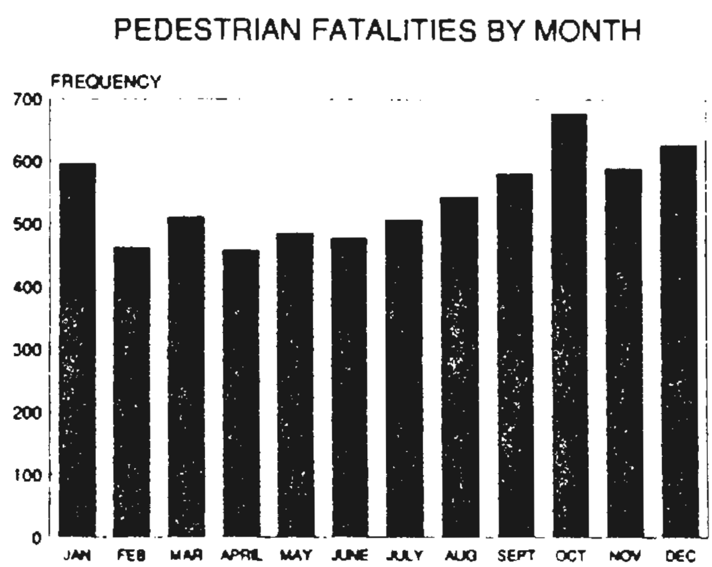


Figure 10. Pedestrian fatalities by month.

Source: Reference 14.

areas, compared to rural areas. The table also reveals that rural areas account for only 14.3 percent of non-fatal injury pedestrial accidents, but 25 percent of fatal pedestrian accidents are due largely to higher speeds in rural areas. [21]

Land Use

Several studies sampling pedestrian accidents by land use are summarized below:

- Thirteen major cities [22]

  Sample - 2100 Pedestrian Accidents

Central Business District	1%
Residential Areas	50%
Mixed Commercial	7%
Commercial Area	40%
School Area	2%

- Wayne County, Mich. [13]

  Sample - 268 Fatal Pedestrian Accidents

Shopping Business Area	58%
Residential Area	29%
School Area	2%
Expressway Area	2%
Other	9%

- Rural and Suburban Area Sample [10]

Residential Area	50%
Commercial Area	24%
Open Area	16%
School Area	7%
Other	3%

- Tucson, Ariz. [23]

Business Area	60%
Residential Area	37%
School Crossing	1%
Other	2%

Intersection vs. Nonintersection

Almost 60 percent of the urban pedestrian accidents in the United States occur at places other than intersections.

In rural areas, the proportion is closer to 67 percent. When considering fatalities only, the proportion remains essentially the same in urban areas. In rural areas, about 85 percent of the deaths occur at places other than intersections. [21]

A special 1977 survey of child pedestrian accidents, involving more than 1,900 cities, indicated about 75 percent occurred at nonintersection locations. This increases to between 80 and 90 percent for the 5-year-old and under age group. [7] This high percentage is no doubt the result of the high incidence of occurrences of young children running into the street at midblock locations, which too often result in midblock dart-out accidents.

A 1989 summary of pedestrian injuries and deaths by age was estimated by NHTSA for intersections and non-intersections. As illustrated in figure 11, a majority of crashes involving pedestrians up to age 44 occur at non-intersections. For ages 45 to 65 there is a nearly equal number of pedestrian crashes at intersections and non-intersections. Pedestrians aged 65 and older are more often struck at intersections than non-intersections. Although pedestrian exposure data are limited by crossing location, older pedestrians are generally more likely to cross at intersections than younger ones. [4]

ACCIDENT TYPES AND CAUSAL BEHAVIOR

Several major U.S. pedestrian behavior studies involved field observations, and interviews with pedestrian safety professionals, and data from accident reports. [10, 22, 24] These studies resulted in accident types being identified for urban, rural, and freeway locations as shown in tables 4, 5, and 6. [25] The objective of these studies was to identify accident causes and to develop countermeasures.

A study of freeway pedestrian accidents [24] provided information on driver and pedestrian activities leading to freeway pedestrian accidents. Table 7 gives the percentages of various driver activities preceding the accident, such as going straight, driving off the road, etc. The percentage of pedestrian activities is shown in table 8, such as running across the freeway, standing next to a disabled vehicle, etc.

A 1980 study by Habib [26] identified causal factors related to pedestrian accidents in crosswalks at intersections and recommend possible solutions. While 51.4 percent of such pedestrian crashes involved a through vehicle, left-turn vehicle maneuvers had nearly double the percentage as right-turn crash maneuvers (24.8 vs. 13.1 percent). Further, the

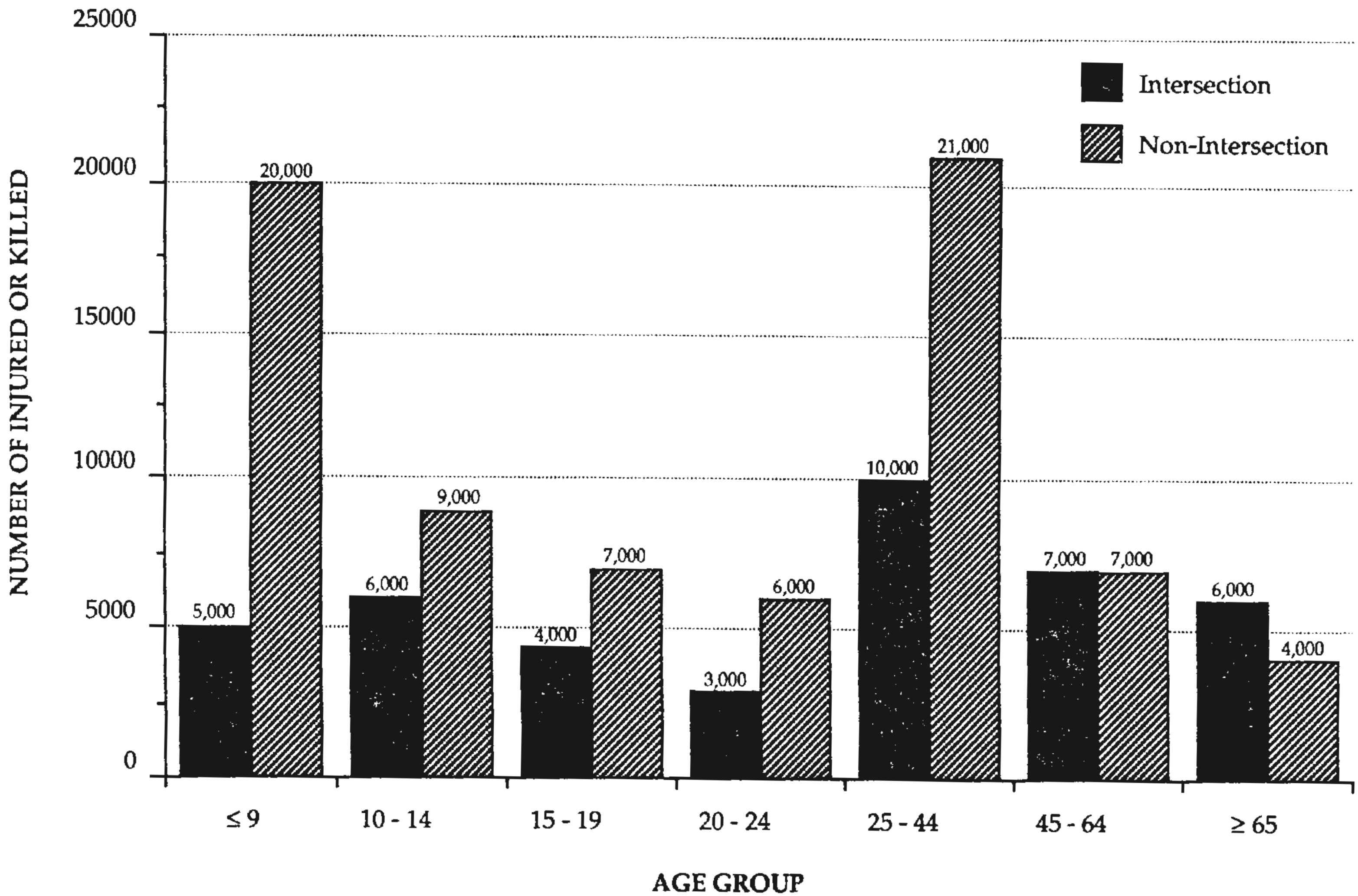


Figure 11. Pedestrian accidents by age and intersection vs. non-intersection.

Source: Reference 4.

Table 4. Urban pedestrian accident types and critical behavior descriptors.

Accident Type	Percent of Accidents 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 time exposure as above.
Intersection Dash	12	Intersection. Short time exposure or running. Same as "Dash 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 different direction than that of 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	1	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: Reference 25.

Table 5. Rural pedestrian accident types and critical behavior descriptors.

Accident Type	Percent of Accidents 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 time 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: Reference 25.

Table 6. Freeway pedestrian accident types and critical behavior descriptors.

Accident Type	Percent of Accidents 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: Reference 25.

Table 7. Driver activity leading to pedestrian accidents on freeways.

Percent of Pedestrian Accidents	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: Reference 24.

Table 8. Pedestrian activity leading to pedestrian accidents on freeways.

Percent of Pedestrian Accidents	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: Reference 24.

left-turn maneuver was about four times as hazardous as the through movement in terms of accidents and exposure. Also, driver error was found to increase when the left-turn movement was made as compared to right-turn maneuvers. Factors identified as contributing to the left-turn accidents with pedestrians include driver visibility problems, poor driver habits, and signal location. Solutions proposed by the author 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. [26]

EXPOSURE-BASED HAZARD INDEX

Several studies [10, 11, 27] have attempted to overcome the problem of dealing with pedestrian accident statistics which do not relate to the relative exposure to hazard.

One example is found in the study of suburban and rural accidents. [10] A hazard index was developed and defined as the ratio of the frequency with which any particular attribute was present in the accident sample to the frequency with which it was present in the general population at the site (base rate), at the same approximate time of day. Tables 9 and 10 show the relative hazards of pedestrian and vehicle actions derived in this manner. Table 9 shows that while crossing at a location other than an intersection was the most frequent action identified in the pedestrian accident sample, when compared with noninvolved 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 highly hazardous to the pedestrian compared to turning vehicles.

In a later study by Knoblauch, additional hazard relationships were updated, as shown in figure 12. [28] Samples of pedestrian accidents and exposure were used to develop hazard scores for various pedestrian and vehicle characteristics. Scores of +1 or higher represent higher than average and -1 or less as a safer than average level of hazard. Pedestrians aged 1 to 4 years old had the highest hazard scores (+8.3) with pedestrians aged 5 to 9 (+4.0), 10 to 14 (+1.2) and 60 and older (+1.7) having higher than average hazard scores. Running is much more hazardous for pedestrians than walking (+4.7 vs. -1.9). Walking against a traffic signal had a hazard score of 5.1 compared to 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 the highest hazards to pedestrians (+3.3 and +2.9, respectively) than other vehicle types. [28]

Table 9. Pedestrian action and accident data with resulting hazard index.

Pedestrian Action	Accident Data Percent	Base Rate Data Percent	Hazard Index Safer	Hazard Index 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: Reference 10.

Table 10. Vehicle action and accident data with resulting hazard index.

Vehicle Action	Accident Data Percent	Base Rate Data Percent	Hazard Index Safer	Hazard Index More Hazardous
Out-of-control	2.7	0.0		∞
Backing up	3.0	0.1		30
Passing	2.5	0.1		25
Other	3.6	0.2		18
Starting 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: Reference 10.

Pedestrian and Vehicle Characteristics	Percentage of Pedestrian Accidents	Percentage of Pedestrians or Vehicles Observed	Hazard Score (Less Hazard -5 -3 -1 / +1 +3 +5 More Hazard)
Pedestrian Age			
1-4 years old	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 12. Relative hazard of selected pedestrian characteristics.

Source: Reference 28.

CONFLICT ANALYSIS HAZARD FORMULA

Conflict analysis has been used in a number of pedestrian accident studies to determine the hazard level as a basis for developing countermeasures. [10,29,30,31,32]

In a Rochester, Michigan study [30], 12 different types of pedestrian conflicts were defined for school zones based on observations at 10 school sites. These conflicts and events included:

- 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.
- Pedestrial 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, were also counted.

The authors selected five conflict variables:

S - Severe Conflicts.
M - Moderate Conflicts.
R - Routine Conflicts.
J - Jaywalkers.
C - Legal Street Crossings.

The relative importance of these as contributors 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. [30]

A conflict analysis technique was developed in 1980 by Cynecki for use in identifying hazardous pedestrian crossing locations. A total of 13 types of pedestrian conflicts were defined with assigned severity levels. The technique was tested at five locations and used to select pedestrian accident countermeasures. The author recommended further investigation of relationships between pedestrian conflicts and vehicle-pedestrian accidents. [32]

A 1989 study by Davis, Robertson, and King [33] attempted to determine the relationship between pedestrian/vehicle conflicts and pedestrian accidents based on a predictive model. Discriminate analysis was used to develop accident group models for the cities of Washington, D.C. and Seattle, Washington. These models were used to predict intersection groups expected to have, for example, 0, 1, 2, or 3 or more pedestrian accidents. The accident 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. [33]

OVERVIEW OF ACCIDENT COUNTERMEASURES AND SAFETY PROGRAMS

Since the early 1970's, numerous publications have discussed alternative countermeasures for pedestrian accidents which may be appropriate. Several studies in the 1970's were conducted which suggested possible countermeasures for predominant pedestrian accident types, such as dart-outs, midblock dash accidents, and others. The matrix of candidate engineering countermeasures is given in table 11. [34] Countermeasures related to education and enforcement are shown in tables 12 and 13, respectively for specific types of pedestrian accidents. These countermeasures were based on judgments of researchers and professionals which were consulted for the study. Possible countermeasures are suggested in these three tables which could potentially help to reduce specific pedestrian accident types.

The FHWA's Model Pedestrian Safety Program [25] written in 1977 and updated in 1987, provides a six step process on planning, implementation, and evaluation relative to an agency's pedestrian safety program. The User's Guide Supplement presents detailed information on the various countermeasures for pedestrian accidents, including their advantages and disadvantages and implementation considerations. [25] Details on work zone management for improved pedestrian protection is given in a 1989 FHWA report. [34]

In 1981, a report was prepared by Vallette and McDivitt [35], which involved a review of available pedestrian literature and operational experiences of 19 U.S. cities on

Table 11. Matrix of potential engineering countermeasures for urban pedestrian accidents.

Countermeasures / Accident Type	Engineering and Physical																					
	Barrier: Median	Barrier: Roadway/Sidewalk	Barrier: Street Closure	Bus Stop Relocation	Crosswalk: Intersection	Crosswalk: Midblock	Diagonal Parking-1 Way Street	Grade Separation	Facilities for Handicapped	Lighting: Crosswalk	Lighting: Street	One-Way Streets	Retroreflective Materials	Safety Islands	Sidwalk/Pathway	Signal: Ped. (Shared)	Signal: Ped. (Delayed)	Signal: Ped. (Separated)	Signal: Traffic	Signs and Markings	Urban Ped. Environment	Vehicular Traffic Diversion
Dart-out (First Half)	●	●				●	●														●	●
Dart-out (Second half)	●	●				●	●					●		●							●	●
Midblock Dash	●	●				●								●							●	●
Intersection Dash					●			●		●	●			●			●	●		●		
Turn-Merge Conflict								●									●	●				
Turning Vehicle								●									●	●				
Multiple Threat								●		●	●					●	●	●	●		●	
Bus Stop Related				●																	●	
School Bus Stop Related				●																		
Ice Cream Vendor																				●		
Trapped					●			●						●		●	●	●				
Backup																						
Walking on Roadway		●									●		●		●					●		
Result Vehicle-Vehicle Crash																				●		
Hitchhiking											●		●									
Working in Roadway																				●		
Disabled Vehicle Related																				●		
Nighttime Situation										●	●		●									
Handicapped Pedestrians									●													

*Dots designate countermeasures believed to positively affect the indicated behavior/accident types.

Source: Reference 25.

Table 12. Matrix of potential educational countermeasures for urban pedestrian accidents.

Accident Type \ Countermeasures	Preschool					Elementary School								High Sch.			General Public						Older Adults		
	Parental Guidance	Safety Town/Safety Clubs	Television Programs	Walking In Traffic Safely	Watchful Willie	Officer Friendly	Education Within the Curriculum	Green Pennant Program	"Big Wheel" Spot	Willy Whistle Program	Safe Street Crossing	Child Intersection Dash TV Spot	"And Keep on Looking" Film	Assemblies	Drivers Education	Youth Traffic Court	Talks to Groups	Community Action Program	Use of the Mass Media	Multiple Threat Spot	Vehicle Turn-Merge Spot	Adult Intersection Dash Spot	Safety Courses	Talks to Groups	Community Contact Programs
Dart-out (First Half)					●					●															
Dart-out (Second Half)					●					●															
Midblock Dash																									
Intersection Dash												●	●									●			
Turn-Merge Conflict													●								●				
Turning Vehicle													●												
Multiple Threat													●							●					
Bus Stop Related						●																			
School Bus Stop Related						●																			
Ice Cream Vendor																									
Trapped																									
Backup	●																								
Walking on Roadway																									
Result Vehicle-Vehicle Crash																									
Hitchhiking																									
Working in Roadway																									
Disabled Vehicle Related																									
Nighttime Situation																									
Handicapped Pedestrians																									
Pedestrian Safety in General	●	●	●	●	●	●	●	●	●		●			●	●	●	●	●	●				●	●	●

Source: Reference 25.

Table 13. Matrix of potential enforcement countermeasures for urban pedestrian accidents.

Countermeasures / Accident Type	Child Protection					Enforcement/Regulations									
	Safe Route to School Prog.	School Bus Routing Plan	School Bus Patrols	School Crossing Guards	Play Streets	Enforcement	Ice Cream Truck Ordinance	Bus Stop Ordinance	School Bus Regulations	Dismounted Motorist Regs.	Vehicle Hazard Lights Regs.	Freeway Walking Regs.	Regs. for Peds. on Highways	Vehicle Overtaking Law	Parking Near Intersections
Dart-out (First Half)					●										
Dart-out (Second Half)					●										
Midblock Dash					●										
Intersection Dash															●
Turn-Merge Conflict															
Turning Vehicle															
Multiple Threat														●	
Bus Stop Related								●							
School Bus Stop Related		●	●						●						
Ice Cream Vendor							●								
Trapped															
Backup															
Walking on Roadway													●		
Result Vehicle-Vehicle Crash															
Hitchhiking												●			
Working in Roadway															
Disabled Vehicle Related										●	●				
Nighttime Situation											●				
Handicapped Pedestrians															
Pedestrian Safety In General	●	●	●	●	●	●									

*Dots designate countermeasures believed to positively affect the indicated behavior/accident types.

Source: Reference 25.

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 in terms of their safety program coordination, traffic engineering, school and child safety programs, provisions for the handicapped, public information and education, enforcement of pedestrian-related laws, accident analysis, and safety program recommendations and philosophy.

The WALK ALERT program is a national pedestrian safety program which is a cooperating effort of the National Safety Council, the FHWA, NHTSA, and more than 100 service and community organizations, with the primary objective of reducing pedestrian accidents. The 1989 WALK ALERT Program Guide [36] provides the steps needed to organize, initiate, 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 safety for pedestrians. Information is also provided to working with the news media, along with a resource guide which lists pedestrian safety programs, audiovisuals, and print materials recommended for the WALK ALERT program.

In 1988, a TRB synthesis was published on "Pedestrians and Traffic-Control Measures" by C. Zegeer and S. Zegeer. [37] This report provides details on publications and information related to 21 specific types of engineering traffic-control measures. This includes information from questionnaire responses from 48 city and state transportation agencies on pedestrian facilities, including traffic and roadway conditions under which each measure is most effective and least effective. The report includes discussions on 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). Also, recommendations are provided on selecting effective traffic control measures to improve pedestrian safety and movement. [37]

A 1987 NCHRP report "Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas" by Smith et. al. [38] provides information on 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 implementing such facilities. A summary is given of pedestrian facility problems and possible solutions from that study, and a sample of such information is given in figure 13. Many of the

Description of Problem	Magnitude of Problem	Possible Solutions	Current Level of Use or Acceptance	Limitations in Applicability	Potential Effectiveness	Barriers to Implementation	Cost	Impact on Other Groups	Comment
Cross-section 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 highways. 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 hwys.	Low	Must usually narrow lanes on existing hwys. to accommodate [illegible]ge islands. Must be well lighted.	High	Moderate	Low to moderate	Minimal impact	This solution is greatly underutilized in U.S.
		3. Design for reduced street width between signalized intersections (since capacity constraints are at signals).	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 were 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. Does not necessarily make crossing easier.
		6. Provide ped overpass.	Low	Only effective where at-grade crossing is blocked or is inconvenient.	Moderate - depends on no. 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 in frequent U-turn capability	High	High	Moderate to high	Negative	Merchants and drivers will object heavily.
		2. Install 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 impact	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 impact	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	

Figure 13. Partial summary of pedestrian facility problems and possible solutions.

Source: Reference 38.

deficiencies which were found in suburban and developing rural areas were attributed to the failure of the planners to think about how to get pedestrians safely and conveniently from one place to another. [38]

In 1989, Bowman, Fruin, and Zegeer [39] authored a report entitled "Handbook on Planning, Design, and Maintenance of Pedestrian Facilities." The focus of this report was to pull together current information to help engineer, 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 (i.e. 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. [39]

In 1990 a NHTSA publication was written entitled "Planning Community Pedestrian Safety Programs -- An Agenda for Action." This guide was intended to assist local communities in either integrating pedestrian safety into an existing community traffic safety program (TSP) or to develop and implement 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. [40]

As discussed above, there are a number of recent Users Guides and Procedural Manuals 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). [36,40,34] Other publications document city pedestrian safety programs and/or provide some information from previous pedestrian literature in selected areas (e.g. Vallette and McDivitt, TRB Synthesis report). [35,37] Still others assist in the planning, design, implementation, and maintenance of pedestrian facilities (e.g. Smith et. al. and Bowman et. al.). [38,39]

The purpose of this Synthesis report, however, is to summarize some of the literature from the U.S. and abroad which relates to pedestrians. Pedestrian safety is emphasized throughout this report, particularly regarding results of evaluations of pedestrian-related measures and facilities. A limited discussion of education and enforcement is given near the end of this report following the information on pedestrian accidents, exposure, and physical facilities. Although this report emphasizes engineering treatments, it is important to emphasize that education and enforcement are equally important ingredients in pedestrian safety efforts. More details on those topics are given elsewhere. [36]

BARRIERS TO RESTRICT PEDESTRIAN MOVEMENTS

Median Barriers

As part of a test of a variety of countermeasures [41], median fence barriers were installed at two sites (Washington, D.C., with a 4-foot-high fence, and New York City, with a 6-foot-high fence). One site had two gaps at intersecting minor streets. After installation of the barrier, most of the pedestrians (61 percent) 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 forcing them to cross at the intersection.

The majority of pedestrians (61 percent) in that study who were crossing midblock before the installation did so out of convenience. About one-third indicated they would only use the crosswalk if midblock traffic were "very heavy." After installation of the fence, 32 percent of the 22 pedestrians interviewed who were making midblock crossings stated inconvenience as the major factor, with high volume turning traffic at the intersection as a close second (23 percent). Generally, older pedestrians were concerned with the intersection turning-traffic problem. Many cited recent accident 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 its major effect was to discourage customers from shopping both sides of the street. Most residents accepted the barrier. Only 7 percent wanted it taken out. A few complained about inconvenience and its unsightly appearance. [41]

Freeway Barriers

As part of the analysis of freeway pedestrian accidents [24], three different approaches were taken to identify maximum national impact of barriers on freeway accidents if pedestrian barriers were employed (right-of-way fencing and/or median barriers) and were completely effective in controlling accidents identified as related to this countermeasure. The field investigators involved in the analyses estimated that 14 percent of the freeway pedestrian accidents were susceptible to the countermeasure. One analysis of the accident types and the contributing factors suggested that between 160 and 222 accidents per year were susceptible to this countermeasure.

Roadside/Sidewalk Barriers

Chains, fences, guardrails, and other similar devices have been proposed in several studies as a means for channelizing and protecting pedestrians. [10, 22, 24, 25]

Parking meter post barriers were tested at three sites in urban areas. [41] In Washington, D.C., six parking meter post barriers were created on one side of a street, resulting in a series of 12-foot long single chain sections at a 3-foot height. In New York City, 19 posts were utilized--9 on one side of the street and 10 on the other side. These were 12-foot sections with two chains 3 feet high. The third site was a section of one-way street along which three chain sections were installed on eight posts. The installation also created a 3-foot high barrier. The results were mixed. A vandalism problem (stolen chains) interfered with the experiment and is a noteworthy phenomenon. Twenty-six percent of those interviewed who crossed at the intersections after the installation noted the illegality of crossing elsewhere as a factor in their choice of crossing location. Since only 12 percent had noted this before the change, the barriers may have served to remind the pedestrians of the illegality of jaywalking.

While 65 percent of the merchants perceived no negative effects from the countermeasure, 15 percent noted the interference to street crossing, and 18 percent cited a problem when loading and unloading goods. [41]

A 600-yard length of road in London having pedestrian barriers was observed and pedestrian crossing movements mapped. [42] The barriers were located on both sides of the road. They had openings for access which were not directly across from each other. Accident data for the site were also analyzed to arrive at a measure of risk as the ratio of the number of accidents over the past 8 years to the pedestrian flow over a 4-hour period. Over 20,000 pedestrians were observed.

The resulting risk ratios were compared with those for 11 other sites in London which did not have pedestrian barriers. The only significant differences occurred at points within 50 yards of a signalized intersection (over twice the risk ratio with the pedestrian barrier) and at other midblock locations within 20 yards of an intersection where controlled crossings were not present (about 10 times the risk ratio). The overall risk ratio was lower at the test site, but it was not found to be statistically significant. [42]

The longitudinal path component 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 10 yards. It was suggested by the author that longitudinal distances between the openings on opposite sides of a street be greater than 10 yards. [42]

Pedestrian barrier fences were installed along 18 sections of road in Tokyo. [43] Accidents were analyzed before and after the installation. Accidents related to the crossing pedestrians were reduced by nearly 20 percent. An overall 4-percent reduction was obtained including nonpedestrian related accidents. It had been conjectured that even though accidents related to pedestrians crossing out of crosswalks might decrease, accidents related to pedestrians crossing on crosswalks might increase. The results indicated both types of related accidents were reduced equally by 20 percent.

CROSSWALKS

While pedestrian crosswalks may be marked or unmarked, numerous considerations relate to crosswalks. These include their location and type of marking, crosswalk remarking, alternative crosswalk treatments, and crosswalk illumination. These topics are discussed on the following pages.

Crosswalk Location and Marking

Marked and signed crossings, with appropriate legislative definition, have been widely employed as a means of reducing pedestrian hazard when crossing a street. Recent evidence indicates these do not guarantee reduced risk and must be applied with care.

An analysis was made of 5 years of accident data at 400 intersections in San Diego, Calif., comparing marked and unmarked crosswalks. [44] Traffic counts and further analysis were also made for 40 of the sites at which a marked crosswalk existed on one side of the intersection but no crosswalk was on the other side. Figure 14 shows the results of the analysis of the 400 intersections as a function of time of day.

Study results show pedestrian accident and crosswalk use ratios tend to cover a range of values depending on the type of intersection where the crosswalk is located. In general, more pedestrian accidents occur in marked crosswalks than in unmarked crosswalks by a ratio of approximately 6 to 1.

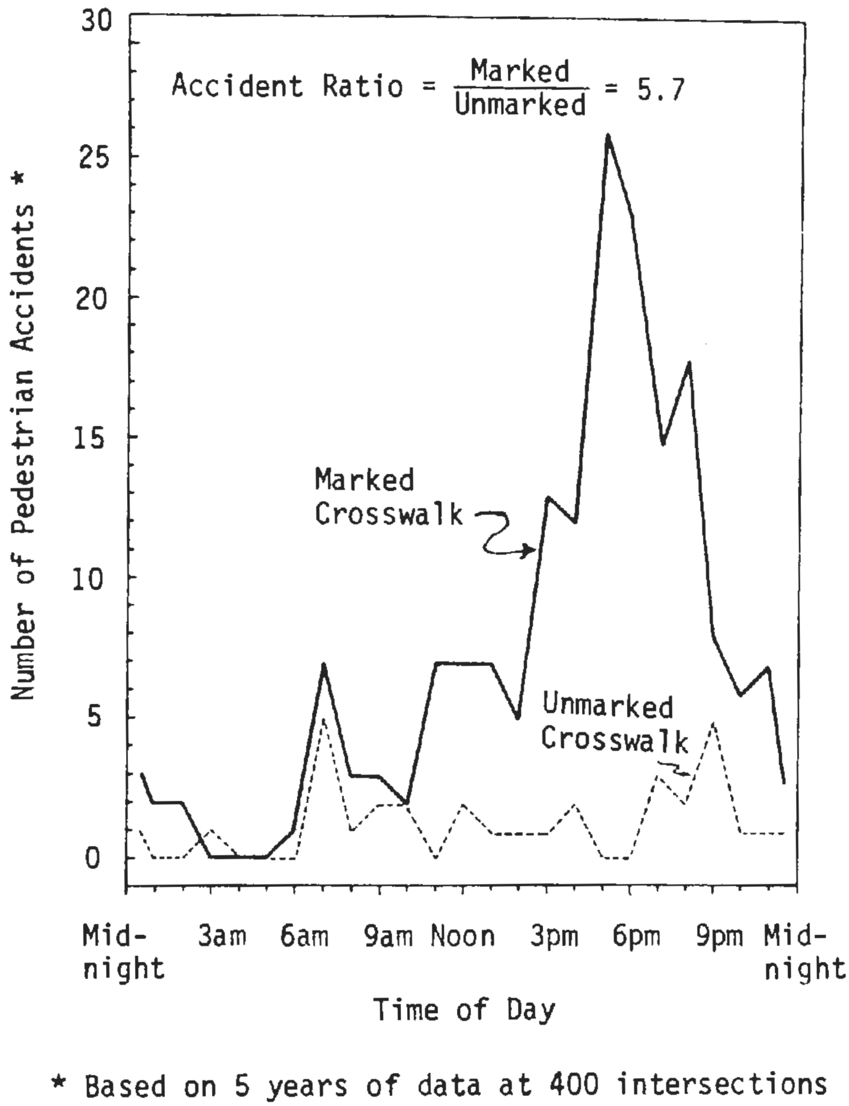


Figure 14. Pedestrian accidents in marked and unmarked crosswalks by time of day.

Source: Reference 44.

Further comparison of the volume of pedestrians using the marked and unmarked crosswalks shows that the crosswalk use ratio is approximately 3 to 1. This would indicate, in terms of use, that approximately twice as many pedestrian accidents occur in marked crosswalks as in unmarked crosswalks. [38]

Evidence suggests this poor accident record is not due to the crosswalk being marked as much as it is a reflection on the pedestrians' attitude and behavior when using the marked crosswalk.

In general, marked crosswalks were found to have the following advantages: [44]

1. Help orient pedestrians in finding their way across complex intersections.
2. Help show pedestrians the shortest route across traffic with the least exposure to vehicular traffic and traffic conflicts.
3. Help position pedestrians where they can be seen best by oncoming traffic.
4. Help utilize the presence of illumination to improve pedestrian night safety.
5. Help channel and limit pedestrian traffic to specific locations thus aiding enforcement of pedestrian crossing regulations.
6. Act as a warning device and reminder to motorists of locations where pedestrian conflicts can be expected.

Marked crosswalks also exhibit some disadvantages: [44]

1. Cause some pedestrians to have a false sense of security, which would place them in a hazardous position with respect to vehicular traffic.
2. Cause the pedestrian to think the motorist can and will stop in all cases, even when it is impossible to do so.
3. Cause a greater number of rear end and associated collisions due to pedestrians not waiting for gaps in traffic.
4. Cause an increase in fatal and serious injury accidents.
5. Cause an increase in community-wide accident insurance rates.

6. Cause disrespect for all pedestrian regulations and traffic controls.

Unjustified and poorly located marked crosswalks may cause an increased expense to the taxpayers for installation and maintenance not justified in terms of improved public safety. Such crosswalks may tend to increase the hazard to pedestrians and motorists alike.

The Herms study [44] states that marked crosswalks will continue to be a useful traffic control device. It is important for the general public to recognize what marked crosswalks can and cannot do. It is also important for public officials to not install them unless the anticipated benefits clearly outweigh the risks discussed in the study.

In contrast to the Herms study was a 1983 study for FHWA by Tobey, Shunamen, and Knoblauch [45], which included an assessment of the relative hazard score of marked vs. unmarked crosswalks. Locations with <u>unmarked</u> crosswalks had a PxV hazard score of +2.5, that is, the hazard score based on the exposure measure P (the number of pedestrians) times V (the number of vehicles). A positive hazard scare denotes higher hazard, and a negative scare represents a lower hazard. Locations with both marked crosswalks had a PxV hazard scare of -2.5, which indicates that they are relatively safe compared to locations with unmarked crosswalks. The results also showed that sites with marked crosswalks had lower PxV hazard scares for nearly all roadway conditions. [45]

There are no obvious reasons for different results on the effects of marked crosswalks between the two studies. However, it is believed that marked crosswalks can be quite beneficial at some sites but inappropriate or harmful at other sites. [37]

The most commonly used crosswalk markings are parallel lines painted for pedestrian use. In the U.S., zebra crosswalks generally refer to diagonal lines painted between the parallel lines crossing a street, while ladder crosswalks consist of short stripes painted parallel to the direction of traffic flow. Solid marking of crosswalks are sometimes used by painting the area within the crosswalk lines. (see figure 15). A 1987 study by Knoblauch, Testin, Smith, and Pietrucha [28] evaluated alternative crosswalk marking designs in terms of which type of marking was most readily detected by an approaching motorist. Laboratory tests were made of 59 test subjects who viewed 35 mm photographs of 18 types of crosswalk markings taken at distances of 100 to 600 feet. The ladder crossing design was consistently found to be the best from a driver's visibility point of view. [28]

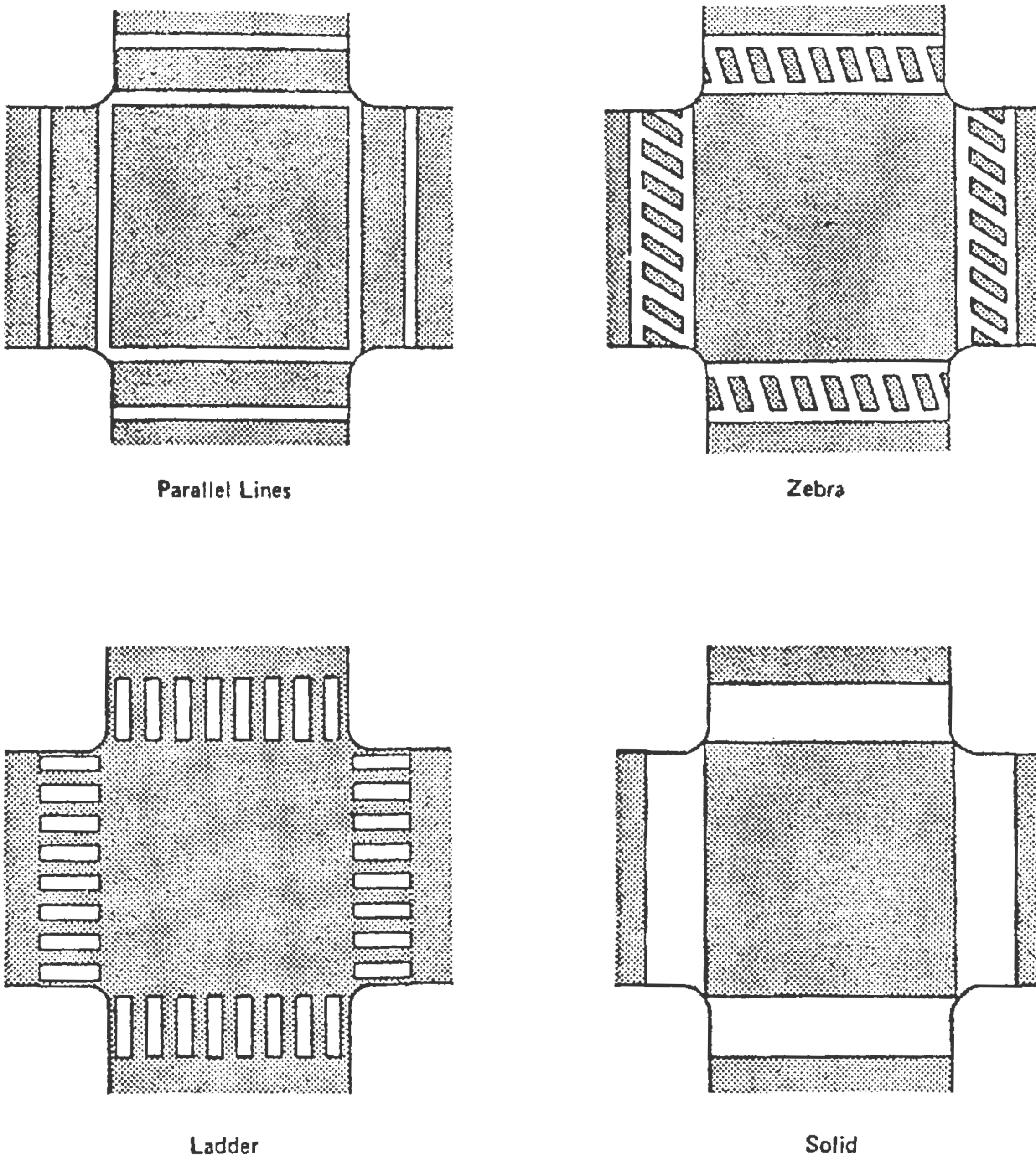


Figure 15. Illustration of various crosswalk marking patterns.

Source: Reference 28.

Based on a review of crosswalk marking guidelines in other countries, input from traffic engineers, and other factors, Knoblauch et. al. developed recommended guidelines for marking crosswalks. The authors recommended that crosswalk markings be installed under the following conditions: [28]

- at all signalized intersections which have pedestrian signal heads.

- at all locations with a school crossing guard who is normally available to assist children cross the street.

- at all intersections and midblock crossing locations which satisfy the minimum volume criteria in figure 16 for pedestrians and vehicular traffic. To satisfy this criteria a marked crosswalk is warranted if the basic criteria for sight distance and speed limit are met, and the pedestrian and vehicular volume are high enough to place the location above the appropriate curve in figure 16. Each approach leg is analyzed separately, so a crosswalk may be warranted on one or both sides of an intersection.

- at other locations with a need to clarify the preferred crossing location when the confusion may otherwise exist for pedestrians.

Zebra crosswalk markings (which were actually a ladder design, according to U.S. definitions) were evaluated in a 1988 study in Sweden by Ekman [46] in terms of their effect on pedestrian accidents. Based on police-reported injury accidents and normal pedestrian counts on a total of 56 kilometers of urban streets, pedestrians were found to experience approximately twice the risk of being injured when crossing at a zebra crossing compared to a crossing location without any signs or road markings (all else being equal). The reason for this finding could perhaps be explained partly from another study finding that car drivers had minimal speed reductions when approaching the crossing, regardless of whether pedestrians were about to cross or in the street. The authors concluded that pedestrians seem to rely more on zebra crossings to keep them safe than they should, and zebra crossings do not cause motorists to react more safely toward pedestrians. [46]

Crosswalk Remarking

A study of the effect on pedestrian and vehicular behavior of crosswalk markings was conducted in Peoria, Ill. [47] As part of a pavement marking program, 17 sites (15 at

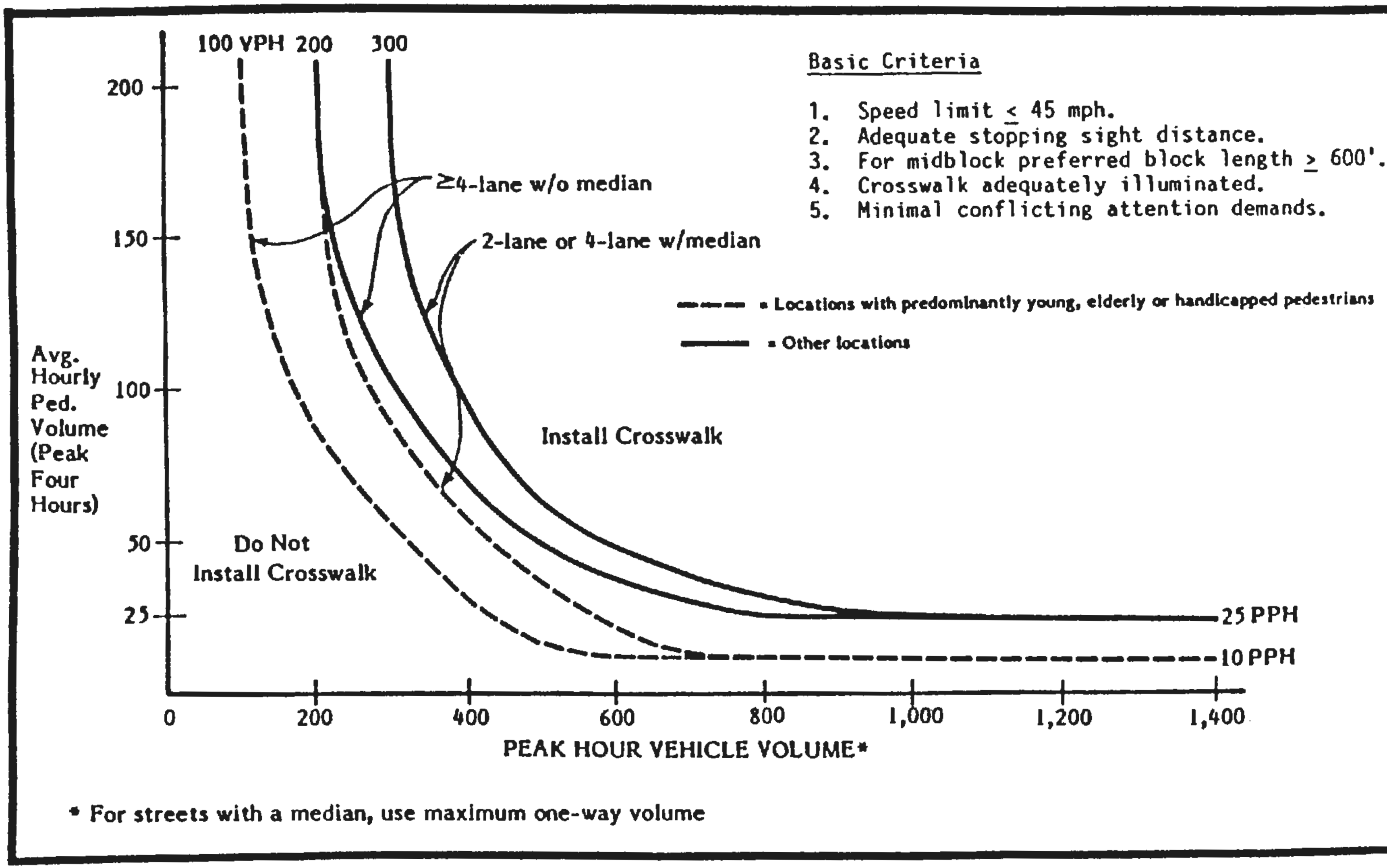


Figure 16. Guidelines for crosswalk installation at uncontrolled intersection legs, midblock crossings and signalized intersections without pedestrian heads.

Source: Reference 28.

signalized intersections) with badly worn markings were newly marked with thermoplastic stripes containing reflective beads. Two marking configurations were employed. Each had a 24-inch stop line placed 4 feet back of the crosswalk. Alternative crosswalk designs were the conventional 8-inch parallel stripes, 10 feet apart; and the crossbar (zebra) type employing 24-inch wide stripes, 30 inches apart placed parallel to the direction of traffic, and 10 feet wide. The types of violations studied and the composite change reported are shown in table 14. It appears that the marking increased observance by both pedestrians and motorists. The comparative effect of the two configurations was not reported nor was their relative frequency of application. [47]

Alternative Crossing Treatments

Innovative approaches to pedestrian crossing protection were tested in Detroit, Michigan. [48] 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 accident records and/or judgment which 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. [48]

The engineering studies led to the following findings: [48]

- There was a significantly greater relative use of crosswalks following installation of devices primarily during daylight hours.
- The speed distribution of unencumbered vehicles in the vicinity of the crosswalk did not respond substantially to the installations.
- Many more drivers slowed for pedestrians waiting to cross the street.
- Increased pedestrian usage of push buttons occurred but not to the level expected.

Table 14. Comparison of pedestrian and motorist behavior before and after crosswalk remarking.

	Violation Ratios*	
Violation Types	Old Crosswalk	ReMarked Crosswalks
Step Out of Crosswalk	.0523	.0406
Jaywalk	.0670	.0388
Cross on Don't Walk	.1086	.0533
Stop in Crosswalk	.0199	.0140
Drive Over Crosswalk in Front of Pedestrians	.0043	.0020
Drive Over Crosswalk Behind Pedestrians	.0118	.0035

$$* \quad \frac{\text{Violators}}{\text{Violators + Nonviolators}}$$

Source: Reference 47.

Interviews of pedestrians and drivers showed drivers were usually satisfied with the devices. Pedestrians were not satisfied with driver response, however. Drivers, it was concluded, did not expect to have to stop or slow down significantly unless a traffic signal or stop sign was in use. Pedestrians expected traffic to slow down when the device was activated. This clearly indicated a dangerous set of conflicting expectations. It was generally concluded the devices tested have only limited value for Detroit pedestrians, except in special situations. [48]

Canada conducted a study of special crosswalks in use in five of its major cities. [49] Four evaluation criteria were used--safety, delay, aesthetics, and cost. Special crosswalks were defined as those with some extra protection in the form of overhead signs and lighting, pavement markings, parking prohibitions, and, in some cases, special laws. [49]

The best system in terms of performance rating per unit cost was used in Toronto. If cost was excluded as a factor, the Calgary system performed best. The Toronto system consisted of pavement markings and roadside signs. Large "X's" were marked on the pavement in each lane 100 feet back on the approach to the crosswalk. The stripe widths were between 12 and 20 inches, and the "X" was 20 feet long. A standard advanced pedestrian crossing warning sign was mounted adjacent to the "X" at the roadside. The crosswalk was marked no less than 8 feet wide with two 6-inch to 8-inch stripes, 88 inches apart, delineating each side of the crosswalk. The Calgary system employed a large overhead sign bearing the word "PEDESTRIAN" with two large "X's" on either side of the word. On either side of the "X's" were mounted 8-inch 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 150 to 250 feet prior to 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. [49]

Before-and-after studies in Toronto showed a marked decline in pedestrian fatalities. Two hazardous patterns of behavior were noted, however. First, some pedestrians would step off the curb without signaling their intention to cross the roadway. These pedestrians apparently expected vehicles to stop instantaneously. Second, pedestrians noted the hazardous practice of vehicles passing 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. [49]

Illuminated crosswalk signs were installed and evaluated at 20 locations in Tokyo, Japan using before-after comparisons of accidents. [43] Findings show both pedestrian crossing related and other unrelated accidents increased after the installation of the signs by 4.8 and 2.4 percent, respectively, in 200-meter sections on either side of the installation. Both types increased 11.4 percent in 50-meter sections. It was concluded that the illuminated crosswalk signs did not seem to be effective in reducing accidents. It could not be concluded whether this type of device definitely increases accidents, however, since the average annual rate of accident growth on major streets in Tokyo has been around 24 percent.

Crosswalk Illumination

A two-stage study of floodlighting of pedestrian crossings was conducted in Perth, Australia. [50] 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 12 feet from the crosswalk at a height of 17 feet, and aimed at a point 3 feet 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 accidents as shown in table 15.

Table 15. Accident effects of providing sodium floodlights at pedestrian crossings (Perth, Australia).

	Pedestrian Accidents			Accidents 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 57 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: Reference 50.

A combined illumination and signing system for pedestrian crosswalks was developed and tested in Israel. [51] The nighttime accident reduction achieved at the 99 illuminated study sites and 39 unilluminated control sites is shown in table 16 below:

Table 16. Effects of crosswalk illumination on pedestrian accidents (Israel).

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

Source: Reference 51

The reductions were concluded to be primarily due to the illumination, since daylight accidents were relatively unchanged. Other threats to validity were checked, including changes in pedestrian and vehicle flow, weather differences, and national accident trends. None of these showed any effect on the results. [51]

A study was conducted in Philadelphia to assess the impacts of installing improved lighting at seven sites. [52] The impacts were evaluated on the basis of behavior as measured for 728 pedestrians and 191 drivers at the seven study sites and seven control sites. The study sites were high accident locations while the control sites were low accident locations. The illumination improvement consisted of 90-watt low-pressure sodium lamps. Each system was controlled by a photocell which 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 factor before and after lighting improvements showed that "Perceived Clothing Brightness," increased significantly on the basis of all comparisons for high accident 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. [52]

SIGNALIZATION

Signals designed to direct and protect the pedestrian at crossings are widely employed. Also included in this discussion is the effect of signalized intersections without special pedestrian signals.

A study of 30 locations in Tokyo where pedestrian activated signals were installed showed accidents being reduced by 37.5 percent. [43] Little difference was noted in the severity of accidents between the before and after periods. The effective range of the impact seems to be between 25 and 50 meters on either side of the signal. The pedestrian activated signals were found to be much more effective in reducing night accidents than daylight accidents. Rear-end vehicular accidents, which are usually expected to increase after signalization, decreased by 12 percent.

Several behavioral studies of pedestrian signals have been conducted in the United States. Most have concluded pedestrian observance to be very poor. A study was made to compare pedestrian crossing behavior at sites with and without standard pedestrian signals. [53] Observers noted specific behaviors twice on different days. A total of 24 sites in Detroit, Michigan, were analyzed, 12 of which had pedestrian signals. Over 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, N.Y., noted the change occurring with an installation of a pedestrian signal. [54] A before/after accident analysis was also performed on 11 additional sites at which pedestrian signals had been installed. Neither the behavioral analysis nor the accident analysis showed any significant difference between the before and after periods.

As part of a behavioral analysis of a variety of intersections in Washington, D.C., and San Francisco and Oakland, California [29], observations were made of observance of 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 appears from this analysis between flashing and steady "WALK" signals in terms of pedestrian usage of the cycle. A very large portion of the users pay little, if any, attention to the pedestrian signal.

This same study [29] 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.

A study was made in Massachusetts of the relative behavior of pedestrians at intersections with flashing and solid "WALK" segments of the pedestrian signals. [55] 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 to 51 percent who did so at the sites with a steady "WALK" indication. The percent 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.

A variety of pedestrian signals are employed in Great Britain and other European countries. [56-59] Studies of their relative effectiveness have been conducted. The effectiveness of these has been varied, and the study results cannot be generalized.

An areawide centralized computer-controlled signal system was installed in West London. The impact on pedestrian safety and other impacts were studied. [60] A significant 5-percent reduction in pedestrian accidents occurred in the experimental area while a 20-percent increase in pedestrian accidents occurred in a comparison (control) area.

More recent studies in the U.S. and Israel have been successful in better quantifying the effects of pedestrian signals and signal timing on pedestrian accidents. The most comprehensive study was conducted in 1982 by Zegeer, Opiela, and Cynecki for FHWA. [61] The study involved the collection and analysis of pedestrian accidents, traffic and pedestrian volume, signal timing, roadway geometrics, and other data at 1,297 intersections (2,081 total pedestrian accidents) in 15 U.S. cities. All intersections had traffic signals, and the following were the pedestrian signal schemes which existed: [61, 62]

- 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 pedestrians' path. These represented 658 (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 diagonally across the street. There were 109 intersections (8.4 percent) in the data base with sample size.

- 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 (1.7 percent) had one of these timing patterns.

- No pedestrian signals (i.e. traffic signals only) were present at 508 (39.2 percent) of the sample intersections.

The study also found that the factors significantly related to increased pedestrian accidents include higher pedestrian and traffic volumes, street operation (two-way streets have higher pedestrian accidents than one-way streets), wider streets, higher bus use, greater percent turning movements. The presence of concurrently-timed pedestrian signals had no significant effect on pedestrian accidents, when compared to 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 carefully 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 17. [61,62]

Some of the reasons given by the authors for the possible lack of effectiveness of concurrent signal timing include: [61,62]

Table 17. Summary of effects of pedestrian signal timing on pedestrian accidents.

Comparison	Dependent Variable	Adjusted Means (Sample Sizes in Parenthesis)	Control Variables	Significant Difference (at the 0.05 level)	Level of Significance
1. All Ped. Signal Alternatives	A. Mean Pedestrian Accidents 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 Accidents 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 Accidents 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 Accidents 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 Accidents 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 Accidents 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 Accidents 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 Accidents 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: Reference 61.

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

- The false sense of security which some pedestrians 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 and respect exists by many pedestrians for pedestrian signals in general in many of the 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 only 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 along with their effectiveness and need at a given location. The authors also mention that there is a real need for pedestrian signals at some signalized locations (e.g., within established school crossings, where vehicle signals are not visible to pedestrians) as discussed in the Manual on Uniform Traffic Control Devices. [63]

In a 1987 study in Israel by Zaidel and Hocherman [64] pedestrian accidents 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 exclusive timed pedestrian interval, and no pedestrian control. Numerous control variables were collected for use in the analysis.

A total of 1,310 pedestrian accidents and 5,132 vehicle accidents 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 accidents and no effect on vehicle injury accidents, particularly where vehicle volumes were relatively low (i.e. less than 18,000 vehicles per day). Exclusive-timed pedestrian signals showed evidence of accident reduction where high vehicle and pedestrian volumes existed. [64]

A 1984 study by Robertson and Carter [5] 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 accidents, a delay analysis, and a benefit/cost analysis. The authors concluded that pedestrian signal indications appear to reduce pedestrian accidents at some intersections, have little or no effect at others, and even increase such accidents at other intersections. Also, while the presence of pedestrian signals did not appear to 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. [5]

SIGNING

A variety of signs are used by state and local agencies which relate to pedestrians. Examples of regulatory signs include "PEDESTRIANS PROHIBITED," "WALK ON LEFT FACING TRAFFIC," "NO HITCHHIKING," and others. Warning signs directed at pedestrians include the 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" [63] and supplemented by the "Traffic Control Devices Handbook." [65] 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. [37]

RIGHT-TURN-ON-RED

The effects of right-turn-on-red (RTOR) on pedestrian safety was investigated in a 1981 study by Preusser et. al. [66] Based on all pedestrian accidents, right-turn accidents increased from 1.47 to 2.28 at signalized intersections after RTOR went into effect. A common RTOR pedestrian accident 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 accidents involving pedestrians and bicyclists are illustrated in figure 17. The study concluded that there was a small but clear safety problem for pedestrians due to RTOR. [66]

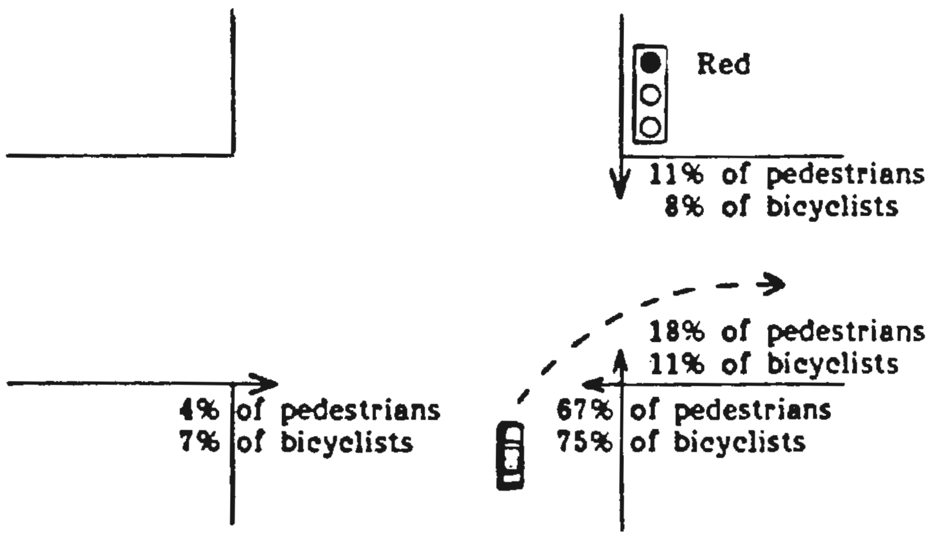


Figure 17. Directional movements of pedestrians and bicyclists involved in right-turn-on-red accidents.

Source: Reference 66.

A 1985 study by Zegeer and Cynecki [67] 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, D.C., 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, about 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 18. [67]

According to the study results [67] approximately 23.4 percent of all RTOR violations result in a conflict with a pedestrian. These types of conflicts are summarized in table 19 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 which 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 at least in part to the greater opportunity for a rolling stop or no stop (due to typically lower side street volumes and pedestrian activity at stop-sign locations compared to signalized locations). Based on locational factors, 30 candidate countermeasures were developed to improve pedestrian safety relative to RTOR. [67]

A follow-up field evaluation was conducted of promising countermeasures for RTOR pedestrian accidents in a later effort by Zegeer and Cynecki. [67] Seven countermeasures were tested at 34 intersection approaches in six U.S. cities based on motorist violations and pedestrian-vehicle conflicts related to RTOR and RTOG (right-turn on green). The results showed that the NTOR sign with the red ball (see figure 18) 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 (which is actuated only during critical times, such as during school crossing times) was slightly more effective, although considerably more costly than traditional signs. 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 18. [67]

Table 18. Violations and conflicts related to right-turn-on-red.

	Total Number of Hours	Number of Approaches	Number of RTOR Maneuver (No. per Hour)	Number of RTOR Conflicts (Per Hour)		Percent 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	Pedestrian	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: Reference 67.

Table 19. Summary of traffic conflicts related to right-turn-on-red pedestrian accidents.

Type of Sites	Hours of Data Collected	Type of Conflict	Near Crosswalk			Far Crosswalk			Total Crosswalks		
			Conflicts	Interactions	Totals	Conflicts	Interactions	Totals	Conflicts	Interactions	Totals
RTOR – Allowed	496.7	RTOG	118 (0.24)	161 (0.32)	279 (0.56)	5,018 (10.10)	2,404 (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: Reference 67.

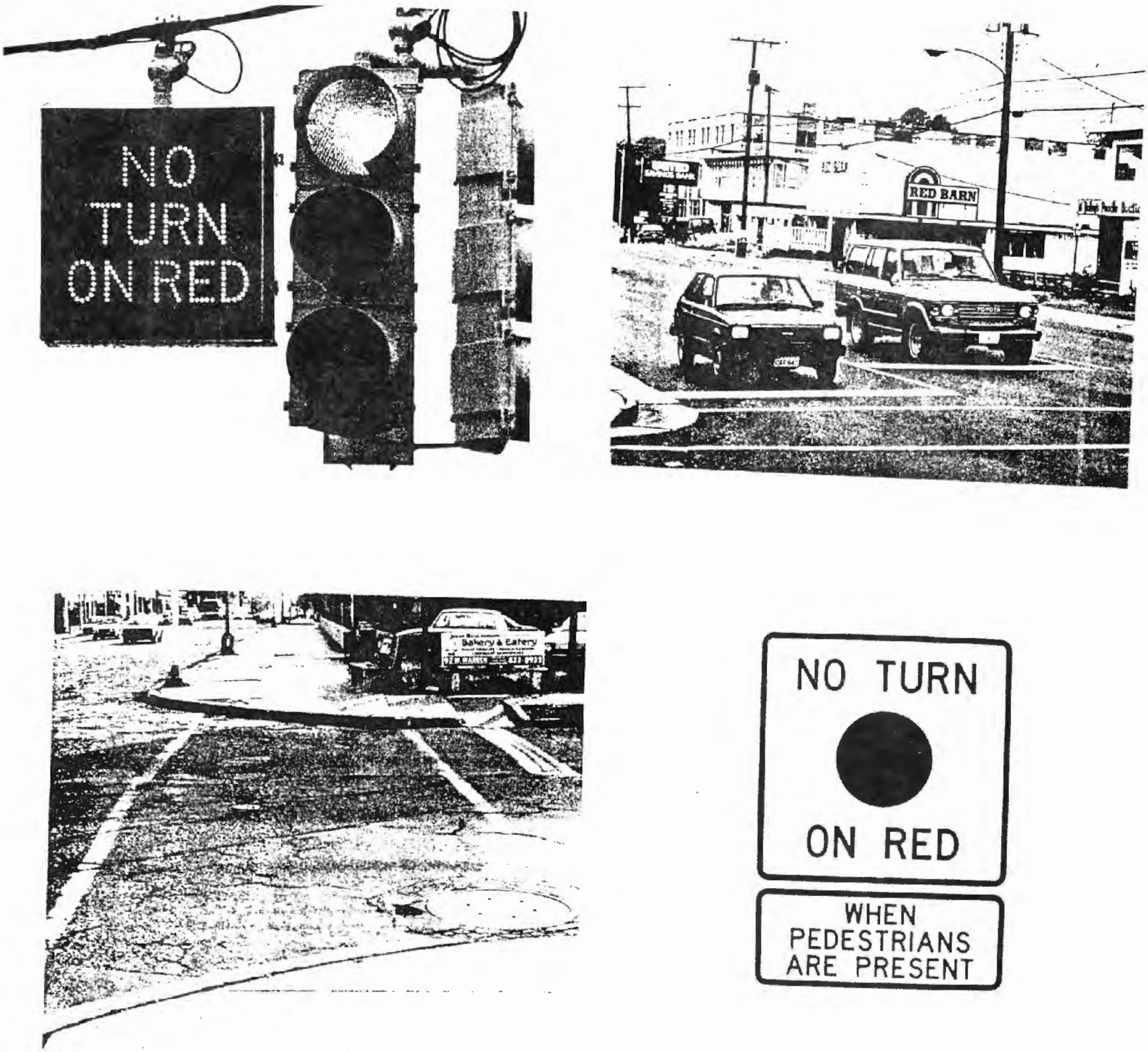


Figure 18. Examples of potential countermeasures related to right-turn-on-red pedestrian accidents.

Source: Reference 67.

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 1983 study by Zegeer et. al. [62] developed and field 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 (i.e. Washington, Milwaukee, and three Michigan cities -- Detroit, Ann Arbor, and Saginaw). The Z-test for proportions was used to evaluate the effects of each device on pedestrian violations and conflicts. The results revealed that: [62]

- A red and white triangular (36 in. by 36 in. by 36 in.) "YIELD TO PEDESTRIAN WHEN TURNING" sign 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 accidents involving turning vehicles.

- A "PEDESTRIANS WATCH FOR TURNING VEHICLES" warning sign with black letters on a yellow background was also found to significantly reduce vehicle turning accidents involving pedestrians. It was also recommended as an optional sign to be incorporated into the MUTCD.

- A signal explanation sign had no effect at two sites (i.e., in Saginaw where pedestrian violations were not a problem prior to installing the signs) but reduced pedestrian violations and turning conflicts at two other sites (i.e., in Washington, D.C. where pedestrian violations had been a serious problem).

- 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 which run red lights). The signal message resulted in reduced pedestrian signal violations and also decreased turning-related conflicts. This special message was recommended as an addition to the MUTCD for use only with a high number of pedestrian accidents (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. [5] As part of the Zegeer et. al. study, [62] several devices were developed as alternatives to the flashing DON'T WALK interval. Such alternatives include: [62]

- a three-read 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 reduction in pedestrian violations and conflicts (compared to the flashing DON'T WALK) at three of four test sites. Further testing of this message was recommended for possible adoption nationwide in the future.

- 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 signal alternatives are given in figure 19.

PEDESTRIAN REFUGE AREAS

Pedestrian refuge areas between traffic lanes offer a place where pedestrians may pause while crossing a multi-lane street. These areas may be delineated by markings on the roadway or raised above the surface of the street. Some pedestrians are not able to complete the crossing of an intersection within the signal time provided. Running across intersections has been shown to be a common cause of pedestrian accidents.

The use of central refuge islands, or medians, for pedestrians is often proposed but seldom studied. One available analysis reports before/after comparisons of personal injury accidents at sites where pedestrian refuges were installed. [68] "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 hatch markings. The accident records for comparable before and after periods were subjected to statistical tests to determine significant changes. It was concluded the provision of refuges, which are often thought of as being a facility for pedestrians, was found, somewhat surprisingly, to reduce vehicle accidents but increase pedestrian accidents. Significant accident reduction at intersections could be identified only for those cases where the purpose of the refuge was very clearly established. Examples of such purposes were: provision of the refuge specifically on the basis of safety, reinforcement of the refuge with hatch markings, or provision of the refuge for channelization or vehicular traffic. [68]

Figure 19. Examples of innovative pedestrian signalization alternatives.

Source: Reference 62.

For single refuges not at junctions, it was possible to identify significant reductions in vehicle accidents when the refuges were fitted with fully illuminated bollards. It was possible to identify overall significant reductions in accidents where the refuges were provided in the vicinity of pedestrian generators. [68]

PROVISIONS FOR THE HANDICAPPED PEDESTRIAN

A study of handicapped pedestrian accidents in Atlanta, Georgia [15], led to conclusions regarding general countermeasures for reducing elderly and handicapped pedestrian accidents. A total of 989 possible pedestrian accident reports were submitted to a telephone interview process to determine information not on the city accident or hospital records. Field reconnaissance was made of the accident sites. The number of accidents in the sample having the possibility of being impacted by each of the following countermeasures is noted below: [15]

- Design and operate pedestrian facilities to accommodate the handicapped: 5 accidents.

- Design vehicular traffic facilities for the safety of vehicular traffic and pedestrian traffic: 17 accidents.

- Provide an appropriate delineation or separation between pedestrian areas and nonpedestrian areas: 5 accidents.

- Use traffic engineering countermeasures to insure each street is used for its intended purpose: 2 accidents.

- Provide a safer school trip for young pedestrians: 3 accidents.

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

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

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

- Prosecute drivers for repeated violations of traffic regulations: 14 accidents.

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

- Remove objects which obstruct visibility between drivers and pedestrians: 3 accidents.

- Provide information to the public about the dangers associated with the overconsumption of alcoholic beverages: 1 accident.

In addition to those accidents analyzed for Atlanta, the same study [15] sampled reactions of handicapped people living in five U.S. cities to environmental hazards. Four elements of the pedestrian system were identified which accounted for 81 percent of the accidents they reported:

Walks and Corridors	36%
Streets and Crosswalks	17%
Curbs and Curb Ramps	11%
Stairs	17%

Blind Pedestrian Countermeasures

One of the major hazards experienced by blind people is crossing the street. A nonvisual system to assist the blind has two distinct aspects. [69]

- Making the blind person aware of the special facility in order for it to be properly used.

- Conveying to the blind pedestrian the information normally displayed by visual means.

A series of interviews with 10 blind persons in Washington, D.C. [69], showed the need for careful consideration of this disability when widening streets and intersections, or accomplishing other physical changes. Major recommendations by those interviewed included:

- Wider pavements and crosswalks.

- Greater segregation of 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.

Particular problems noted for blind pedestrians at signalized crossings are the registering of pedestrian demand at actuated signals and signaling the pedestrian clearance interval. Conveying signal information to the blind pedestrian has been achieved by both tactile and audible means. These may be used to provide both information regarding signal status and crossing guidance. [69,70] In Japan [71], sound equipment has been used to generate bird calls or little songs to indicate signal status. These have been found least disturbing to others and can be installed so as to vary loudness with ambient sound levels.

Combinations of buzzers and beepers have been used in Australia. [72] These have been combined with a vibrator which the blind pedestrian 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 blind pedestrians uncovered a pronounced mistrust of mechanical aids at intersections, based upon experience with the vibrating signal. Several new designs were tested using blind pedestrian behavior for the evaluation. 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 adjustable to the ambient noise level. [72]

An evaluation of audible pedestrian signals was conducted in a 1988 study by the San Diego Association of Governments. [73] The study estimated that as many as 100 cities in the United States use audible pedestrian signals, and they were reported to be used in Australia, Japan, Canada, Great Britain and other countries in Europe. One of the aspects of the study involved a review of pedestrian accidents at 60 intersections in San Diego, California, where pedestrian signals had been installed. No differences were found in the number of pedestrian accidents before and after installation of the audible devices. Drivers were at fault in more than half of the pedestrian accidents, and most of the accidents occurred between 9 A.M. and 6 P.M. in clear weather with the vehicle going straight. In spite of their lack of a measurable effect on pedestrian accidents, the authors developed specific criteria for their use. [73]

Tactile strips have been employed to assist the blind pedestrian in crossing the street. In San Diego, tests [74] with blind pedestrians at three sites, have shown tactile guide strips made of epoxy cement and pea gravel to be effective and durable under sustained traffic and variable weather conditions. There was no evidence the raised strip (4 in wide with 0.25-in gravel) has caused any subsidiary problems for motorists, bicyclists, or other pedestrians. It was cautioned these 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.

Another device for the blind, being tested in Japan, [71] uses a radio receiver carried by the blind pedestrian to receive coded signals from the signal installation regarding the traffic signal status. For the color blind, red and green are most often difficult to distinguish, so blue has been included in the green signal, or replaced it, for easier identification.

Deaf Pedestrian Countermeasures

A survey of 60 deaf persons in Washington, D.C., [70] emphasized the visual dimension of travel on foot. 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.

Recent Guides and Manuals

In recent years several reports, guides, and manuals have been written which provide guidance on the selection and use of facilities for pedestrians with physical or mental impairments. For example, the 1987 publication "Accessibility for Elderly and Handicapped Pedestrians -- A Manual for Cities," was written [75] to provide guidance to planners and other officials in the development of a program for improved accessibility. The manual includes information on planning, programming, and design of such facilities and also provides example problems and solutions along with a checklist which 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. [75]

Several other FHWA reports have also been published regarding efforts to better accommodate elderly and handicapped pedestrians in U.S. cities. They involve the priority accessible network (PAN) approach, which is based on planning principles which are designed to provide for the special needs of these pedestrian populations. [76,77] The goals of the PAN approach are to:

- Provide continuous accessibility to all desired pedestrian destinations

- Provide a transportation network which is tailored to the special needs of all handicapped users (e.g. wheelchair users, blind)

- Efficiently use resources so the highest priority routes are constructed first

Examples of cities where the PAN process has been applied successfully and documented are Seattle, Washington; New Orleans, Louisiana; and Baltimore, Maryland. [76, 77, 78] 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. [78]

BUS STOP LOCATION

The bus stop accident has been noted as a type into which 2 percent of the pedestrian accidents in urban areas may be classified. In rural areas, the school bus stop related pedestrian accident was identified in 3 percent of the accidents. The countermeasure proposed for the urban type accident involved bus stop relocation to the far side of the intersections so pedestrians would cross in back of the bus, instead of in front and, therefore, be seen by, and see, oncoming traffic. In an attempt to determine the effect of relocation on pedestrian crossing behavior, two studies before and after bus stop relocation were conducted. One was a site in Miami, Fla., 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, California, on a two-way, four-lane street intersecting with a one-way, three-lane street at a signalized location which included pedestrian signals. [41] The relocation of the bus stops to the far side eliminated the undesired crossing behavior, whereas in the original condition, half those crossing after disembarking were doing so in the undesired manner.

An analysis of pedestrian accidents in Sweden [79] found school bus stops were not being located with the greatest care regarding pedestrian safety factors. 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 United States study of school trip accidents by Reiss [80] investigated the location of school bus stops and developed guidelines for the planning, routing, and scheduling of school buses.

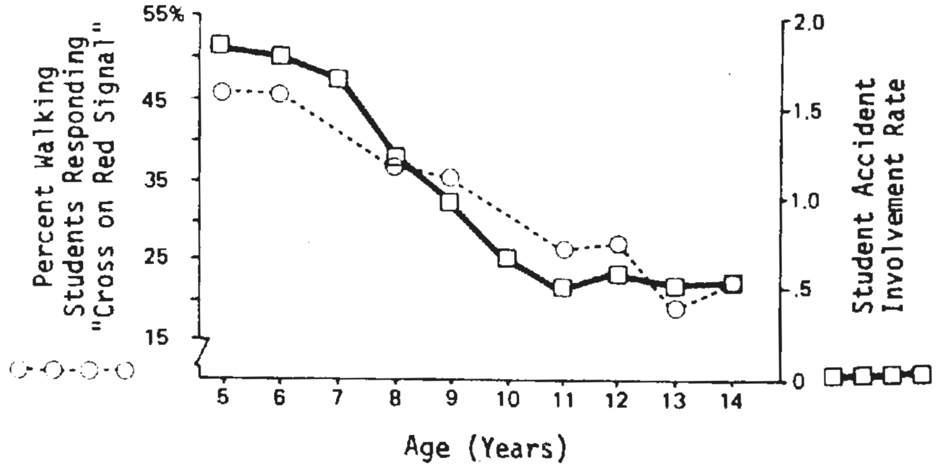
SCHOOL TRIP SAFETY

Pedestrian safety dealing with the school trip has been given much attention by 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 accidents in 1,335 cities in the United States [81] revealed out of 220 child pedestrian deaths reported for 1967, 25.4 percent occurred as children were enroute to or from school. Out of 1,854 child pedestrian injuries, 18.6 percent took place enroute to or from school. On the basis of this, a national estimate was made of 500 fatalities and 11,000 injuries resulting from the school walk trip. The highest proportion of these occur at ages 12 to 14. This is the junior high school age where 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.

An intensive study of the school trip was conducted at sites in New York, Maryland, and Virginia. [80] Surveys were made of students and drivers. Accidents for the sites 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.

The four sites studied employed school warning and speed limit signs. Figure 20 compares the student accident involvement rate with a measure of traffic signal knowledge. The distribution with age differs from the previously noted study. [80] School trip walking accidents were found to represent between 10 and 20 percent of the annual young pedestrian accidents (10,000 to 20,000) in the United States. Significantly more of the younger students than the older ones indicated they are unaware of or do not discriminate between



$$\text{Student Accident Involvement Rate} = \frac{\text{Percent Student Accidents}}{\text{Percent Student Population}}$$

Figure 20. Comparison of national students' accident involvement rate and surveyed students' traffic signal knowledge.

Source: Reference 80.

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.

An evaluation was conducted of the "25 MPH WHEN FLASHING" sign at 48 Kentucky school zone locations in a 1979 study by Zegeer and Deen. [82] Vehicle speeds overall were an average of only 3.6 mph less during the flashing periods compared to the non-flashing periods. Speed reductions of 10 mph or more were found at only two sites, and only 18 percent of all motorists complied with the 25 mph flashing limit. The regulatory flashing signs were generally not considered to be effective in reducing vehicle speeds to 25 mph, as illustrated in figure 21. At rural school zone locations, the 25 mph flashers during school periods resulted in an increase in speed variance and thus, they created the potential for increased rear-end vehicle crashes. [82] The presence of crossing guards and/or police speed enforcement contributed to improved speed compliance.

ALTERNATIVE SIGNALIZATION FOR SCHOOL CROSSINGS

A school pedestrian signal design concept has been proposed using stop signs on the minor approach and traffic signals on the major approach. Many 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 disabled where full signalization was not warranted.

A 1977 study by Petzold [29] was directed at identifying and evaluating alternatives to full signalization at school pedestrian crossings. These crossings are located at the intersection of a high-volume arterial street and a low-volume residential street where adequate gaps do not exist to allow pedestrians to cross the arterial street safely without an unreasonable time 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 cities in the United States: [29]

- Sign and Stop Sign - 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.

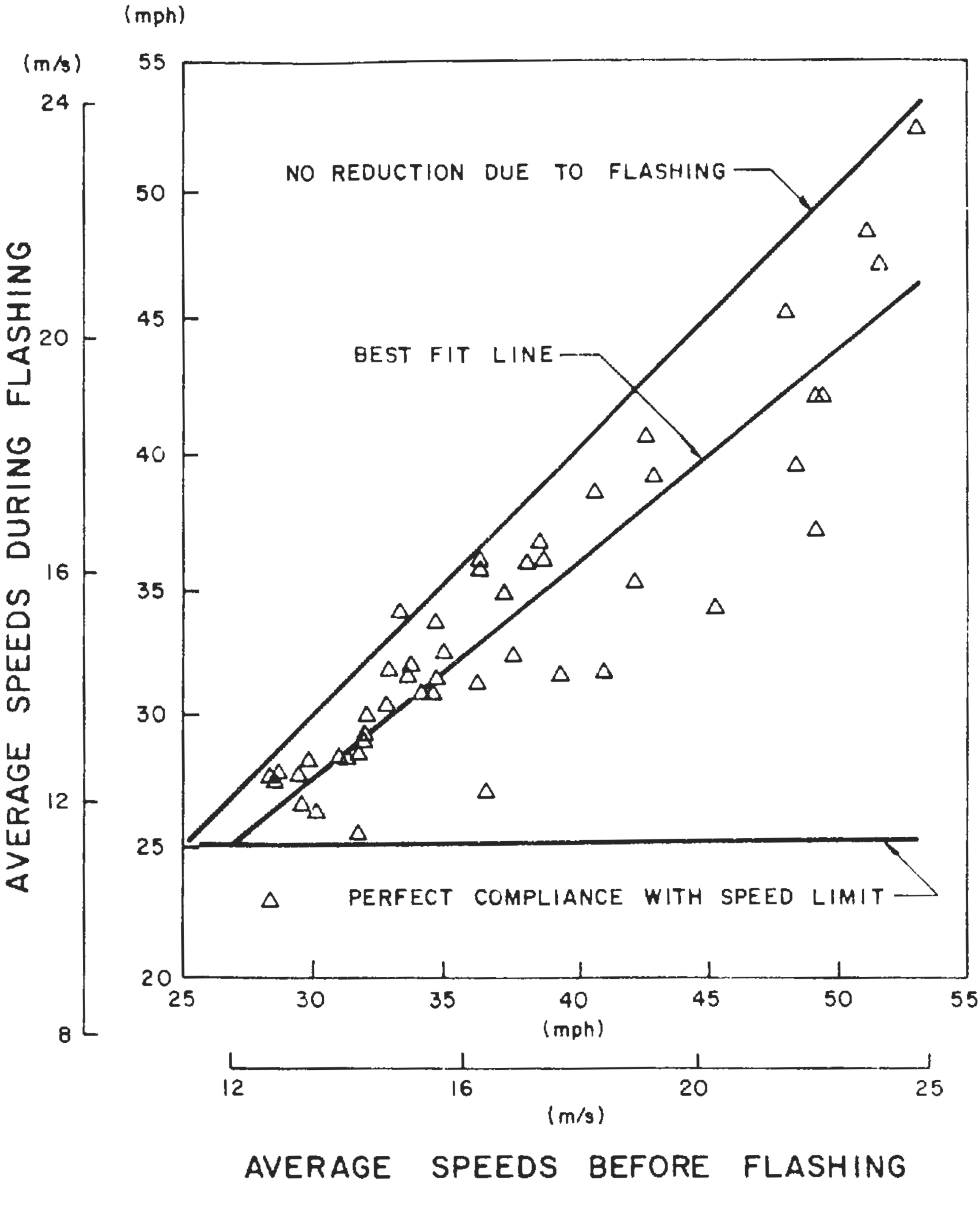


Figure 21. Effects of regulatory school flashers on vehicle speeds before and during flashing.

Source: Reference 82.

- 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 the local residential street.

The five school pedestrian crossing designs were evaluated in a time series, matched experimental-control site experimental 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. [29]

Based on the data analysis and observations at each school pedestrian crossing design, the following are the advantages and disadvantages as compared to full signalization:

ADVANTAGES: [29]

- Increased pedestrian compliance to 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: [29]

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

- Increase in vehicle angle conflicts, but nonsignificantly.

Based on the comparison between each school pedestrian crossing design and its fully signalized control site, the following conclusions were developed:

- The sign and stop sign design revealed many undesirable characteristics especially concerning vehicle compliance to the flashing red beacon. It was concluded full signalization is more desirable than the sign 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 is 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 sign and stop sign, and 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 (Sg-44), and flashing green signal and stop sign designs. [29]

REFLECTORIZATION APPLIED TO PEDESTRIANS

Research on visibility has identified reflectorization as a highly effective means of improving visibility. [83,84,85] In a survey of safety specialists, [80] reflectorization countermeasures were identified as having the highest overall rating as a means for reducing school children accidents occurring during darkness. The key issue is attaining proper usage. A study of reflectorization treatments [86] showed a person dressed in black wearing a thumb-sized retroreflective tag is detected at longer distances than a person completely dressed in white. Maintaining the retroreflective power of the tag was also shown to be important to achieve good results, thus highlighting the need for regular replacement or cleaning of the tag.

A 1984 study by Blomberg et. al. [87] 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 to pedestrians with dangle tags, a flashlight, jogger's vest, and rings (retroreflective material on head band, wrist bands, belt, and ankle bands). On average, the flashlight was detected by a driver at 1,379 feet, which was more than 600 feet further away than rings (which were the next best target at (760 feet) and jogging vest (744 feet), as shown in figure 22. The average detection distance of the baseline pedestrian was 224 feet. [87]

As an engineering countermeasure, retroreflective materials are used for roadway markings such as crosswalks, stop lines, and lane markings as well as on the clothing of pedestrians. These materials reflect light from vehicle headlights and from roadway illumination. Reflectorization has been shown to increase the visibility of a pedestrian by a factor of five.

ONE-WAY STREETS AS A PEDESTRIAN ACCIDENT COUNTERMEASURE

A comprehensive study of pedestrian and bicycle accidents in several Canadian cities [11] found lower accident experience on the one-way streets in the core of a city than on the two-way streets. Thus, conversion to a one-way street system may also be a relatively low-cost pedestrian countermeasure having as high as 40- to 60-percent effectiveness on amendable accidents. However, the applicable accidents were estimated to represent only about 10 percent of the city total.

A study in Manhattan, New York, [2] highlighted the aspects of one-way street grids which tend to provide safer traffic operation. 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 accidents, occurring over a 5-year period in a 8-block by 4-block grid, were studied. Almost 70 percent of these occurred at intersections. Only five fatalities occurred in the area during the 5 years. These all occurred to males over the age of 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 crossings on the turning conflict side of the intersection accounted for 69.7 percent of the intersection accidents. This total consisted of 44.7 percent turning accidents, 17.5 percent straight accidents, and 7.5 percent backup accidents. Thus, the 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 nonturning conflict side. [2]

Short vehicle and pedestrian counts were taken at the intersections in the study area. While the conclusions were not statistically significant, the results raise some useful

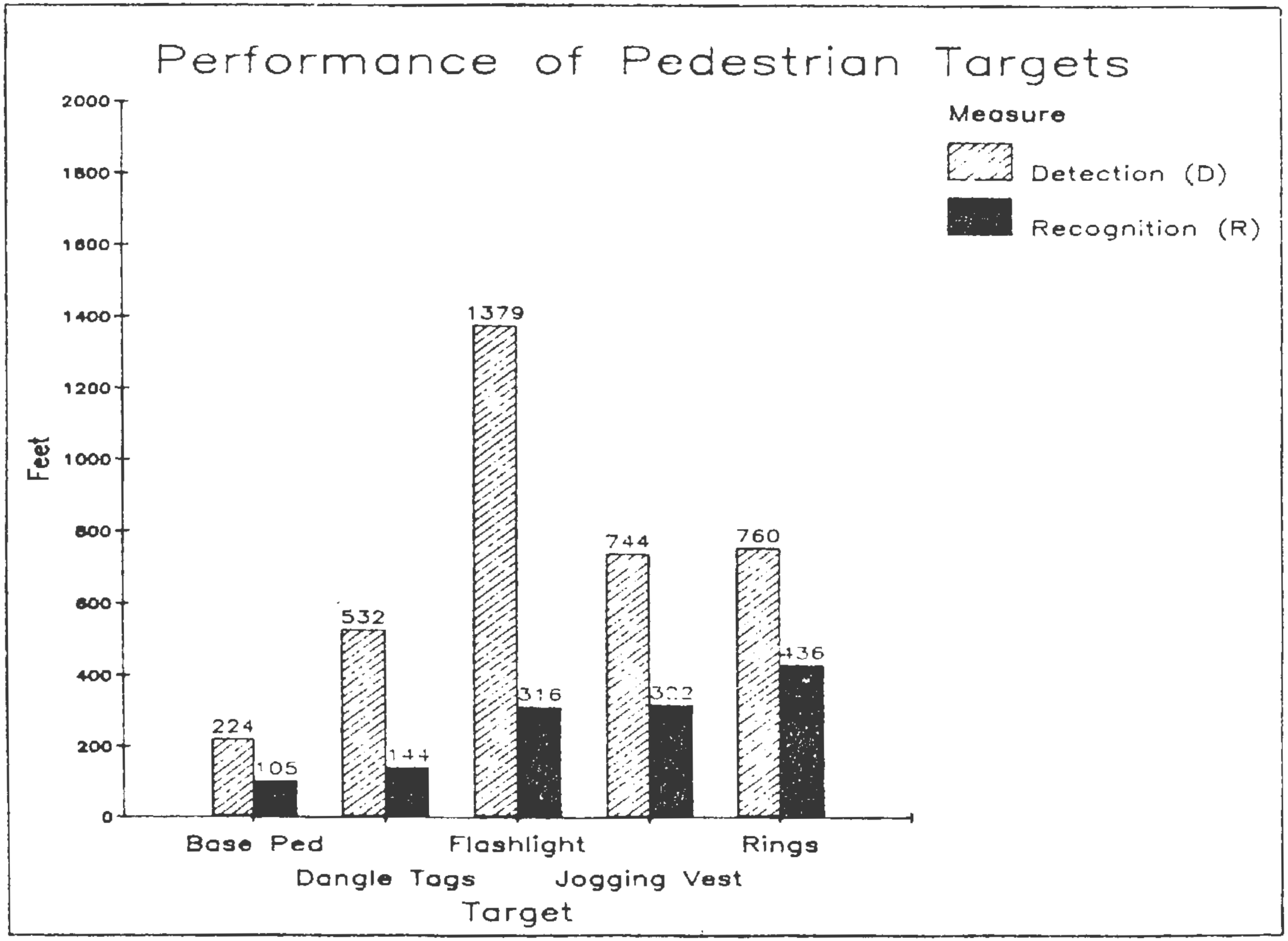


Figure 22. Detection and recognition distance of pedestrian targets.

Source: Reference 87.

perspectives. Although vehicle turning movements averaged only 14 percent of the total intersection volume, turning accidents were almost 45 percent of the total, being overrepresented by a factor of over six. Backing was even more overrepresented in the accidents, being 1 percent of the traffic movements and 11 percent of the accidents. Left-turn accidents exceeded right turn accidents by a ratio of two to one. The front left vehicle post was suggested as a factor, causing blockage of the driver's view of a critical part of the crosswalk area. [2]

PEDESTRIAN OVERPASSES

An analysis was made of reported pedestrian accidents for 6 months before and 6 months after the installation of pedestrian overpasses at 31 locations in Tokyo, Japan. [43] The overall results are shown in table 20. The table shows data for 200 meter sections and 100 meter sections on either side of each site. The related accidents decreased substantially after overpass installation, but nonrelated accidents (not defined) increased by 23 percent in the 200 meter sections. The greatest impact was within 50 meters of either side of the structures. Another result was a greater reduction in daylight accidents than in those occurring at night.

The effectiveness of pedestrian overpasses depends largely on the amount of use by pedestrians. A study by Moore and Older [88] found that their use depended on walking distances and convenience of the 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 23, the study found that about 95 percent of pedestrians will use an overpass if the walking time in using the overpass were the same as crossing at street level (i.e. R=1). However, if an overpass takes 50 percent longer than crossing at street level (R=1.5), almost nobody will use the overpass. Usage of pedestrian underpasses (subway) was not as high as overpasses for similar values of R.

Problems have also been identified relative to pedestrians' use of overpasses. A panel of disabled persons was asked to comment upon problems after using three pedestrian overpasses in San Francisco, California [89] The major elements identified as creating a barrier or hazard to the disabled user included:

- Lack of adequate, or no railings to protect pedestrians from dropoffs on the bridge approaches.

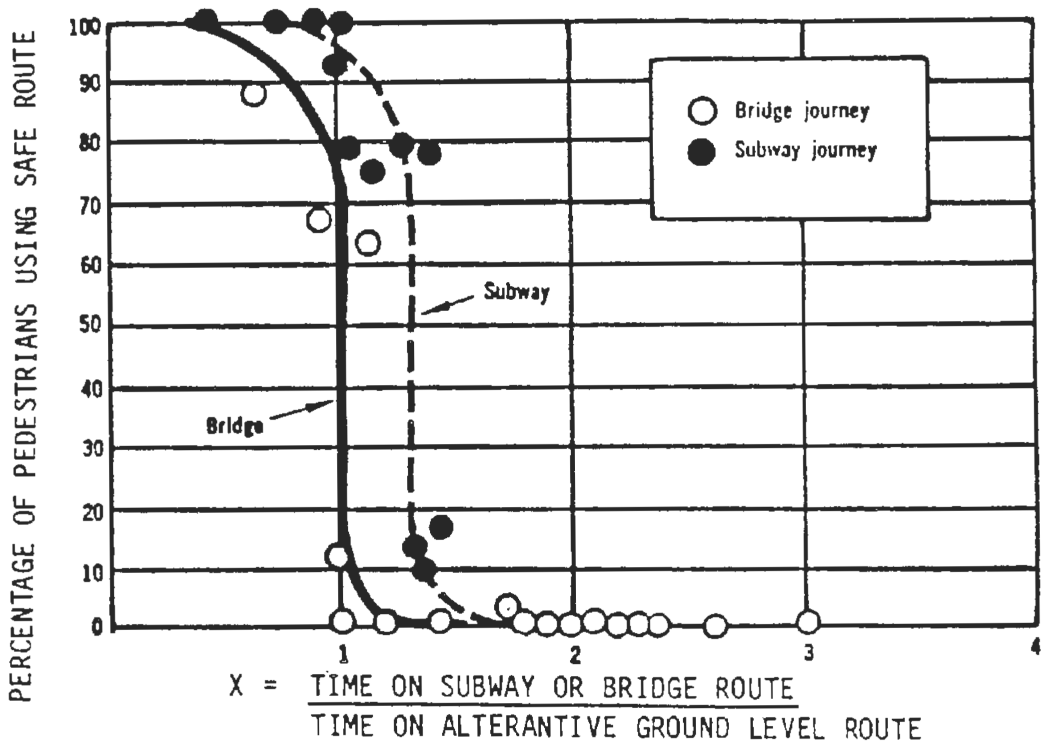


Figure 23. Expected usage rate of pedestrian bridges and underpasses.

Source: Reference 88.

- 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 down bicyclists) which create a barrier to the blind and wheelchair users.

- Lack of sound screening on the bridge to permit blind people to hear oncoming pedestrian traffic, and otherwise more easily detect direction and avoid potential conflicts.

A 1980 study by Templer and Wineman [90] investigated the feasibility of accommodating physically handicapped pedestrians on existing overpass and underpass structures. A

Table 20. Accident effects of pedestrian overpasses. (Tokyo, Japan).

Type of Accidents	Accidents per Structure (6 months before and after)					
	200 Meter Sections			100 Meter Sections		
	Before	After	Reduction	Before	After	Reduction
Related Accidents	2.16	0.32	85.1%	1.81	0.16	91.1%
Nonrelated Accidents	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: Reference 43.

review of 124 crossing structures revealed that 86 percent of them had at least one major barrier to their access by physically handicapped. Some of the most common access barriers included: [90]

- Stairs only (i.e. no ramps for wheelchair users) leading to the overpass or underpass

- Ramp or pathway to ramp which is too long and steep

- Physical barriers along the access paths on structure

- Sidewalk on the structure which is too narrow

- Cross slope on the ramp which is too steep

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

MOTOR VEHICLE RESTRICTION FROM PEDESTRIAN ORIENTED SPACE

Techniques have been employed to restrict motor vehicle use of a street or area to provide a pedestrian oriented atmosphere. These techniques may involve:

- Complete street or area closure on a full-time basis (includes creation of "auto free zones").

- Closing during specific time periods (includes creating play areas for children).

- Limiting street use to authorized and local vehicles only (may include use by delivery, refuse collection, emergency, mass transit, and/or for-hire vehicles).

- Use of controls to discourage motor vehicle use and/or reduce speeds (includes speed bumps, rumble strips and cul-de-sac arrangements).

Residential Yards

In the Netherlands, an experiment has been proceeding on the concept of a "residential yard." [91] These are areas where the physical and visual treatments of the public right-of-way create a pedestrian oriented area. Local traffic only is allowed to use the roadway on the basis of being the "intruder." The residential yard's function differs from a conventionally designed residential street. The same paved area is used 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. In the Netherlands, the most outstanding new traffic regulations applying in residential yards are: [91]

- 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.

- Pedestrians and children must not unnecessarily obstruct the progress of drivers.

- 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.

The effectiveness of the residential yard was evaluated in two neighborhoods of Delft, Netherlands, through the use of a conflicts analysis. One neighborhood included a conventional street system and the other included residential yards. Conflicts were used as a surrogate for accidents, although the validity of this was not established. Results indicated: [1]

- Residential yards did not produce less serious conflicts than the conventional street.

- Wheeled traffic had priority on conventional streets and parents supervised young children more in these locations resulting in fewer serious conflicts than in the residential yards.

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 to take place in the roadway. A series of interview studies were performed at

20 sites in Philadelphia, and New York City. The interviews sought behavioral and opinion data from users, residents, merchants, supervisory play street staff, and city officials regarding play streets. [92]

The 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 number of children hit by cars. Eighty-eight percent noted no problems to them due to the 1 p.m. to 8 p.m. street closure. Only 12 percent of the play supervisors interviewed perceived a safety benefit. It was recommended that signing and barricades be used judiciously to control vehicular access to a play street. 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. [92] No evaluations of the safety benefits of play streets were conducted.

A study of the effect of recreational facilities on child pedestrian accidents was made in Philadelphia. [93] Traffic accident records were analyzed for 2 years prior to, 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 accidents involving children ages 5 to 14 for the combined areas after the opening of these facilities. Outside the seven areas a city-wide trend was an increase in child pedestrian accidents. The greatest impact was noted within a radius of one-quarter mile of each facility. This occurred even though a greater volume of children were using the facilities and crossing streets going to and from the sites. [93]

Transit Malls - Shared Use of Pedestrian-Oriented Space

Transit malls are being increasingly employed in U.S. cities. Studies were conducted of accidents occurring before and after implementation of transit malls in Philadelphia and Minneapolis [94]

The analysis showed nonpedestrian accidents decreasing sharply on transit malls with no evidence of increases on nearby unimproved streets. Total pedestrian accidents appear stable with an increase relative to exposure rates based on pedestrian and vehicular volumes. Bus-pedestrian conflicts, other than accident, are much higher on transit malls than on unimproved streets. Factors related to pedestrian accidents in Philadelphia include: [94]

- 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 accidents in which pedestrians are at fault.

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

- Inadequate mall design. This includes too narrow roadways and the lack of barriers to discourage jaywalkers.

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

- Construction of bus shelters too far away from crosswalks encourages discharging bus riders to cross the roadway under hazardous situations.

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

- Operational problems may contribute to accidents.

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

As a result of a review of studies involving shared use of pedestrian oriented space [94, 95], it was concluded that schemes which restrict private vehicles from small sections of the roadway but allow all other public service vehicles seem to have only marginal or small positive accident benefits. Other pedestrian measures, such as delay, are improved. The numbers of buses, taxis, and trucks are sufficient to keep the noise levels high.

The overall net gain in accident reduction may be limited and, perhaps, problems at the periphery are more intense.

Areawide Traffic Restriction

Areawide traffic restriction schemes 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 areawide traffic restriction scheme in the center of town. [96] This involved street closings to vehicular traffic, institution of one-way flow on bypass routes, and creation of bus-only streets. Risk was defined as the probability of an accident occurring that would result in personal injury and was predicted from serious traffic conflicts for various types of pedestrian and driver behaviors. Risk for the pedestrian in the restriction area was reduced by 29 percent. Risk for pedestrians on the surrounding streets outside the restriction area (which experienced a 30 percent increase in volume after the restrictions were implemented) increased by 12 percent.

In similar traffic management efforts in London, [97] the impact on accidents of street closures and a few other devices was analyzed for 19 areas. Ten sites showed reductions in pedestrian accidents and two sites remained the same. The overall effect was a pedestrian accident reduction of 24.4 percent, although this was not statistically significant.

SIDEWALKS AND PEDESTRIAN PATHS

Several types of pedestrian walkways have been defined, including: [34, 37]

- Sidewalks - Walkways which 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 which 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 1983 study by Tobey et. al. [45] 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 includes pedestrian volumes times traffic volume) of +2.2. This indicates that accidents 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 to 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 least hazardous where sidewalks are present on both sides of the road.

A later study by Knoblauch in 1987 developed guidelines for sidewalk installation separately for new and existing streets, as given in figure 24. [28]

EDUCATION CONSIDERATIONS

Numerous studies have been conducted to evaluate the effects of safer pedestrian behavior through education. For example, the NHTSA film on WILLIE WHISTLE [98] is aimed at grades K through 3, and teaches children the correct behavior to safely cross streets. It is 7 minutes long and contains line action plus animation. It is directed at reducing midblock "dart-out" or "dash" accidents by teaching children to always 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 found to reduce dart and dash accidents by over 30 percent among 4 to 6-year old children, as illustrated in figure 25. Non-midblock pedestrian accidents were used as a control group, since they were not considered to be affected by the WILLIE WHISTLE program. Accidents in this group remained relatively unchanged, suggesting that the drop in midblock pedestrian accidents was the result of the educational messages and not a general decline in pedestrian accidents. [98]

A 15-minute follow-up educational film called "AND KEEP ON LOOKING" [99] was later developed by NHTSA to convey street crossing advice to older children (grades 4 through 7) such as crossing busy streets, safety in parking lots, and crossing at signalized locations. The effectiveness of showing this film was found based on testing in Connecticut, Seattle, and Milwaukee. In a two-year test in Milwaukee of the film's effects on pedestrian-motor vehicle crashes, 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 of children's observed behavior and in Connecticut of retained information after showing the film. [99]

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

- Pittsburgh, Pa. [100] - A short film was shown and discussed with grade school students resulting in improved "looking behavior" but no significant improvement in slowing or stopping before crossing

- Stamford, Conn. [100] - 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

Proposed Minimum Sidewalk Widths

Central Business Districts - Conduct level of service analysis according to method in 1985 Highway Capacity Manual.

Commercial/industrial areas outside a central business district - Minimum 5 feet (1.5 m) wide with 2-foot (0.6 m) planting strip or 6 feet (1.8 m) wide with no planting strip.

Residential areas outside a central business district:

Arterial and collector streets - Minimum 5 feet (1.5 m) with minimum 2-foot (0.6 m) planting strip.

Local Streets:

- Multi-family dwellings and single-family dwellings with densities greater than four dwelling units per acre - Minimum 5 feet (1.5 m) with minimum 2-foot (0.6 m) planting strip.
- Densities up to four dwelling units per acre - Minimum 4 feet (1.2 m) with minimum 2-foot (0.6 m) planting strip.

Land-Use/Roadway Functional Classification/Dwelling Unit	New Urban and Suburban Streets	Existing Urban and Suburban Streets
Commercial & Industrial/ All Streets	Both sides.	Both sides. Every effort should be made to add sidewalks where they do not exist and complete missing links.
Residential/Major Arterials	Both sides.	
Residential/Collectors	Both sides.	Multi-family - both sides. Single-family dwellings - prefer both sides required at least one side.
Residential/Local Streets More than 4 Units Per Acre	Both sides.	Prefer both sides, required at least one side.
1 to 4 Units Per Acre	Prefer both sides; required at least one side.	One side preferred, at least 4-foot (1.2 m) shoulder on both sides required.
Less than 1 Unit Per Acre	One side preferred, shoulder both sides required.	At least 4-foot (1.2 m) shoulder on both sides required.

NOTES:

(1) Any local street within two blocks of a school site that would be on a walking route to school - sidewalk on at least 1 side.

(2) Sidewalks may be omitted on 1 side of new streets where that side clearly cannot be developed and where there are no existing or anticipated uses that would generate pedestrian trips on that side.

(3) Where there are service roads, the sidewalk adjacent to the main road may be eliminated and replaced by a sidewalk adjacent to the service road on the side away from the main road.

(4) For rural roads not likely to serve development, provide a shoulder at least 4 feet (1.2 m) in width, preferably 8 feet (2.4 m) on primary highways. Surface material should provide a stable, mud-free walking surface.

Figure 24. Guidelines for sidewalk installation and minimum width.

Source: Reference 28.

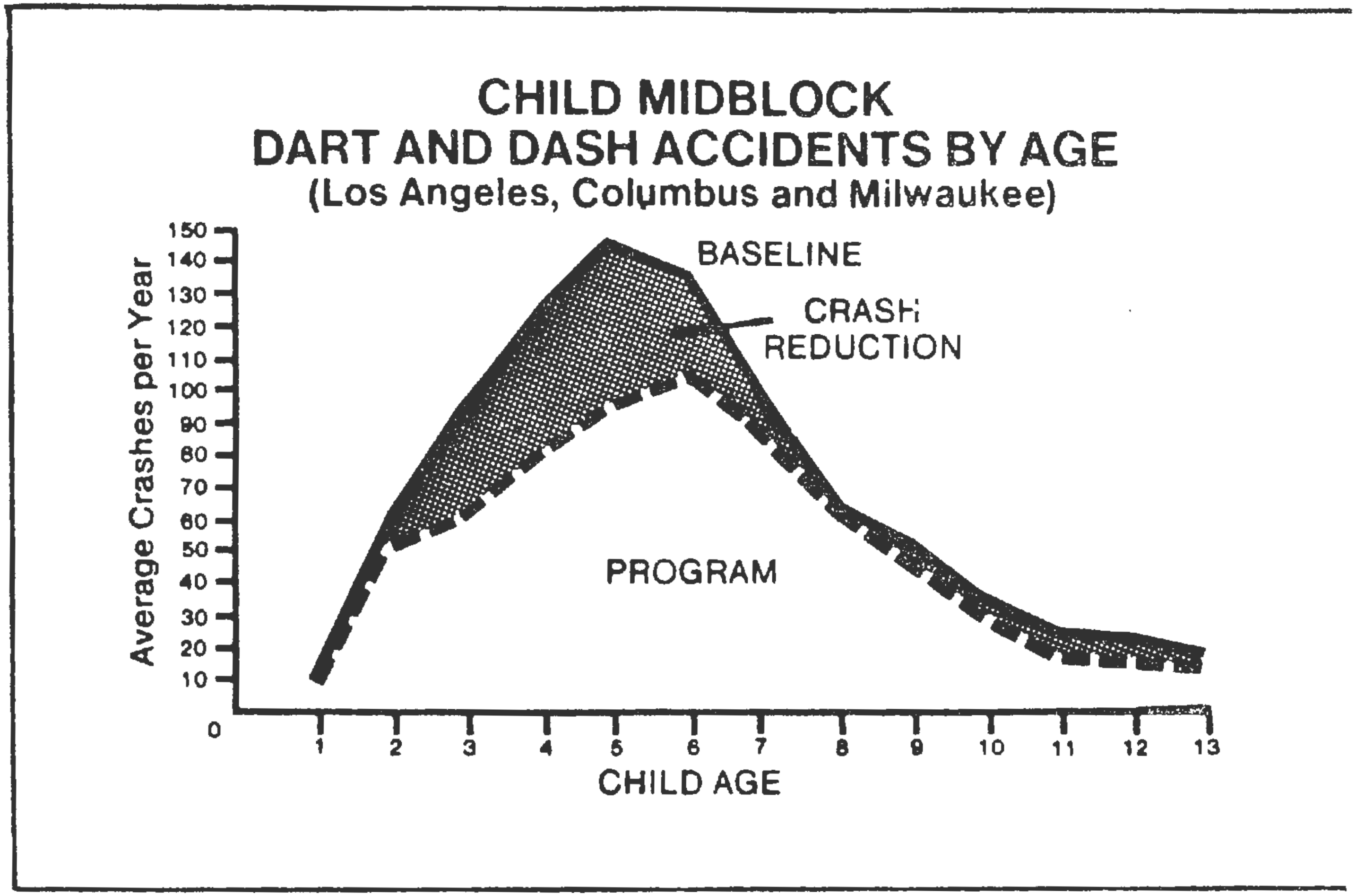


Figure 25. Effects of WILLIE WHISTLE educational campaign on pedestrian accidents.

Source: Reference 98.

often at intersections than at midblock but looked less at the intersections.

- New York City [100] - 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.

- Salt Lake City, Utah [101] - "Public awareness" was developed through radio, television, and the press. A pedestrian safety contest was begun. Following classroom instruction, students in a primary school who were observed crossing safely were rewarded with a compliment and a "good pedestrian certificate." Correct crossings increased from 20 percent before to 80 percent after instruction.

- England [102,103] - The "Tufty Club," organized by the Royal Society for the Prevention of Accidents 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 accident rate was reduced 11 percent. The greatest reduction in accidents was observed between the ages of 5 and 9, the target audience. Monetary savings in the 3-month period exceeded the expenses of the educational program.

- Sweden [104] - On the basis of an elaborate program of developmental and educational research in safety relevant behavior, the researcher found children of pre- and primary-school age not having the perceptual, motivational, and judgmental maturity to learn to meet the demands of modern traffic.

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 programs. Most of these programs have been directed at helping different age groups of pedestrians, while some are intended for either the parents or teachers of young children. As discussed in the WALK ALERT Program Guide, [36] some of these pedestrian educational materials include the following: [36]

- 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 K to 3), represent the age group most at risk, and in fact 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) include 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
    - Drivers' 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

- In the work place
- 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 which have historically had a low incidence of pedestrian accidents have typically had active pedestrian education programs. More information on various educational programs for pedestrian safety and specific messages are given in recent publications. [36,105]

ENFORCEMENT AND REGULATIONS

In addition to engineering and education, 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, such as jaywalking and crossing against the signals, but also motorist actions as they relate to pedestrians. Motorists which exceed the speed limit, fail to yield the right-of-way to pedestrians when turning, run a red light or stop sign, or drink and drive can place pedestrians in jeopardy. Strong police enforcement programs are needed to help reduce these violations. [36]

Unfortunately, no quantitative studies are known which have determined the specific effects of various types of police enforcement on pedestrian accidents and injuries. However, many cities in the U.S. with exemplary pedestrian safety achievements such as Milwaukee, Seattle, and San Diego have maintained active enforcement programs in addition to other program elements. [36] The effects of enforcement alone is difficult if not impossible to properly quantify because of the multitude of factors which affect the pedestrian accident experience over a given time period.

Several model pedestrian ordinances have been developed by the National Highway Traffic Safety Administration which have the potential to reduce certain types of pedestrian accidents. These include the following: [36,106,107,108]

- Model ice cream truck ordinance - this type of regulation is needed in many areas to deal with the problem of children which walk or run into the street to or from ice cream 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 was put into effect in Detroit in June of 1976. During the first partial vending season, related accidents dropped 54 percent. In the first full vending season, related child accidents were reduced by 77 percent (i.e., from a three-year average of 48.7 accidents per year to 11 in 1977). [107]

- 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 accidents.

- Multiple vehicle overtaking ordinance - One of the common types of pedestrian accidents on multilane roadways is termed a "multiple threat" accident. This accident type involves pedestrians which step into a traffic lane (often in a crosswalk) in front of a stopped vehicle and then into the adjacent lane without looking prior to being 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 accidents 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 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 50 ft. of a marked crosswalk or within 60 ft. of an intersection without a marked crosswalk on that approach. This ordinance, when obeyed, should help drivers approaching an intersection to see pedestrians more easily.

The above ordinances can potentially help to reduce pedestrian accidents when implemented and followed by local jurisdictions. Effective police enforcement may, of course, be needed to help ensure reasonably high compliance to 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. [36]

SUMMARY AND DISCUSSION

Pedestrian accidents have been a serious problem for decades and continue to be a problem today, with between 15 and 20 percent of all motor-vehicle fatalities involving a pedestrian. Pedestrian accident frequency is particularly high among young pedestrians (2 to 14 years old), while pedestrian fatalities are excessive among the 65 and older group. Other factors related to pedestrian accident problems include alcohol use, pedestrian handicaps, reduced nighttime visibility, and poorly designed streets and highways without adequate provision for pedestrians. While most pedestrian accidents occur in urban areas, rural pedestrian accidents are more often fatal.

A considerable amount of pedestrian research was conducted in the late 1960's and the 1970's, including the development of well-defined pedestrian accident types and possible countermeasures. Also, through the 1970's and 1980's, pedestrian safety research increased relative to the specific safety effects of physical roadway treatments and pedestrian educational programs. The relative scarcity of pedestrian accidents at a given intersection or location, however, has presented problems in properly evaluating the accident effects of various safety treatments. Pedestrian conflict analyses techniques and exposure-based hazard indices have assisted in conducting safety evaluations and identifying potential problem areas and features.

The 1980's have also yielded an increase in the number of studies in the U.S. and abroad on effective pedestrian accident countermeasures. For example, much has been learned recently on the effects of pedestrian signals, signs, and crosswalk markings, where such devices need to be carefully and selectively used. Provisions for elderly and handicapped pedestrians have received growing attention due to our aging society. Research has also continued on the effects of barriers, pedestrian overpasses, sidewalks, roadway lighting, and school crossing treatments, including conditions where their use is most appropriate.

Improved research methodologies and several comprehensive federal research studies in the past 10 years have greatly advanced our current knowledge on pedestrians. Several national programs and user guides have been developed recently on pedestrian safety, due in part to a growing interest at the local, state, and national levels on pedestrian safety. For example, the "Model Pedestrian Safety Program User's Guide" and the "WALK ALERT Program Guide" provide useful information for conducting comprehensive pedestrian safety programs. However, there is still much to be learned on the specific safety effects of the dozens of engineering treatments and the traffic and roadway conditions where they are most and least effective.

Another area of importance as a pedestrian safety concern involves work zones, where the needs of pedestrians have often been overlooked. A 1989 FHWA publication "Work Zone Traffic Management Synthesis: Work Zone Pedestrian Protection" describes current practices in controlling and protecting pedestrian traffic in work zones. Further efforts are needed, however, to develop, install, and evaluate improved work zone protection methods for pedestrians under various traffic and roadway conditions.

Improved developments in pedestrian educational films and programs have also been a product of the 1980's and early 1990's. Recent evaluations of several of these programs have revealed that the training of children with appropriate messages on improved street crossing techniques can reduce pedestrian accidents by an impressive 20 to 30 percent. The great promise shown with some pedestrian educational programs for children raise hope for further programs which are effective for other age groups. More is also known about the nighttime visibility of pedestrians as seen by approaching motorists and some of the measures which can increase pedestrian conspicuity.

While enforcement is considered to be an essential element of a successful pedestrian safety program, little quantitative information exists on the effectiveness of enforcement activities on pedestrian accidents. Model regulations have been developed which can potentially be effective. Research is greatly needed to address the topic of enforcement and regulations as they relate to pedestrian safety.

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