# PEDESTRIAN PLANNING IN SUBURBAN AREAS — A STATE OF THE ART REVIEW

Volume I

of

Development of Guidelines for Accommodating Safe and Desirable Pedestrian Activity Within the Highway Environment

by

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ABSTRACT

This study develops general guidelines for planning and evaluating suburban pedestrian systems. Pedestrian characteristics and capabilities which affect walking demand are summarized using the results of previous research. Reported research results are also used to examine the effectiveness of the physical walking system by analyzing various components. A list of pedestrian planning and facility design guidelines is derived using the information that was reviewed. Total walking distance emerged as the predominant factor controlling suburban pedestrian demand. Few people were willing to walk further than one mile (1.6 km.) from generator to attractor, with a majority unwilling to walk further than one-half mile (0.8 km.). These findings are tested in a set of case studies of pedestrianism in suburban areas that are described in Volume II of the study report.

# CONCLUSIONS AND RECOMMENDATIONS

This report defines a series of factors which have been found to be determinants of pedestrian behavior. The influential human capabilities (analogous to vehicle characteristics in the contemporary traffic engineering methodology) which provide constraints on pedestrian travel and performance — such as walking speeds, walking distances, and human perceptions — are related. In general, measured pedestrian speeds have shown considerable variation. Walking speeds increase as the temperature decreases, differ between the sexes, relate to the age of the pedestrian, and decrease as the grade of the path gets beyond 5%. The analysis revealed that the standard design walking speed of 4 ft./sec. (1.22 m/sec.) as recommended by the Manual on Uniform Traffic Control Devices, is, in most cases, an acceptable standard for timing the walk cycle in traffic signals; however, it should not be used indiscriminantly. Furthermore, the pedestrian population should always be examined and if a high percentage of very young, elderly, handicapped, or female pedestrians will be using the crossing, a lower design walking speed should be considered.

Variations in walking behavior relative to sex, age, and economic status were cited, but the available information did not indicate any significant relationship between trip purpose and acceptable walking distances. In general it was found that most people are unwilling to walk distances greater than one mile, with at least 50% unwilling to walk more than one-half mile (0.8 km).

Preschool and school age children should be kept from interacting with vehicular traffic whenever possible. This is especially true for males in their preteens and teens. Teenage females are much more reluctant than their male counterparts to cross streams of traffic and, therefore, are more likely to voluntarily utilize total separation facilities, such as overpasses.

An examination of the physical walking system revealed the following planning and design guidelines:

(1) Painted crosswalks should be installed only in conjunction with some type of traffic control device (stop signs, signal lights, etc.).

(2) Every effort should be made to construct overpasses so that they do not greatly increase the total walking distance.

(3) The sides of the overpass should be constructed of a material which allows complete visibility in order to reduce the probability of criminal acts directed toward the pedestrians.

(4) The sides of the overpass should be constructed of a mesh material with openings large enough to allow for free air circulation but small enough to prevent cans or other objects from being thrown at passing vehicles.

(5) If the overpass is to be used at night, it should be adequately lighted.

(6) The overpass design should prevent children from getting on the outside or top of the structure. An 18-in. (45.7 cm.) opening in the top center of the structure will discourage this type of activity.

(7) Pedestrian ramps, with sharp turns to discourage speeding bike rides, are preferred over stairs because they allow a more diverse use of an overpass. Both the handicapped and the elderly usually find ramps easier to navigate than stairs, as long as the grade is not excessive. Ramps should be designed with slopes that do not exceed a one-inch (2.5 cm.) rise per foot (30.5 cm.) (8.33% grade).

(8) The construction of pedestrian underpasses should be avoided if at all possible because of extremely high construction costs, the need for frequent maintenance, and their extremely high potential for crime.

(9) Because underpasses are subject to vandalism and other crimes, recessed "vandal proof" lighting should be installed where necessary to maintain a minimum level of illumination.

(10) In some cases, gates may be needed so that the underpass can be closed during times when it is not in use.

(11) The walls of underpasses should be constructed of a material which will resist wall drawings. The Basildon Development Corporation has found that the following surfaces not only resist drawing, but provide an attractive finish:

   (a) 5/8 in. (1.6 cm.) thick dragged surface glazed tile,

   (b) 3/4 in. (4.8 $cm.^2$) square vitreous mosaics,

   (c) a white calcined flint 1/16 in. (0.16 cm.) down sprayed aggregate roofing finish.

(12) A regular maintenance schedule should be set up to deal with the dirt and debris which tend to collect in most underpasses.

This study revealed that the state of the art regarding methodology for planning and designing suburban pedestrian facilities in suburban areas is nonexistent. That is, the majority of the studies reviewed concentrated on very specific cases in urban areas and drew conclusions based on isolated observations. The findings of this report attempt to synthesize the findings from the urban studies and relate them to the analysis of pedestrianism between generator/ attractor pairs in suburban environments. The next stage in this research, which performs a series of case studies on pedestrianism in selected suburban areas in Virginia, is documented in Volume II of this report entitled "Pedestrian Attitudes and Behavior in Suburban Environments."

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## INTRODUCTION

The majority of the research dealing with elements of pedestrianism has focused on walking activity within highly developed areas, particularly central business districts.[1,2,3,4,5,6,7, In such circumstances people can walk short distances from a number of origins to a multitude of opportunities (destinations) and, accordingly, large numbers of pedestrians are observed using typical walking facilities such as sidewalks, crosswalks, and stairs throughout the area. In such cases there is a very definite need to expedite pedestrian movements.

The significance of walking as a mode of travel is obscured in less densely populated areas such as the typical suburban environment. Here pedestrian travel is scattered, periodic, and not particularly noticeable due to the decreased population to land area ratio, and the lack of activity concentration. Consequently, most subdivisions in the counties of Virginia do not even provide sidewalks. Children usually travel to school on buses and most families use the automobile for trips which their urban counterparts can make via walking or by using public transit. Hence, the provision of pedestrian facilities in suburban areas is a rather ambiguous issue since the walking mode plays a very minor role in the typical suburban resident's travel behavior. There have been, however, certain cases where pedestrian overpasses and underpasses have been provided to counteract barriers created by major highways or topographical features. Such structures, in the majority of cases, connect residential neighborhoods with local schools and have often been built without the benefit of a comprehensive study. Currently, public requests for such pedestrian accommodations continue to be treated in a relatively subjective fashion mainly because of the lack of a proven method to estimate the demand for walking travel in suburban areas.

This report is Volume I of a two-volume set which documents the study entitled "Development of Guidelines for Accommodating Safe and Desirable Pedestrian Activity Within the Highway Environment". It establishes the state of the art regarding guidelines for planning and evaluating suburban pedestrian facilities. In this respect the findings of previous research on pedestrian characteristics and physical walking systems are synthesized to specify those human and physical factors which have been shown to be influential on walking activity.

Volume II documents the findings of a series of case studies on pedestrianism in selected suburban areas of Virginia. Here public opinion is used to determine how well existing or proposed facilities meet pedestrian needs, to define the characteristics which should be incorporated into the design of pedestrian facilities to guarantee success, and to develop a set of general guidelines as well as a planning methodology to assist the Department in planning for the pedestrian in suburban areas.

## PEDESTRIAN CHARACTERISTICS

The pedestrian characteristics and capabilities which appear to influence the design of suburban pedestrian systems are: (1) walking speeds, (2) walking distances, and (3) human perceptions. Due to the significantly lower population and building densities found in suburban regions as compared to urban areas, the pedestrian traffic found in these regions is almost always free-flow or sub-critical in nature. Consequently, walking speeds and walking distance are the major human physical characteristics considered in the analysis of pedestrian travel in suburban areas.

Human perception, the process of gathering and analyzing sensory inputs, is also an important factor in the analysis of pedestrian behavior. Vision and hearing inputs are constantly being analyzed by pedestrians to keep track of the distances, relative speeds, and directions of movement of vehicles and other pedestrians. These perceptual abilities affect the pedestrian's ability to safely interact with vehicular traffic and other pedestrians. Much of the previous research on pedestrians has been directed toward defining the limits of one or more of these physical and perceptual capabilities.

## Pedestrian Speeds

Most design standards assume a normal walking speed of 4 feet per second (1.22 m./sec.) when calculating pedestrian clearance times for traffic and pedestrian signals.[9,10] A number of studies have been conducted which indicate that this may be an overly simplistic assumption. For example, Figure 1 indicates that the walking speeds for men vary from 2.5 ft./sec. (0.76 m./sec.) to 6.7 ft./sec. (2.04 m./sec.) with a mean of 4.5 ft./sec. (1.37 m./sec.), while the values for women vary from 2.5 ft./sec. (0.76 m./sec.) to 6.3 ft./sec. (1.92 m./sec.), with a mean of 4.1 ft./sec. (1.25 m./sec.).[10] These figures indicate that 25% of the men and 45% of the women observed would be unable to cross at a signalized crossing which had been timed using the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) standard of 4 ft./sec. (1.22 m./sec.).

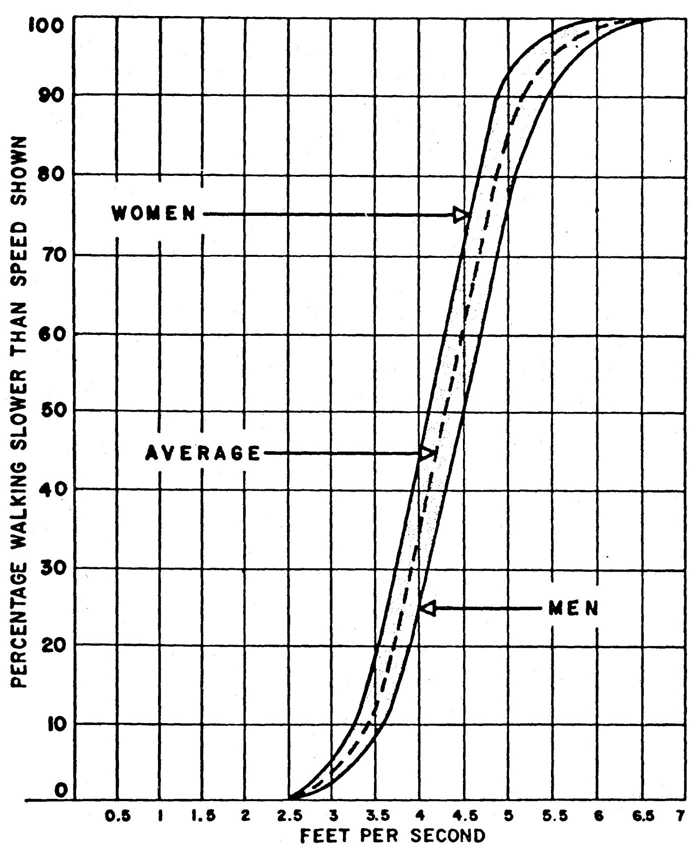



Figure 1. Variations in pedestrian street crossing speeds.
Note: 1 ft./sec. = 0.3048 m./sec.
(Source: Figure 4.1 of Reference 10.)

Studies conducted in the Pittsburgh central business district[3] and at the University of Missouri[11] indicate a significant difference in the mean pedestrian rates of men and women. The results of the Pittsburgh study for both mid-block and intersection pedestrian movements and those of the University of Missouri study are compared in Table 1. The t test revealed a significant difference in the mean rates for men and women. In the Pittsburgh study the mean travel rates for men were identical for both cases while the mean mid-block travel rates for women were slightly greater than the intersection rates. In the Missouri study a t test between the aggregate means of the walking speeds for both sexes gives a significant difference at 95%: women walked slower than men.[11]

Table 1

Pedestrian Travel Rates
Note: 1 ft./sec. = 0.3048 m./sec.

| | |
|---|---|
| Pittsburgh: | |
| Mid-block: | |
| All pedestrians | 4.80 ft./sec. |
| Males | 4.98 ft./sec. |
| Females | 4.63 ft./sec. |
| Intersection: | |
| All pedestrians | 4.72 ft./sec. |
| Males | 4.93 ft./sec. |
| Females | 4.53 ft./sec. |
| Missouri: | |
| All pedestrians | 4.3 ft./sec. |
| Males | 4.3 ft./sec. |
| Females | 4.25 ft./sec. |

Source: References 3 and 7.)

A study conducted inside the Port Authority Bus Terminal and Pennsylvania Station in New York City confirmed the hypothesis that pedestrians' free-flow walking speeds vary over a wide range.[5] The results from this study revealed walking speeds ranging from 2.0 ft./sec. (0.61 m./sec.) to 6.0 ft./sec. (1.83 m./sec.), with the average for all pedestrians being 4.4 ft./sec. (1.34 m./sec.). This survey also indicated a difference in the mean walking speeds of men (4.5 ft./sec.) (1.37 m./sec.) and women (4.2 ft./sec.) (1.28 m./sec.)

Acute temperature changes were found to have an observable effect on travel rates. A decrease in temperature from 50°F (10°C) to 25°F (-4°C) produced an increase in travel rates from 4.6 ft./sec. (1.40 m./sec.) to about 5 ft./sec. (1.52 m./sec.). This conclusion is only valid for temperatures between 0°F (-18°C) and 50°F (10°C), since 65% of the observations occurred while the temperature was less than 50°F (10°C).[3]

A study into the effects of age on normal and fast walking speeds revealed a significant difference between the 20 to 25 year old group and the 60 to 65 year old group. It was also determined that the fast walking speed was 45% faster than the normal walking speed. This would seem to indicate that the subjects in the 60 to 65 year old group could match the normal walking speeds of the 20 to 25 year old group, for short time periods, by lengthening the stride and increasing the number of strides per unit of time.[12]

Studies have shown that for grades up to 5%, the walking rates are not significantly altered. An increase in grade from 5% to 10% decreased the average walking rates by 11.5% and a further increase of grade to 20% decreased the walking rates by 25%.[5,10]

## Pedestrian Walking Distances

The average distances people are willing to walk appear to be dependent on sex, age, income, and trip purpose.

Tables 2 and 3 contain the results of surveys, in Manhattan[7] and Washington, D. C.,[8] which give some indication of the relationship between walking distances and sex. The Manhattan study indicated that, on the average, men will walk further (1,900 ft.) (579 m.) than most women (1,520 ft.) (463 m.). Chi-square analyses of the Washington, D. C. data indicate that there is a significant difference in the distribution of trip lengths with respect to sex. The average male trip length appeared longer than the average female trip length. It was hypothesized that "the difference in trip length is somewhat influenced by the relatively long work trips made by men".[8]

Table 2

Walking Distance By Age and Sex
at Two Office Buildings
Note: 1 ft. = 0.3048 m.

| | Percent- age of Trips | Average Walking Distance (ft.) | Estimated Average Net Walking Time (min.) |
|---|---|---|---|
| Males under 25 | 10.2 | 1,502 | 4.70 |
| Males 25-50 | 35.1 | 2,044 | 6.83 |
| Males over 50 | 6.5 | 1,711 | 6.50 |
| Females under 25 | 28.8 | 1,608 | 5.60 |
| Females 25-50 | 14.6 | 1,443 | 5.47 |
| Females over 50 | 4.8 | 1,244 | 5.59 |
| All males | 51.8 | 1,900 | 6.37 |
| All females | 48.2 | 1,520 | 5.67 |
| Total (16,740 trips) | 100.0 | 1,720 | 6.03 |

Source: Table 7 of Reference 7.

Table 3

Pedestrian Trip Length by Sex
Note: 1 ft. = 0.3048 m.

| Pedestrian Trip Length (feet) | Sex | |
|---|---|---|
| | Male | Female |
| 1 - 500 | 10.7% | 18.4% |
| 501 - 1,000 | 14.5% | 15.3% |
| 1,001 - 1,500 | 14.5% | 12.9% |
| 1,501 - 2,000 | 22.1% | 26.4% |
| 2,001 - 2,500 | 6.9% | 4.9% |
| 2,501 - 3,000 | 6.1% | 14.7% |
| 3,001 - 4,000 | 0.8% | 0.6% |
| 4,001 - 5,280 | 4.6% | 2.5% |
| 5,281 - 7,000 | 8.4% | 3.1% |
| 7,001 - 8,500 | 2.3% | 1.2% |
| 8,500 - 10,000 | 1.5% | 0.0% |
| 10,001 - 12,500 | 7.6% | 0.0% |
| Total | 100.0% | 100.0% |

Source: Table 3 of Reference 8.

A chi-square analysis of the data in Table 4 indicated no significant difference between the average trip lengths with respect to age. In the Manhattan study[7] the younger females walker further than the older females. The one big surprise in these results is that the average walking distance for males under 25 years of age (1,502 ft.) (458 m.) is less than the average walking distance for males over 50 years old (1,711 ft.) (522 m.) and considerably less than the average for males 25 to 50 years old (2,044 ft.) (623 m.). The author made no attempt to explain this finding; in fact, the only reference to it was the statement that "generally younger people walk further than older people".[7]

The results of a Washington, D. C. study,[13] conducted to determine the distances people on the way to work will walk from their homes to a bus stop, as a fuction of car ownership and socioeconomic status, are listed in Table 5. The socioeconomic status index is divided into four levels (high, medium, medium-low, and low) while car ownership is divided into two categories (no car and one or more cars). For each of the eight categories the mean walking distances and standard deviations were calculated and each of the means was compared with all the others to determine if the differences were significant.

The results of these statistical comparisons indicate that non-car owners have significantly different walking distributions depending on their socioeconomic levels. Individuals in the highest socioeconomic levels walk much shorter distances than individuals in the lowest levels. Auto-owning people of all socioeconomic levels have average walking distances which are midway between the walking distances for the high and low socioeconomic levels of non-auto owners. The narrower range of walking distances between individuals of the highest and lowest socioeconomic levels of auto-owners seems to indicate that car ownership has a leveling effect on the distances people are willing to walk.[13

Tables 6 and 7 show the results of two studies[7,8] whose objective was to determine the effect of trip purpose on walking distances. A comparison in Table 8 of the parallel purposes found in both studies reveals much more than the conclusions of the individual studies. In the Manhattan study there was relatively little difference in the average walking distance for work, shopping, and recreational/ pleasure trips.[7] For these three categories the average shopping trip was the longest (2,250 ft.) (686 m.) and the average recreation/ pleasure trip was the shortest.

The results of the Washington, D. C. study show a rather distinct difference in the average walking distances for the three trip purposes.[8] In this case the average work trip was the longest (5,890 ft.) (1,795 m.) while the average shopping trip was the shortest (1,320 ft.) (402 m.). Not only is the relative order of average trip lengths different for each case, but a comparison of the average walking distances for each purpose also reveals a significant difference in the results obtained in the two cases.

Table 4

Pedestrian Trip Length by Age Group
Note: 1 ft. = 0.3048 m.

| Pedestrian Trip Length (feet) | Age Group | | |
|---|---|---|---|
| | 18-39 | 40-59 | 50 or older |
| 1 - 500 | 18.0% | 15.9% | 6.4% |
| 501 - 1,000 | 18.0% | 15.2% | 10.6% |
| 1,001 - 1,500 | 10.1% | 13.0% | 21.3% |
| 1,501 - 2,000 | 18.0% | 28.3% | 27.7% |
| 2,001 - 2,500 | 5.6% | 6.5% | 6.4% |
| 2,501 - 3,000 | 19.1% | 3.6% | 19.1% |
| 3,001 - 4,000 | 1.1% | 0.7% | 0.0% |
| 4,001 - 5,280 | 2.2% | 5.8% | 0.0% |
| 5,281 - 7,000 | 5.5% | 2.9% | 0.0% |
| 7,001 - 8,500 | 0.0% | 2.9% | 2.1% |
| 8,501 - 10,000 | 0.0% | 1.4% | 0.0% |
| 10,001 - 12,500 | 2.2% | 3.6% | 6.4% |
| Total | 100.0% | 100.0% | 100.0% |

Source: Table 1 of Reference 8.

Table 5

Distances People in Washington, D. C. Will
Walk to Bus Stops on the Way to Work
Note: 1 ft. = 0.3048 m.

Distribution Characteristics

| Socioeconomic Status | Car Ownership | Sample Size | Mean (feet) | Standard Deviation | Standard Error (feet) |
|---|---|---|---|---|---|
| High | 1 | 658 | 614 | 538 | 21.0 |
| High | 0 | 531 | 494 | 498 | 21.6 |
| Medium | 1 | 174 | 570 | 564 | 42.8 |
| Medium | 0 | 252 | 596 | 500 | 31.5 |
| Medium-Low | 1 | 180 | 596 | 484 | 36.1 |
| Medium-Low | 0 | 294 | 634 | 528 | 30.8 |
| Low | 1 | 91 | 700 | 542 | 57.9 |
| Low | 0 | 223 | 727 | 542 | 36.3 |

Note: The class interval was established at 200' and the range from 0 to 2,600'. Observations which exceeded 2,600 were excluded from these computations.

Source: Table 2 of Reference 13.

Table 6

Cumulative Aslking Distance Distribution by Purpose of Trips by All Modes at Two Office Buildings
Note: 1 ft. = 0.3048 m.

| Walking Distance | Percentage of Trips Shorter than the Indicated Distance | | | | | |
|---|---|---|---|---|---|---|
| | All Trips | To Eat | To Work | Pleasure | To Shop | Business |
| 250 | 7 | 5 | 9 | 5 | 4 | 8 |
| 500 | 13 | 22 | 16 | 19 | 12 | 14 |
| 750 | 27 | 45 | 27 | 29 | 22 | 23 |
| 1,000 | 45 | 64 | 42 | 42 | 35 | 35 |
| 1,250 | 61 | 78 | 55 | 54 | 50 | 45 |
| 1,500 | 67 | 83 | 64 | 62 | 57 | 54 |
| 1,750 | 74 | 88 | 71 | 69 | 65 | 61 |
| 2,000 | 76 | 90 | 73 | 71 | 68 | 65 |
| 3,000 | 83 | 96 | 78 | 82 | 78 | 82 |
| 4,000 | 86 | 97 | 82 | 92 | 82 | 94 |
| 5,000 | 93 | 97 | 91 | 96 | 89 | 98 |
| 5,280 (1 mile) | 94 | 98 | 94 | 98 | 89 | 98 |
| 6,000 | 95 | 98 | 95 | 99 | 89 | 98 |
| 7,000 | 96 | 99 | 97 | 99 | 89 | 99 |
| 8,000 | 97 | 99 | 99 | 99 | 90 | 99 |
| 9,000 | 98 | 99 | 100 | 100 | 92 | 100 |
| 10,000 | 99 | 100 | - | - | 95 | - |
| 10,560 (2 miles) | 99 | - | - | - | 96 | - |
| Average walk | 1,720 | 1,073 | 1,830 | 1,666 | 2,253 | 1,737 |
| Median walk | 1,070 | 810 | 1,120 | 1,130 | 1,250 | 1,405 |
| Number of Trips | 17,305[a] | 1,118 | 7,294 | 669 | 640 | 955 |

[a]Trips to home, delivery trips, other trips, and those with an unreported purpose totaling 6,630 are included in this figure but not shown separately.

Source: Table 8 of Reference 7.

Table 7

Pedestrian Trip Length by Purpose of Trip
Note: 1 ft. = 0.3048 m.

| Pedestrian Trip Length (feet) | Trip Purpose: Work | Personal Business | Shop | Social | Outdoor Recreation | Other | Change Mode |
|---|---|---|---|---|---|---|---|
| 1- 1,000 | 12.1% | 20.0% | 32.1% | 47.4% | 24.4% | 7.7% | 73.9% |
| 1,001- 2,000 | 0.0% | 40.0% | 54.0% | 36.8% | 41.5% | 11.5% | 26.1% |
| 2,001- 3,000 | 6.1% | 26.6% | 13.9% | 5.3% | 12.2% | 61.6% | 0.0% |
| 3,001- 5,280 | 18.2% | 0.0% | 0.0% | 0.0% | 7.3% | 11.5% | 0.0% |
| 5,281- 8,500 | 48.5% | 0.0% | 0.0% | 10.5% | 7.3% | 0.0% | 0.0% |
| 8,501-12,500 | 15.2% | 13.3% | 0.0% | 0.0% | 7.3% | 7.7% | 0.0% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

Source: Table 5 of Reference 8.

Table 8

Comparative Pedestrian Trip Lengths
Washington, D. C. Versus Midtown Manhattan
Note: 1 ft. = 0.3048 m.

| Trip Purpose | Average Pedestrian Trip Length (feet): Washington, D.C. Residential Area | Midtown Manhattan Business District |
|---|---|---|
| To Work | 5,890 | 1,880 |
| Shopping | 1,320 | 2,250 |
| Recreation/Pleasure | 2,620 | 1,670 |

Source: Table 22 of Reference 24.

This comparison of the two studies suggests that the average walking distances were strongly influenced by some variable other than trip purpose. It is possible that the differences in the average walking distances were due to the relative proximity of activity sites rather than to the trip purpose.

## Human Perceptions

A combination of the human capabilities of vision, hearing, distance judgement, and relative motion judgement has a significant effect on pedestrian movement. The pedestrian is constantly analyzing sensory input to keep track of the distances, relative speeds, and direction of movement of vehicular traffic and other pedestrians. While hearing does have an effect, the most important sensory input for most people comes from visual cues.

The area of maximum acuity for the human eye is a cone shaped field with a range of from 3° to 5°. Beyond 10° to 12° vision becomes less detailed, with the comfortable range of general vision being defined by a 60° to 70° cone.(5) The angle of peripheral vision varies from 120° up to 160°. This area is sensitive to light and motion with limited acuity.(14)

An experiment was conducted at the University of Queensland for the purpose of examining the use of the peripheral field in judging the size and distance of objects.(15) The experiment was conducted on a large athletic field with the subject facing a man who was standing 100 ft. (30.5 m.) in front of him. The subject was instructed to keep his eyes focused on this man while the experiment was in progress. On a given signal another man would start walking along one of three radial lines, set at angles of 20°, 40°, and 80° with respect to the sight line from the subject to the stationary man. In some cases the man was moving towards the subject while in others he would be moving away. The subject was instructed to signal when the walking man appeared either to be the same size, or the same distance away, as the stationary man. In all, ten subjects were tested with some of them being tested for size judgement first while the rest were tested for distance judgement first. In each case the actual distance from the subject was measured and recorded. The average distances obtained for the six different cases are shown in Table 9. The meaning of these results is that an object 60 ft. (18.3 m.) to the side of a person will appear to be much further away. It is possible that to a pedestrian about to cross a traffic stream the approaching traffic may seem to be much further away than the actual distance.(15)

Table 9

Mean Distances (feet) Away from Subject at Which the Walking Man Appeared Equal to the Stationary Man

Note: 1 ft. = 0.3048 m.

| | Peripheral Angle | | |
|---|---|---|---|
| | 20° | 40° | 80° |
| In size | 78.9 | 66.1 | 55.9 |
| In distance | 77.9 | 72.0 | 63.9 |

Source: Table 2 of Reference 15.

Gap acceptance studies conducted in Providence, Rhode Island,(16) and at West Virginia University(17) attempted to determine which factors influence the pedestrian's decision making process involved in crossing an uncontrolled traffic stream. Uncontrolled in this case refers to a non-signalized mid-block crossing. In the Providence study both age and sex were found to be significant variables in a child's ability to classify, as slow, medium, or fast, the velocity of approaching vehicles on a two-lane rural road. Considering the total number of correct classifications, the male made more correct judgements. However, the females tended to err on the conservative side, and therefore were more likely to correctly classify the faster, more dangerous vehicles. This may help explain why the number of preschool and school age males involved in pedestrian accidents is almost double the number of females of the same age group who are involved in pedestrian accidents.(18) For both sexes it was found that the percentage of slow and medium vehicles correctly classified increased with age. Among the females the percentage of fast vehicles correctly classified also increased with age. However, among the males the number of correct judgements of fast vehicles varied inversely with respect to age.(16)

The study at West Virginia University indicates that adult female pedestrians also tend to overestimate the speed of approaching vehicles and are therefore more cautious than male pedestrians. It was also determined that groups of pedestrians accepted shorter gaps and crossed the road at slower speeds than did individual pedestrians.(17)

# PHYSICAL WALKING SYSTEM

The physical walking system is the total path a pedestrian traverses from the trip origin to the ultimate destination. The total pedestrian path from origin to destination can be viewed as a series of accommodations and barriers. Accommodations are factors that the pedestrian perceives as having a positive effect on walking while barriers are those factors that the pedestrian perceives as exerting a negative effect on walking. The following discussion examines the results of previous research with respect to: (1) the physical accommodations that expedite pedestrian movement, (2) the physical barriers which inhibit pedestrian movement, and (3) the features of the surrounding environment which affect pedestrian movements.

## Accommodations

Pedestrian highway accommodations can be grouped into the following categories: (1) above-grade (overpasses, skyways, etc.), (2) below-grade (underpasses, tunnels, etc.), and (3) at-grade (crosswalks, sidewalks, etc.). Since it is considered highly undesirable to have pedestrians and vehicles jointly occupying the same facilities, the basic objective of all pedestrian accommodations is to separate them in some manner. The above-grade and below-grade facilities accomplish this separation by vertical displacement while the at-grade facilities utilize time and horizontal displacement to achieve separation. Each of these accommodations has its own advantages and disadvantages.

### Above-Grade

The major advantage of above-grade accommodations is the complete elimination of interaction between pedestrians and vehicles. Besides reducing the number of pedestrian/vehicle accidents, this separation usually improves the vehicular flow.

In certain situations above-grade crossings can provide shorter, more convenient routes for pedestrians. For example, if the elevation of the adjacent land is significantly higher than the elevation of the highway, the installation of an overpass actually shortens the walking route. Tables 10 and 11 show that the cost of construction for overpasses is considerably less than for underpasses, which require excavation. However, the major disadvantage of above-grade pedestrian accommodations is the high cost of construction as compared to at-grade accommodations. Table 10 contains some basic cost figures for overpasses based on length of span, construction method, and type of materials used. Another disadvantage of overpasses results from the fact that they often detract from the visual environment, especially when they are enclosed.

Table 10

Elemental Construction Costs for Highway Overpasses
(Twelve Feet Wide Overall)
Note: 1 ft. = 0.3048 m.

| (1) UNIT COST OF AERIAL STRUCTURE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Material/ Construction | Conventional Steelwork (cased) | | | Conventional Concrete/Cast in Place | | | Concrete/Precast | | |
| Length of Clear Span (feet) | 40 | 80 | 120 | 40 | 80 | 120 | 40 | 80 | 120 |
| Cost per Lineal Foot ($) | 345 | 380 | 400 | 215 | 245 | 270 | 225 | 260 | 280 |

| (2) OTHER COSTS | |
|---|---|
| Drainage | Add $16 per lineal foot |
| Lighting | Add $28 per lineal foot |
| Pier | Add $2,420 for each pier |
| Median Strip (30' x 8') | Add $1,200 for each median |

ASSUMPTIONS

(1) AERIAL STRUCTURE

12 - 15 foot width overall

Varying depth edge beams/side walls depending on span

Protective screening (fencing cover) provided to serve as safety covering

Lighting and drainage are costed separately

Cost varies with finishing materials, construction and span

(2) PIERS

15 foot high cast-in-place concrete

2 foot wide at terminal of overpass

Median strip, if required, costed separately

(3) MEDIAN STRIP

30 x 8 foot median

Concrete with curbing and guard rails

Source: Table 7 and Figure 12 of Reference 24.

Table 11

Unit Construction Costs for Highway Underpasses
Note: 1 ft. = 0.3048 m.

| | CONDITION | $ PER LINEAL FOOT |
|---|---|---|
| (1) | Cut and Cover Construction, No Restriction | 780 |
| (2) | Cut and Cover Construction With Street Decking to Maintain Traffic Flow | 1,170 |
| (3) | Tunnelled Underpass, Cast-In-Place Concrete | 2,040 |

ASSUMPTIONS:

(1) CONDITION 1 - BUILT IN CONJUNCTION WITH NEW ROADWAY CONSTRUCTION

Concrete, continuously supported

12-15 feet wide by 10 feet high, minimum length of 80 feet

Natural ventilation (for lengths $<$ 200 feet)

Lighting and drainage cost included

Normal cut and fill excavation (rock and other foundation problems will incur extra cost)

(2) CONDITION 2 - BUILT UNDER EXISTING ROADWAY

Same as condition 1 except that added costs are incurred to remove road (street) surface and provide decking to maintain traffic flow

(3) CONDITION 3 - TUNNEL UNDER EXISTING ROADWAY

Same as condition 1, except costs reflect tunnel excavation including normal shoring and cast-in-place concrete

Traffic flow is unimpeded

---

Source: Table 8 and Figure 3 of Reference 24.

When the surrounding right-of-way is at the same elevation as the highway, the overpass lengthens the walking distance. Such circumstances then create problems since studies[19,20] have shown that people are very reluctant to use facilities which increase walking distance and/or require more energy output from traversing ramps or stairs. Therefore, unless some type of channeling restrictions are implemented, many people can be expected to ignore an overpass and cross traffic at grade.

An Institute of Traffic Engineers committee report suggests that the following features be incorporated in the design of any pedestrian overpass:[19]

(1) The sides should be constructed of a material which allows complete visibility in order to reduce the probability of criminal acts directed toward the pedestrians.

(2) The sides should be constructed of a mesh material with openings large enough to allow for free air circulation but small enough to prevent cans or other objects from being thrown at passing vehicles.

(3) If the structure is to be used at night, it should be adequately illuminated.

(4) The design should prevent children from getting on the outside or top of the structure. An 18-in. (45.7 cm.) opening in the top center of the structure will discourage this type of activity.

(5) Ramps, with sharp turns to discourage speeding bike rides, are preferred over stairs because they allow a more diverse use of the structure.

Both the handicapped and the elderly usually find ramps easier to navigate than stairs, as long as the grade is not excessive. Ramps should be designed with slopes that do not exceed a 1-in. (2.59 cm.) rise per foot (30.5 cm.) (8.33% grade).[5]

<u>Below-Grade</u>

As in the case of above-grade accommodations, the major advantage of below-grade accommodations is the complete separation of pedestrians and vehicles. Below-grade accommodations also provide protection from adverse weather conditions and they are not as visually disruptive of the landscape as most above-grade accommodations.

The installation of a below-grade crossing will also improve the flow of traffic and reduce the number of pedestrian/vehicle accidents, providing pedestrian access to the at-grade crossing area is restricted. If the adjacent right-of-way is at the same elevation as the highway, a below-grade accommodation will provide a shorter walking distance than an above-grade accommodation. This is due to the fact that greater clearances are required for vehicles than for pedestrians.

The major disadvantage of below-grade accommodations is the extremely high cost of construction, upkeep, damages, lighting, security, etc. A comparison of the figures in Table 10 to those in Table 11 indicates that the construction costs for underpasses are two to eight times greater than the construction costs for overpasses. Underpasses normally have a very high potential for crime and vandalism because of their enclosed nature. Below-grade accommodations usually require more elaborate drainage facilities. This latter fact effectively rules out the use of below-grade accommodations in areas, such as tidewater regions, where the water table is so close to the surface that proper drainage is not possible.

The following factors should be considered in the design of underpasses:

(1) Because underpasses are subject to vandalism and other crimes, recessed "vandal proof" lighting should be installed where necessary to maintain a minimum level of illumination.

(2) In some cases, gates may be needed so that the underpass can be closed during times when it is not in use.

(3) The walls should be constructed of a material which will resist wall drawings. The Basildon Development Corporation has found that the following surfaces not only resist drawing, but provide an attractive finish:

(a) 5/8 in. (1.6 cm.) thick dragged surface glazed tile,

(b) 3/4 in. (4.8 cm.$^2$) square vitreous mosaics,

(c) a white calcined flint 1/16 in. (0.16 cm.) down sprayed aggregate roofing finish.[(21)]

(4) A regular maintenance schedule should be set up to deal with the dirt and debris which tend to collect in most underpasses.

## At-Grade

When compared to above- and below-grade accommodations, the major advantage of at-grade accommodations is the relatively low cost. As a result, it is easier to make adjustments to at-grade accommodations in order to meet changing demands. Local merchants usually favor these accommodations because their shops are exposed to the passing pedestrian flow.

The major disadvantage of at-grade accommodations is the exposure of pedestrians to the risks of pedestrian/vehicle accidents, which usually result in more permanent damage to the pedestrian than to the driver of the vehicle.

The simplest and least expensive at-grade pedestrian accommodation is the painted crosswalk. Crosswalk markings serve two basic purposes. At locations where traffic is subject to controls, such as stop signs or signals, the crosswalk's primary function is to direct the pedestrian to the proper path. In situations where traffic is not controlled by stop signs or signals, the crosswalk markings also act as a warning to motorists to be on the alert for pedestrians. Some states place a legal requirement on the driver of a vehicle to yield the right-of-way to a pedestrian crossing within these bounds.[22]

According to the MUTCD,[9]

> Crosswalks should be marked at all intersections where there is substantial conflict between vehicle and pedestrian movements. Marked crosswalks should also be provided at other appropriate points of pedestrian concentration, such as at loading islands, mid-block pedestrian crossings, and/or where pedestrians could not otherwise recognize the proper place to cross.
>
> Crosswalk markings should not be used indiscriminately. A careful engineering study should be required before they are installed at locations away from traffic signals or STOP signs.
>
> Since non-intersectional pedestrian crossings are generally unexpected by the motorist, warning signs should be installed at locations away from traffic signals or STOP signs.

At first glance it would appear that, from the pedestrians' point of view, there are no major disadvantages connected with crosswalks. However, a San Diego study of the pedestrian accident experience at marked and unmarked crosswalks located at unsignalized intersections produced some surprising results.[23] Analysis of the accident data for 400 intersections revealed that approximately 6 times as many pedestrian accidents occurred in marked crosswalks than in unmarked crosswalks. Pedestrian volume counts conducted at these intersections showed a usage ratio of approximately 3 to 1 for marked vs. unmarked crosswalks. Taking usage into account, these results indicate that about two times as many pedestrian accidents occur in marked crosswalks as in unmarked crosswalks.[23]

The authors felt that this poor accident record was due to the pedestrians' attitude and behavior when using a marked crosswalk. They hypothesize that the presence of marked crosswalks gives the pedestrian a false sense of security. The pedestrian unconsciously believes that the markings completely shift the responsibility of maintaining vigilance to the vehicle driver. Thus the pedestrian may tend to place himself in more hazardous positions with respect to traffic.[23]

These results suggest that the second paragraph in the preceding quotation from the MUTCD should be changed to read as follows: Crosswalk markings should not be used indiscriminately. A careful engineering study should be required before they are installed at any location other than a signalized intersection.

Signalized crossings are the most complex and expensive of the at-grade accommodations. They also provide more positive yet flexible control over vehicular traffic than any of the other at-grade accommodations. There are a number of reasons why signalized crossings are the most utilized of the pedestrian accommodations:

(1) The initial installation costs for signalized crossings are considerably less than the cost of constructing either an overpass or an underpass.

(2) Since pedestrians are extremely reluctant to use any accommodation which increases their walking distances, signalized crossings normally provide a more direct and continuous path than overpasses or underpasses.

(3) Most signalized pedestrian crossings occur at traffic intersections where the signals are needed to control the intersecting vehicular traffic streams, in addition to providing separation of pedestrians and vehicular traffic.

The MUTCD contains warrants and guidelines for the installation of pedestrian signals. These warrants and guidelines are contained in Appendix I.

There are three major disadvantages of signalized pedestrian crossings. First, even though time separation of pedestrians and vehicles is achieved, they are still utilizing the same physical facilities. Second, considerations of vehicular movemements rather than pedestrian safety are still predominant in the timing of signal lights. Third, by their very nature signalized crossings involve waiting time and prior research has proved that waiting time is much more disagreeable to pedestrians than walking time.[16]

## Barriers

For the purposes of this report, a barrier is defined as any physical configuration which interferes with the safe, continuous flow of pedestrian travel. Barriers fall into classes according to their effect on pedestrian movements: (1) those that cause an abrupt stop, or (2) the frictional type, which merely impede pedestrian movement.

Examples of the abrupt stop type are natural barriers such as rivers, ravines, and cliffs, and man-made barriers such as walls, buildings, and limited access freeways. In dealing with barriers of this nature the decision process is simplified because the possibility of installing crosswalks or signalized crossings is eliminated. The question of whether or not to build an accommodation which crosses this type of barrier becomes primarily a matter of convenience to the pedestrian. Although the following general principles are recommended for use in evaluating the need for pedestrian overpasses across limited access roads, they are readily applicable to any of the abrupt barrier type of situations.

(1) Every effort must be made in freeway planning and design to avoid severance of communities. In addition, wherever pedestrian patterns have been established across the freeway route every effort must be made to retain these patterns. Consideration should be given to existing and projected data from planning and transportation studies, availability and circuity of alternate freeway crossings, zoning, land use, sociological and cultural factors.

(2) Special consideration must be given to the needs of school children going to and coming from schools. Future plans of school agencies should be considered.

(3) In general, if a long circuitous route is involved, a pedestrian overcrossing would be warranted, even though the number of pedestrians is small. An overcrossing would also be warranted in the case of a large number of pedestrians, even if the amount of circuitry is not excessive.[19]

Examples of frictional type barriers are traffic streams, ramps, stairs, snow, ice, curbs, sidewalks which are too narrow, and any other physical object which can impede the continuous flow of pedestrian traffic. While it is relatively easy to identify frictional type barriers, the difficulty arises in attempting to measure the effect such a barrier has on the pedestrian flow.

The most commonly used method for determining the effect of traffic on pedestrians is to measure the pedestrian delay time. A Road Research Laboratory study revealed that pedestrian delay times at non-signalized crossings are related to pedestrian and vehicle flows.[24] Average pedestrian curbside waiting times become longer with increasing vehicle flows and shortened with increasing pedestrian flows. Multiple regression analyses of data for signalized crossings showed no significant relationship between pedestrian delays and pedestrian or vehicle flows. It was suggested that the portion of cycle time available to pedestrians for crossing was the main factor affecting pedestrian delay. Except for cases where the vehicle flow was very high the average curbside pedestrian waiting time was lower at non-signalized crossings.

Ramps and stairs are known to have negative effects on pedestrian movements, but no one has successfully devised a method for measuring these effects. Studies into the possibility of using energy consumption as a means of measuring relative impedance have so far been inconclusive.[25] Walking time and distance have also proved to be unreliable measures of the relative impedance of ramps and stairs. It has been found that even in situations where the time required to use an overpass or underpass is equal to the time required to cross at-grade, only 80% of the pedestrians will use the safer facilities. The percentage using the overpass or underpass dropped off sharply as the time required to cross increased with respect to the at-grade crossing time.[5,25]

A New York study determined that age has a more pronounced effect on pedestrian speeds on stairs than it did on horizontal speeds.[5] A one-third reduction in speed occurred between the 29 years and younger group and the 50 years and over group. This study also noted that higher rise heights and steeper stair angles resulted in slower speeds. Based on the results of this study, a stair design with 6-in. (15.2 cm.) riser, 12-in. (30.5 cm.) tread, and $27^{\circ}$ angle was recommended as being the most efficient.

The effects of frictional type barriers are extremely difficult to evaluate because each individual reacts to a different degree. A minor inconvenience to one pedestrian may form an abrupt barrier to another. The most obvious example is the situation with which handicapped pedestrians are often confronted; so-called accommodations frequently present as great a barrier as the original obstacle. For example, stairs, especially those with high riser height and projecting nosing, present the handicapped pedestrian with a difficult if not insurmountable problem. Appendix II contains some recommended design standards to make pedestrian facilities more usable for the handicapped pedestrian.

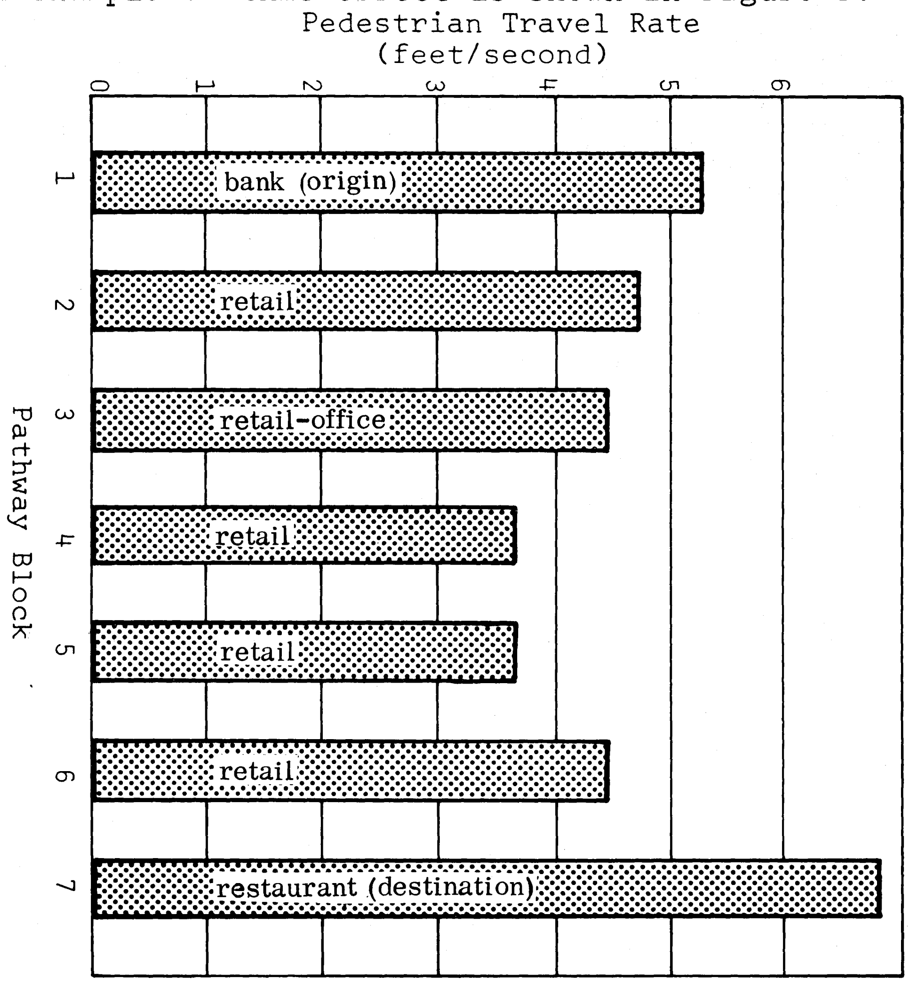
## Pedestrian Environment

Evaluating the effects of the environment on pedestrian activities is extremely difficult because reliable methods which produce accurate results are not available. This problem is further compounded by the diversity of responses to each situation by different elements of the population. Even each individual's response to similar situations varies from day-to-day. Compounded with the fact that the pedestrian environment includes such diverse items as the influence of other people, aesthetics, weather, and adjacent land use, the complexity of the problem becomes evident.

Results of a pedestrian survey conducted in Helsinki showed that the primary reason given for rating a place as unpleasant for pedestrians was the presence of unsocial people. This seems to indicate that people might be reluctant to walk in areas where they feel socially out of place. The authors noted that while improvements to the social environment might encourage pedestrian movement the means available are few.[6]

Aesthetics or the image an area presents to the pedestrian can have a definite effect on attitudes toward walking through the area. For a pedestrian environment to be pleasant it should reflect color, atmosphere, imaginative shop windows, trees and plants, and tranquility.[5,6,26]

Another factor which appears to have an effect on pedestrian movements and is closely associated with aesthetics is the adjacent land use. Lovemark has noted that an interesting and undisturbed environment can increase pedestrian trip lengths by about 30%. A study of pedestrian movements in Toronto revealed that lack of interest along a pathway was a detrimental factor influencing the pedestrians' choice of paths.(1) In a study of pedestrian travel rates conducted in Pittsburgh, Hoel showed that the pedestrian travel rate was influenced by the adjacent land use.(3) A typical example of this effect is shown in Figure 2.




Note: 1 ft. = 0.3048 m.

Figure 2. Variation in pedestrian travel rate as a function of adjacent pathway land use.
Source: Figure V of Reference 3.

Still another environmental factor which seems to have an effect on pedestrian movements is the weather. Respondents to a pedestrian survey conducted in Washington, D. C., ranked unfavorable weather second only to crime in a listing of factors which discourage walking.[8]

Studies have indicated that temperature changes have an effect on the number of pedestrians as well as on the pedestrian travel rate. Lovemark noted that a decrease in temperature from 77° F (25° C.) to 23° F (-5° C.) reduced the number of pedestrian shopping trips in a business district by 50%. The same conditions produced a 25% decrease in the number of work related pedestrian trips.[20] Hoel pointed out that a decrease in temperature also caused an increase in the average pedestrian rate of travel.[3] These studies indicate that a complex relationship exists between temperature changes, trip purposes, and pedestrian movements.

A light rain of about 1 mm./hr. also reduced the number of shopping pedestrians by 50% and the number of work related trips by 25%.[20] Not surprisingly the pedestrian volumes in climate controlled pedestrian facilities increased during cold and rainy periods.[25] In addition to decreasing pedestrian volumes, rain increased the daytime accident risk about 3 times and increased the nighttime accident risk by about 9 times.[25]

The results of a study into the needs of blind and deaf pedestrians revealed that snow and ice were considered to be especially hazardous to blind pedestrians.[27]

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APPENDICES

# APPENDIX I

Warrants and Guidelines for the Installation of Pedestrian Signals. (Proposed by the Department of Transportation in the Manual on Uniform Traffic Control Devices for Streets and Highways)

## A. School Crossing Warrant for Signal Installation

A traffic control signal may be warranted at an established school crossing when a traffic engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at the school crossing shows that the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period.

## B. Minimum Pedestrian Volume Warrants for Signals

The Minimum Pedestrian Volume warrant is satisfied when, for each of any 8 hours of an average day, the following traffic volumes exist:

1. On the major street, 600 or more vehicles per hour enter the intersection (total of both approaches); or where there is a raised median island 4 feet (1.22 m.) or more in width, 1,000 or more vehicles per hour (total of both approaches) enter this intersection on the major street; and

2. During the same 8 hours as in paragraph (1) there are 150 or more pedestrians per hour and the highest volume crosswalk crossing the major street.

When the 85-percentile speed of major street traffic exceeds 40 miles (64.4 km./hr.) per hour, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the minimum pedestrian volume warrant is 70 percent of the requirements above (in recognition of differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities).

Signals may be installed at nonintersection locations (mid-block) provided the requirements of this warrant are met, and provided that the related crosswalk is not closer than 150' (45.7 m.) to another established crosswalk. Curbside parking should be prohibited for 100' (30.5 m.) in advance of and 20' (6.1 m.) beyond the crosswalk.

C. Warrants for Combined Pedestrian and Traffic Signals

Pedestrian signal indications shall be installed in conjunction with vehicular traffic signals under any of the following conditions:

1. When a traffic signal is installed under the pedestrian volume or school crossing warrant.

2. When an exclusive interval or phase is provided or made available for pedestrian movement in one or more directions, with all conflicting vehicular movements being stopped.

3. When vehicular indications are not visible to pedestrians such as on one-way streets, at "T" intersections; or when the vehicular indicators are in a position which would not adequately serve pedestrians.

4. At established school crossings at intersections signalized under any warrant. Pedestrian signals may also be installed under any of the following conditions.

    a. When any volume of pedestrian activity requires use of a pedestrian clearance interval to minimize vehicular-pedestrian conflicts or when it is necessary to assist pedestrians in making a safe crossing.

    b. When multi-phase indications would tend to confuse pedestrians guided only by vehicle signal indications.

    c. When pedestrians cross part of the street, to or from an island, during a particular interval.

# APPENDIX II

## Minimum Recommended Design Standards for Accommodating the Handicapped Pedestrian.
(Compiled by J. J. Fruin in Pedestrian Planning and Design)

## A. Walks

1. Walks should be at least 5 feet (1.52 m.) wide, with a maximum grade of 5 percent. Walks with greater than a 5 percent grade are considered ramps.

2. Walks should be of a continuing, common surface, not interrupted by steps or abrupt changes in level.

3. Wherever walks or roadways cross, the pavement should be cut, and the walk ramped to road level.

4. Where walkway systems are frequented by the blind, or where walkways cross streets, changes in pavement texture should be used to provide the blind with tactile signals of route and crossing locations.

5. Longer walks near the maximum grade should have level areas at intervals for purposes of rest and safety.

6. Walks should have nonslip surfaces.

## B. Ramps

Where ramps are provided, the following minimum standards should apply:

1. Ramp slopes should not exceed a slope greater than 1 inch(2.5 cm.) per foot (30.5 cm.), or 8.33 percent grade.

2. Ramps should have handrails on at least one side, and preferably on both sides, extending at least one foot beyond the ends of the ramp. Handrails should be set at a height of 32 (77.4 cm.) inches, measured from the ramp surface.

3. Ramps should have nonslip surfaces.

4. Ramps should have level platforms at 30-foot (9.14 m.) intervals and at ramp ends for rest and safety. Where a door opens on the ramp end minimum platform dimensions must be at least 5 feet (1.52 m.) by 5 feet (1.52 m.), or sufficient to allow door opening and wheelchair maneuvering.

C. Stairs

1. Stairs should have plain faces. Open riser stairs, or stairs with edges projecting out over the face of closed risers, are not recommended.

2. Maximum riser heights should be 7 inches (17.8 cm.), preferred riser heights would be between 5 and 6 inches (15.2 cm.). Tread width should be at least 11 inches (27.9 cm.).

3. Handrails should be set at 32 inches (77.4 cm.), measured from the tread at the face of the riser, and should extend 18 inches (45.7 cm.) beyond the stair ends.

4. All treads should be of nonslip surfaces.

5. Stair lighting should be a minimum of 5 foot-candles on the average; preferred lighting levels should be above 10 foot-candles on the average.